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Exploring Farmers' Indigenous Knowledge of Soil Quality and Fertility Management Practices in Selected Farming Communities of the Guinea Savannah Agro-Ecological Zone of Ghana

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Abstract: Efforts to improve soil productive capacity aimed at boosting crop production in the Northern Ghana has primarily focused on field-based experiments with little documentation on farmer practice and local indigenous knowledge of soil management. A sample group of 114 farmers from five farming communities in the Guinea Savannah was interviewed to evaluate their indigenous knowledge of crop production practices in the context of soil health, fertilization management, and crop yield. Data were collected using semi-structured interviews and responses for each category were calculated using simple proportions. Farmers' fertilization practice was primarily influenced by fertilization resource availability and crop yield response. The results showed that inorganic fertilization was the commonest fertilization type among farmers. Farmer local indicators of soil health were predominantly limited to visually observable signs such as presence or absence of indicator plants, growth vigor of plants, soil color, and tilth, texture, and compaction. Non-tactile and visible indicators, notably soil chemical composition and presence of soil microorganisms, was rarely used. The listed indicators were congruent with scientific reports, although some knowledge gaps, particularly on the use of indicator plants, were identified. The use of indicator plants as determinants of healthy or non-healthy soils appeared to be influenced by the ease of control of weeds, its utilitarian benefits, benefits to the soil, and threats on cultivated crops. Famers were well informed about the decreasing crop yield. Fertilization practices and limitations in soil management practices with proposed capacity building approaches aimed at enhancing productive capacities of cultivated farmlands are discussed.

Keywords: Ghana; Guinea savannah ecological zone; farmer; soil health; soil health indicator; fertilization; indigenous knowledge; Ferric Acrisol/Ferric Lixisol

1. Introduction

In recent years, sustainable soil management practices have become a major concern to farmers, researchers, and policymakers in Ghana. This is particularly important in the Guinea Savannah (GS) ecological zone where less productive soils are notably prevalent [1]. The GS covers the widest area among the five main ecological zones of Ghana, known for cereal and legume production and rearing of small ruminants [2]. Unit of land per farmer in the region is usually less than 2 hectares [3], characterized by declining yield output [4,5]. This has partly been attributed to the deteriorating soils [6] and unpredictable rainfall conditions [7]. A study by Issaka et al. reported of the low soil nutrient levels in the GS [8], partly due to its continuous use for crop production with little or no proper management schemes. A sustainable soil management strategy involving relevant stakeholders is therefore important in enhancing the productive capacity of soils in the GS zone.

Traditional soil management experience among farmers in Ghana is image driven. Regardless of the impacts of climatic variables on soil degradation, farmers' view and knowledge of soil is a significant production factor [9]. In most cases, in-depth knowledge of soil processes by farmers reflects sound soil management and vice versa. In order to ensure effective policy formulation towards solving problems of soil productivity in the GS, it is important to actively involve farmers in the requisite capacity building programs. Farmers' experience, local knowledge, and indigenous practices are necessary resources that should be developed in combination with scientific knowledge. Such participatory research approach involving farmers are important for the development of technologies and management innovations [10–12]. However, numerous soil productivity enhancement studies in the GS have mainly been on-station trials with little or no feedback on its adoption by farmers. Such studies have principally focused on crop yield and specific soil parameters with limited attention to farmers' local knowledge and their holistic view of the soil.

Soil quality is the capacity of the soil to function as a vital living system to sustain biological productivity, promote environmental quality, and maintain plant and animal health [13]. Good soil management, which integrates the biological, chemical, and physical attributes, usually connote enhanced soil quality [14]. In many cases, there is a direct link between farmers' fertilization practices and the resultant effects on soil quality status [15]. The indicators of soil quality assessment commonly used are largely based on scientific methodologies. Consequently, most of these indicators have been recommended in the literature and tend to override the existing local knowledge among farmers. However, diverse farming practices among farmers in the GS exist and such responses could be adopted into policies for future agricultural innovation development. Hence, an effective collaboration among farmers, scientists, extension agents, and other stakeholders is needed to develop a practical based adaptive soil management technique to improve soil productivity. A practical strategy is to combine the indigenous sustainable land management strategies with already common management practices [16].

To develop the indigenous knowledge of soil management aimed at increasing crop yield output at the community level, a starting point is to understand farmers' thoughts and perception of their current management methods. Thus, this paper attempted to evaluate the state of farmers' knowledge on soil health and crop production practices within the context of fertilization practices, organic residue management, and crop yield in selected farming communities in the GS zone of Ghana.

2. Materials and Methods

2.1. Description of Study Area

The study was conducted in five farming communities in the GS; Dimabi, Nyankpala, Dindo, Gbulung, and Golinga in the Tolon/Kumbungu district of Ghana (Figure 1). The communities lie within latitude 09°15′ to 25′ N and longitude 0°52′ to 58′ W with an altitude ranging between 120 and 200 m. The communities are located on a plain dominated by Ferric Acrisols or Ferric Lixisols soil types [17]. The area has uni-modal mean annual rainfall of about 1100 mm (Ghana Meteorological Agency, Accra, Ghana) beginning from April through to September. The climate is characterized by unreliable rainfall; flash floods and drought that hugely impacts crop production. Farming activity in the area is heavily dominated by smallholder farmers who mainly grow cereals (maize (*Zea mays* (L.), sorghum (*Sorghum bicolor* (L.), and millet (*Pennisetum glaucum* (L.)), legumes (soybeans (*Glycine max* (L.) Merr.), cowpea (*Vigna unguiculata* (L.) Walp.), and pigeonpea (*Cajanus cajan* (L.) Millsp.)), and tuber crops (yam (*Dioscorea* L.), cassava (*Manihot esculenta* Crantz)) [2]. A significant proportion of the farmers keep livestock (Cattle, sheep, and goat) generally for meat. Most cultivated farmland soils in the GS ecological zone have shown evidence of declining soil fertility and low organic matter [1]. The main system of farming is purely traditional with little mechanization, which employs the use of hoe and cutlass with labor primarily provided by family members.

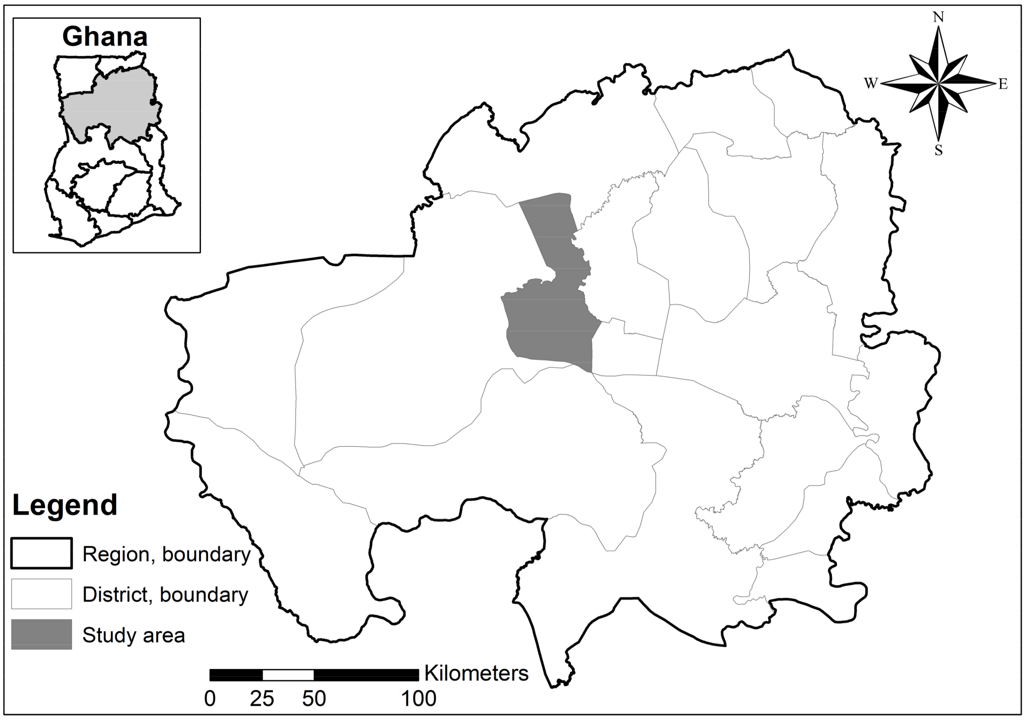

Figure 1. Map of Ghana showing the location of the study site.

2.2. Data Collection

A household survey was conducted from February to March 2015, where 114 farmers were selected from five farming communities. Resident government researchers in the district assisted in the identification of the villages and households through key informant interviews and consultations. This study targeted farmers who were active in their crop production process. Face-to-face interviews were conducted using semi-structured questionnaires [18]. The interviews were carried out with the help of interpreters in cases where language barrier existed. The interpreters had previously been briefed about the objectives of the study and were sensitized especially on the key terminologies in the questionnaire. Interviews were conducted in the mornings and during afternoons, which were usually the best times to minimize disruption of farmers' busy schedule. Special care was taken to ensure that the sample size had a significant proportion of women. The questionnaires were first pretested among the key informants and interpreters and necessary changes were effected before administering to each participant. The interview questionnaires were composed of both closed and open-ended questions that explored farmers' perceptions and indigenous knowledge on soil health, fertilization practices, organic residue management, and crop yield in the respective communities. During the survey, it was emphasized that plant as bioindicators of healthy or non-healthy soil means plant species whose dominance on soil connotes a corresponding soil quality and vice versa.

2.3. Data Analysis

The interview data were subjected to basic descriptive analysis using IBM SPSS (version 21, IBM, Armonk, NY, USA). The descriptive statistics tools comprised simple proportion, percentages, and frequencies of all studied variables. Categorical variables were analyzed using cross-tabulations. A two-way Chi-square (χ^2) test was used to test the level homogeneity among the categorical variables [19].

3. Results and Discussion

3.1. Demographic Characteristics of Respondents

Of the 114 respondents, 21.1% were females and 78.9% males (Table 1). The age of the respondents ranged from 21 to 70 years with an average of 39 years. A significant percentage (53.8%) of the respondents was between 24 and 37 age groups. The majority (66.3%) of the respondents had no formal education. On the other hand, only 7.7% had a tertiary education which comprised colleges, vocational/technical and university institutions. Most of the interviewed farmers began farming activity at an early age with varying degrees of experience ranging from 2 to 50 years. Farming is the main source of livelihood in the surveyed communities with over 90% of the farm sizes between 0.4 and 4.0 hectares. The age distribution, gender, educational background and work experience of the respondents among the communities were not significantly different. This suggests a demographic homogeneity among all the studied communities. For this reason, the five communities were treated as a single population in the subsequent analyses.

3.2. Farmers' Fertilization Practice

Over 95% of the farms had been under cultivation for a minimum of three years (Data not showed). A significant percentage of the respondents, constituted by 48.3% males and 14.9% females practiced inorganic fertilization (IF) (Table 2). This predominantly involved the use of nitrogen (N), phosphorus (*p*) and potassium (K) fertilizers as a basal application with urea or sulphate of ammonia as a top dressing. Of the total respondents, 14.0% combined the application of inorganic and organic fertilizers, while 7.9% who were only males applied only organic materials. 14.9% of the total respondents, which by proportion were predominantly males, applied no fertilizer to their crops. No fertilization comprised crop rotation, land rotation and fallow systems which are usually applicable for farmlands located several kilometers away from farmers' settlements. Regarding the reasons for the choice of IF practice, varied responses were given by farmers. While 36.8% based their choice on the high crop yield response, 22.4% used IFs because it was a common practice in the community. While 15.8% cited less availability of organic materials, 13.2% used IFs because of its availability. Interestingly, 3.9% of the respondents used IFs purposely to minimize the negative effects of *Striga hermonthica* (Delile) Benth.

Among the respondents who practiced no fertilization, a significant proportion (80%) indicated the less relevance of fertilization on the yield of cultivated crops. Their crops comprised soybean, groundnut (*Arachis hypogaea* L.), cowpea, yam and cassava (data not shown). On the other hand, 52.6% of the organic-based fertilization farmers cited material availability in the communities, 26.3% because of the general soil conditioning and 18.4% due to its low cost. The general soil conditioning indicator comprised soil erosion control, drainage and aeration improvement and moisture maintenance. Again, 7.9% cited the long-term positive effects on the soil while 5.3% stated its high crop yield response. Male respondents being sole managers of land in the surveyed communities predominantly cultivated cereals i.e., maize, rice and sorghum (Table 3). On the other hand, more females by proportion cultivated legumes and vegetables such as groundnut, ayoyo (*Corchorus olitorius* L.), tomato (*Solanum lycopersicum* L.), garden egg (*Solanum integrifolium* L.), etc.

Table 1. Chi-square analysis of differences in selected personal and demographic characteristics of respondents.

Household Demographic Characteristics	**Communities**					χ^2	**Significance among Communities**
	Dindo	**Dimabi**	**Nyankpala**	**Gbulung**	**Golinga**		
	% per Comm (4)	**% per Comm**	**% per Comm**	**% per Comm**	**% per Comm**		
	(n = 22)	**(n = 24)**	**(n = 22)**	**(n = 22)**	**(n = 24)**		
Gender						3.0, df = 4,	NS
Male	73.7	90.9	75.0	82.1	72.7	p = 0.6	
Female	26.3	9.1	25.0	17.9	27.3		
Age group						14.4, df = 12,	NS
10–23	5.3	0.0	16.7	19.3	4.5	p = 0.3	
24–37	52.6	54.5	58.3	53.8	50.0		
38–50	10.5	18.2	16.7	19.2	27.3		
51+	31.6	27.3	8.3	7.7	18.2		
Educational background						17.1, df =16,	NS
None	78.9	40.9	66.6	76.9	68.2	p = 0.4	
Primary	10.5	22.7	8.3	7.7	9.1		
JHS (1)/MSLC (2)	5.3	22.7	4.2	11.5	13.6		
SHS (3)	5.3	4.5	4.2	0.0	0.0		
Tertiary	0.0	9.2	16.7	3.9	9.1		
Work experience						8.7, df = 12,	NS
<5 years	18.2	16.7	13.6	18.2	12.5	p = 0.7	
5–10 years	27.3	12.5	40.9	31.8	29.2		
11–20 years	31.8	29.2	31.8	22.7	37.5		
>20 years	22.7	41.7	13.7	27.3	20.8		
Farm size						18.7, df = 12,	
<0.4 ha	31.8	16.7	13.6	40.9	33.3	p= 0.09	*
0.4–0.8 ha	18.2	37.5	40.9	36.4	45.8		
0.8–2.0 ha	40.9	29.2	36.4	22.7	4.2		
>2.0 ha	9.1	16.6	9.1	0.0	16.7		

(1) JHS = Junior High School; (2) MSLC = Middle School Leaving Certificate; (3) SHS = Senior High School; (4) comm = Community. NS and * indicate non-significance and significance at α = 0.10, respectively.

Table 2. Farmers' fertilization practice.

Parameter	(% of Respondents)			
Type of Fertilization Practice in the Farm	**Inorganic**	**Combine**	**Organic**	**No Fertilization**
Male	48.3	9.6	7.9	13.2
Female	14.9	4.4	0.0	1.7
Total	63.2	14.0	7.9	14.9
Reasons for choosing inorganic fertilization	(% of respondents) *			
High crop response & readily available N	36.8			
Common practice	22.4			
Less available organic materials	15.8			
Readily available fertilizer in the market	13.2			
Easy to apply and use	9.2			
Effective in controlling *Striga*	3.9			
Low knowledge in handling organics	2.6			
Reasons for adopting no fertilization	(% of respondents)			
Cultivated crops do not need fertilizer	80			
High cost of fertilizers	20			
Reasons for adopting organic fertilization	(% of organic-based respondents) *			
Availability in the community	52.6			
General soil conditioning	26.3			
Low cost	18.4			
Long term effects	7.9			
Crop response	5.3			

Inorganic; NPK, Urea, Sulphate of ammonia, organic; Compost, crop residues, weed litter cattle, sheep, goat & chicken manure, combine; Organic and inorganic, no fertilization; crop rotation, land rotation, and fallow systems. Frequencies are proportions (%) of farmers' response to a given practice alone. * Percentages add up to more than 100% because of multiple responses.

Table 3. Cross-tabulation by gender of cultivated crops among the respondents.

Gender	Crop (Frequency)			Total
	Cereals	Tubers	Legumes & Vegetables	
Male	59	9	11	79
Female	17	5	13	35
Total	76	14	24	114

Frequencies are proportions (%) of farmers' response. Cereals; maize, rice, millet, sorghum; Tubers; yam and cassava; Legumes and vegetables; groundnut, garden egg, ayoyo.

The results of this study are similar to those of Chianu and Tsujii [20], who reported that significant percentage of farmers in the Savannah region of Nigeria used IFs. In contrast, the use of IFs on bush farming farmlands in the Upper West Region of Ghana (Guinea to Sudan savannah) is practically non-existent except in cereal cultivation particularly maize [21]. Chianu and Tsujii [20] argued that adoption of IF in Nigeria was driven by farmers' high educational background. In the present study, farmers' choice of IFs over the other fertilization practices stemmed from its high crop response, accessibility, and the fact of it being a common practice in the communities. Throughout Ghana, agrochemicals are available in authorized retail outlets or could be obtained from government or non-governmental agencies for free or at subsidized prices [22,23]. Consequently, its use among farmers in the northern Ghana is gaining popularity [1]. However, farmers' rate of fertilizer application is considerably below the recommendations for optimal crop yield [21,24]. Farmers' interest in quick crop response connotes high crop yield relative to soil productivity improvement. This viewpoint characterizes the orientation of many farmers on agricultural production.

Natural fallow system, where less fertile lands are allowed to rest for several years without cultivation has in the past dominated soil fertility improvement approaches in Ghana [1]. In the present study, over 95% of the farmers' field was continuously cropped. In addition, among the 14.9% farmers who applied no fertilizer inputs, only a small proportion left their fields to fallow (Table 2). Hence, the preference of IF by farmers over the other fertilization methods, suggests a gradual decrease in the traditional fallow period. As reported by Braimoh and Vlek [25], adoption of high-yielding varieties by farmers in Ghana triggered the use of IFs, as a result of the fact that high-yielding varieties tend to require more nutrients.

The present study differed from the findings of Dawoe et al. [10]. According to their study, a significant percentage of farmers in the Atwima Nwabiagya District of Ghana (moist deciduous zone) relied mostly on organic inputs from plants (tree litter, weeds, and crop residues) for fertilization. Accordingly, farmers exhibited high knowledge of soil organic matter (SOM) as the driving force for soil productivity maintenance. Thus, the majority of the farmers employed SOM retention strategies such as slash and mulch, no burning, and crop residue addition. Nevertheless, population pressures and the attendant human activities, harmattan condition (dry climate characterized by dusty wind) and less awareness have driven severe burning of farmlands in the GS zone [5,26].

There is the interplay of farmers' status in the household, gender, and cultivated crop on the type of fertilization being adopted (Tables 2 and 3). As emphasized by the respondents, the entire household led by the man draw resources together in the form of labor towards the production of the main staple food during the rainy season. Such staple foods are usually insured through fertilization to attain high yield; hence a reduction in food shortage threat during the dry season. On the other hand, small-sized marginal lands are allocated to the women for the production of non-staple foods (Table 3). Consequently, such different land use strategies partly contribute to the wide soil fertility variability within farmlands in the same community.

3.3. Farmers' Perception of Organic Residue Availability and Management

A significant proportion of farmers (62.5%) indicated that organic materials were less available in their communities (Table 4) although Issaka et al. [8] assert that organic materials abound in the GS. As shown before, farmers who practice sole organic fertilization adopted the practice mainly due to organic resource input availability (Table 2). This suggests that farmers' decision on organic material availability may be influenced by the use given to the particular organic resource in the locality. The relative importance of each organic residue varies geographically [27], as exhibited at the community level and household units. Traditionally in the surveyed communities, farmers keep farm animals, thus depend on specific organic residues as fodder and bedding material for their livestock [28,29]. Moreover, many farmers still stick to the use of grasses for roofing, fuel and as mats in the Savannah. This competitive use of plant organic sources as affirmed by 58.1% of farmers practicing organic fertilization suggests the need for further studies on non-competitive organic resources as potential soil amendments at farm or community level.

A majority (71.7%) of the interviewed farmers indicated that organic resources were underutilized in their respective communities (Table 4). Again, the general soil conditioning of organic amendment is a notable reason for organic fertilization (Table 2). However, this information was not consistent with some farmer adopted management practices. For example, although the notable proportion of farmers (17%) to this survey plough on-field crop residues evenly into the soil after harvest to prevent bushfires, 19% consciously burn their farms as a land preparation tool prior to planting (Table 4). Moreover, farmers' limited knowledge on organic material management as affirmed by 78.1% of the respondents was especially evident in the method-, timing- and rate- of material application. A significant percentage (55%) of farmers leave crop residues as mulch after harvest and such materials subsequently fuel the bush burning activities during the harmattan season. In addition, the results showed that over 60% farmers apply organic materials twice in a single growing season. This application is undertaken during the initial growing stage of crops (first application) and after harvesting when materials are left on the field (second application). However, several successful studies on soil organic material amendment have focused on the one-time application, usually at the beginning of the growing season [30–33], because of its availability and the extended time required to mineralize in the soil. Regarding the rate of application, the common practice among farmers was to apply any quantity available with less emphasis on the rate of application. However, there are several reports on the influence of organic material per unit area of land and biochemical quality composition on N mineralization and subsequent crop yield returns [34–37]. It can be concluded that to succeed in the use of organic materials as soil fertilizing inputs, two conditions are necessary; (i) organic resource availability and (ii) adequate knowledge on effective organic residue management. This study suggests the need for appropriate sensitization of farmers through various capacity building activities such as field days, seminars, practical training aimed at addressing the limited knowledge on organic residue management.

Table 4. Farmers' perception of organic residue availability and management.

Parameter	**(% of Respondents)**	
Are you knowledgeable in organic residue management	Yes	No
Male	18.4	60.6
Female	3.5	17.5
Total	21.9	78.1
Availability of organic materials in the community	(% of respondents)	
No	62.5	
Yes	37.5	
Organic materials mostly used	(% of organic-based respondents)	
Plant sources	58.1	
Animal sources	32.3	
Both	9.7	
Times of application	(% of respondents)	
Twice	60.4	
Once	35.6	
Thrice	3.0	
Others	1.0	
How plant material are utilized after harvesting	(% of respondents) *	
Mulch	55.3	
Burn	19.1	
Ploughed to decompose	17.1	
Firewood and fuel	4.3	
Fodder	4.3	
Composting	4.3	
Disposed of as garbage	4.2	
Are there organic plants materials in your village that are underutilized	(% of respondents)	
No	71.7	
Yes	28.3	

Frequencies are proportions (%) of farmers' response to a given practice alone. * Percentages add up to more than 100% because of multiple responses.

3.4. Farmers' Perception and Indigenous Indicators of Soil Health

Majority of the interviewed respondents showed a fairly good knowledge base and understanding of soil health and its effects on the productivity of crops in diverse ways as reflected in their responses (Table 5). In contrast, 42.1% indicated no knowledge of soil health and its locally identifiable indicators. Farmers predominantly used the presence or absence of a particular weed or plant species as an indicator of a healthy or non-healthy soil. The use of plant species as bioindicators in predicting certain soil properties have been documented in other preceding studies [11,38–40]. In this study, farmers' knowledge of healthy soil in terms of the presence or absence of weed indicators is broadly limited to its ease of management, utilitarian benefits, benefits to the soil and threats on cultivated crops (Table 6). For example, soils that are dominated by *Sida acuta* Burm. *f.* (palatable fodder), *Andropogon gayanus* Kunth (palatable fodder), *Imperata cylindrical* (L.) (good roofing material), and *Crotalaria retusa* (L.) (green manure) were denoted healthy. Similarly, the majority of farmers listed the presence of *S. hermonthica,* a noxious parasitic weed of cereals [41,42], as an indicator of non-healthy soils. This is most likely due to the devastating effects of *S. hermonthica* in the GS, where staple foods such as maize, sorghum, millet and upland rice (*Oryza sativa* (L.) are cultivated. Consistent with Dawoe et al. [10], a sizable proportion (18.2%) of farmers linked the vigorous growth of weeds to healthy soils. Accordingly, sites with deep green-leaf color ubiquitous weeds were categorized as healthy while those with pale-leaved plants were denoted poor-quality land. This vigorous growth and dominance of some plants, which is a function of its increased competitive ability, have strongly been linked to their allelopathic potentials [43,44]. Hence, farmers' choice of certain indicator plants of soil health may be due to their allelochemicals which reduce the species diversity and population of other neighboring plants. For example, *I. cylindrica*, *Rottboellia cochinchinensis* (Lour.), *Commelina benghalensis* (L.), *Centrosema pubescens* Benth. and *Hyptis suaveolens* (L.) Poit. have been reported to show growth inhibitory effects on other weed species [45–47]. Common weed species whose dominance signifies healthy or non-healthy soils according to the farmers have been summarized in Table 6.

Table 5. Farmers' indigenous knowledge on soil health.

Parameter	**(% of respondents)**	
Are you knowledgeable on soil health indicators	Yes	No
Male	50.9	28.1
Female	7.0	14.0
Total	57.9	42.1
Indicators employed in assessing soil health	(% of respondents) *	
Presence or absence of weed species	61.0	
Color	55.8	
Soil tilth	18.2	
Growth vigor of weeds or crops	18.2	
Crop yield	11.7	
Soil texture	11.7	
Soil compaction	10.4	
Presence of soil organisms	2.6	
Soil fertility	2.6	

Frequencies are proportions (%) of farmers' response to a given practice alone. * Percentages add up to more than 100% because of multiple responses.

Although farmers' decision on certain indicator plants of healthy soils possessed little scientific backing (Table 5), a direct correspondence could be deduced from the proposition by Barrios and Trejo [40] and Paniagua et al. [48]. Their study proposed the following parameters to be considered as indicators of a healthy or non-healthy soil determination; growth and vigor of abundant plant species, the presence of native species, and natural succession by native species in regenerative fields. In this study, *Icacina oliviformis* A. Juss., *A. gayanus*, and *Panicum maximum* Jacq. listed as indicators of healthy soils are native species of the Savannah [49–51]. Moreover, *C. benghalensis*, *S. acuta,* and *A. gayanus* are reported to exhibit steady growth in less favorable environments [52–54]. Similarly, *R. cochinchinensis* and *C. benghalensis* are reported to be abundant and tend to dominate fallow fields [54,55].

Table 6. Summary of weed species whose dominance on farmlands are indicators of healthy soil.

Common/Local Name	Scientific Name	Family	Desirable Attributes	Category
Sida	*Sida acuta*	Malvaceae	Palatable, easy to control, medicine for curing ailment	Healthy soil
Pirima (Gamba grass)	*Andropogon gayanus*	Poaceae	Grows on infertile soil, palatable for livestock, fire resistant, mulch, ability to store water	Healthy soil
Crotalaria (Devil bean)	*Crotalaria retusa*	Fabaceae	Add nutrient to the soil, fire resistant, easy to control	Healthy soil
Spear grass	*Imperata cylindrica*	Poaceae	As a roofing material, mulch, fire resistant	Healthy soil
Yinyang (Itch grass)	*Rottboellia cochinchinensis*	Poaceae	As fodder	Healthy soil
False yam (Takwara)	*Icacina oliviformis*	Icacinaceae	As mulch, fire resistant	Healthy soil
Dungumam	*Hyptis suaveolens*	Lamiaceae	Medicinal, easy to control	Healthy soil
Fulinfugu	*Commelina benghalensis*	Commelinaceae	Palatable, medicinal	Healthy soil
Centro	*Centrosema pubescens*	Fabaceae	Adds nutrient to the soil, easy to control, as mulch	Healthy soil
Guinea grass	*Panicum maximum*	Poaceae	As fodder, fire resistant	Healthy soil
Linlirma	*Ipomoea triloba*	Convolvulaceae	Mulch, easy to control	Healthy soil
			Undesirable Attributes	
Woblem	*Striga hermonthica*	Scrophulariaceae	Difficult to control, reduces crop yield	Non-healthy soil
Kponkpongor	*Digitaria horizontalis*	Poaceae	Difficult to control, seeds contaminate cultivated cereals	Non-healthy soil
Sedge	*Cyperus rotundus*	Cyperacea	Difficult to control, nut destroys cultivated tubers	Non-healthy soil

There is, however, conflicting information on farmers' decision on certain plants as indicators of healthy soil. For example, *S. acuta*, *A. gayanus and C. benghalensis* listed as indicators of healthy soil in the present study agrees with previous studies [56–58]. Similarly, *Digitaria* spp. has previously been reported to be associated with non-productive fields in the tropics [11,59,60]. In this study, however, farmers identified fields dominated by *S. acuta* to be healthy although it was previously reported as a dominant species in non-healthy wetlands [52]. Nonetheless, species under the genus *Andropogon*, *Imperata and Rottboellia* being undesirable and low soil fertility indicators [11,40,55] were identified by farmers of the present study as indicators of healthy soils. One reason for such variant views can be due to the differences in the study locations, as affected by peculiar climatic conditions which influence the evolution of weed species and its subsequent effects on the soil. Again, plants are functionally linked to entire assemblages of below-ground species since plants and soil organisms have co-evolved [61]. A direct evidence of below-ground microbial taxonomical diversity as a prerequisite for functional efficiency is required [62,63]. Thus, further studies on soil biology and physico-chemical parameters are needed to understand the mechanisms underlying the complex interactions between the below and above-ground biodiversity.

In the present study, soil characteristic indicators used by farmers to perceive soil health comprised mainly color (55.8%), tilth (18.2%), texture (11.7%), compaction (10.4%), nutrient composition (2.6%) and soil organisms (2.6%) (Table 5). Generally, most of the farmers indicated that dark-colored (black) soil signifies healthy soil due to its high SOM contents while pale (red) or white soils were denoted non-healthy. This perception is similar among farmers in Nepal [64]; Suriname [11,65]; and in southern Ghana [10], where dark or black color was associated with fertile soils. Majority of the farmers could explain that the dark color developed from the plant or animal residue additions to soils. Additionally, notable features such as "loose when stepped on", easy to be dug out during harvesting of tubers and moist outlook were used to describe a good soil tilth, as opposed to hard and bare soil with less vegetative cover characterizing non-healthy soils. Farmers' knowledge of SOM effects on soil was mostly linked to soil tilth and activity of "tiny animals" (microbes). This supports an observation by Barrios et al. [59], that a single indicator by farmers usually comprises an integration of multiple aspects of soil quality. Despite farmers' awareness of SOM on soil quality improvement, maintenance of SOM in practice was less common among farmers, as close to 20% of the visited farms had been subjected to severe burning, substantiating the menace of wildfire in northern Ghana [15,26].

The study findings correspond to Desbiez et al. [11]. According to their study, farmers' indigenous indicators of soil health comprised (i) Biological indicators: plants (other than cultivated crops) and soil fauna whose presence or growth indicates a healthy or non-healthy soil; (ii) Soil characteristic indicators: soil properties which signify the health status of soils; and (iii) Above ground plant vigor: crop or weed-growth characteristics and yield. Healthy soils comprise the integration of physical, chemical and biological components that requires holistic management approaches aimed at optimizing the multiple functions of soil [14]. Farmers' indicators according to this study are generally limited to visible and tactile properties of the soil such as color and tilth, similar to [10,59] in southern Ghana and eastern Africa respectively, and hence could provide a limited assessment of soil health status. Therefore, information transfer through the agricultural extension service on easy farmer friendly approaches on a holistic assessment of soil is needed to bridge the existing knowledge gap among farmers [66]. This calls for expanded research on community- or agro-ecological zone-based specific adaptable methodologies for assessing soils.

3.5. Perception of Crop Yield

A large proportion (83.3%) of respondents to this survey acknowledged their awareness of changes in crop yield in the last ten years (Table 7). Of the 83.3%, 63.1% were males while 20.2% were females. With regards to the trends in yield, 39.5% of the respondents indicated a decreasing crop yield. However, 37.7% rather observed an increasing yield while 10.5% thought crop yield remained the same. The most frequently mentioned reasons for decreasing crop yield were rainfall failure (41.1%), low soil nutrients (34.3%), diseases/pest infestation (12.0%), and low yielding varieties (9.8%). The impacts of unpredicted or erratic rainfall were clearly known by farmers due to their dependence on only natural rainfall for irrigation. However, as reported by Fosu-Mensah et al. [67], the majority of farmers in Sekyedumase district in the southern part of Ghana subjected crop yield decline to climate change, weeds incidence and pest infestation, and disease outbreak. Farmers stated that surface runoff (53.2%), continuous cultivation practices (37.3%), low fertilizer application rates (29.2%) and burning (12.3%) were the notable reasons for the low soil nutrients contents (Table 7). According to the respondents, the continuous cultivation practices which trigger soil surface runoff are inevitable due to increasing population in each community making land less available for agricultural production. Continuous cultivation practice due to population pressures coupled with low fertilizer use in Ghana, (as low as 8 kg ha^{-1}) [68] and particularly in GS mainly due to its high cost have rendered many farmlands in the savannah poor. Hence, the resulting declines in crop yield.

Table 7. Farmers' perception of crop yield trend.

Parameter	(% of Respondents)	
Awareness of changes in crop yield	Yes	No
Male	63.1	15.8
Female	20.2	0.9
Total	83.3	16.7
If yes, what is the trend in the last 10 years	(% of respondents)	
Decreasing	39.5	
Increasing	37.7	
Same	10.5	
Not sure/varies	12.3	
Perceived reasons for the decreasing crop yield	(% of respondents)	
Rainfall failure	41.1	
Soil degradation related problems	34.3	
Weed/diseases/pest infestation	12.0	
Low yielding varieties	9.8	
Others	3.5	
Reasons for low soil nutrients	(% of respondents) *	
Soil erosion	53.2	
Continuous cultivation	37.3	
Low fertilizer/manure application rates	29.2	
Burning	12.3	

Frequencies are proportions (%) of farmers' response to a given practice alone. * Percentages add up to more than 100% because of multiple responses.

4. Conclusions

This study identified soil nutrient management options and its prospects among five farming communities in the GS ecological zone of Ghana. It highlights the key points of farmers' perceived knowledge of organic residue management practices, soil health indicators, and crop yield trends. The study findings reveal that farmers are equipped with some local knowledge that agrees with classical methodologies of identifying healthy soils. Gender is connected to farmers' choice of cultivated crops and fertilization type. Also, sole application of IFs coupled with its low application rates is not enough to deal with the declining crop yield trend and the resultant low soil nutrients in GS. Additionally, know-how on soil and organic material management among farmers are low. From the above observations, this study proposes the following recommendations.

1. Sensitization of farmers through training programs on management of site-specific on-farm organic resources (weeds, crop residues). This must incorporate local knowledge to increase awareness in order to enhance its adoption among farmers.
2. The co-application of IFs with available plant resources should be encouraged. Success in soil health enhancement and the subsequent crop yield improvement will depend on specific on-site

organic materials, its quality characteristics and the best timings where they can be incorporated into the production cycle.

3. Increased participatory approach targeting a healthy collaboration among farmers, scientists, and other stakeholders is necessary. This will offer the opportunity to examine farmers' indigenous knowledge for the subsequent integration with the scientific knowledge. Evaluation of material quality characteristics of soil health indicator plants by farmers as well as the corresponding soil health condition of the sampling sites would be necessary for future studies on sustainable soil management.

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