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# Integrated Soil Fertility Management in Ghana: challenges and opportunities

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**Abstract**

Soil fertility remains a challenge in Ghana and other sub-Saharan African countries. Most nutrient balances on farmers' fields are negative due to nutrient mining resulting from continuous cultivation of farmers' fields. The major farming systems in the region are characteristically low-input and rely heavily on resident soil organic matter, which is very low due to environmental and socioeconomic factors. Ghana has one of the lowest fertiliser application rates in the sub-region as a result of the inability of farmers to afford this input. The introduction of integrated soil fertility management (ISFM) practices, which is premised on combining organic resources and inorganic fertilisers to combat soil fertility decline in combination with appropriate germplasm is being introduced as one possible technology that can reduce soil infertility. This review takes a critical look at the implementation of ISFM in Ghana with particular emphasis on challenges to adoption and implementation. Results indicate that most of the successes of this technology occurred in the northern parts of the country; however, proper implementation will require more effort to address challenges such as information flows in the value chain. The other solution is a need for a policy shift towards implementing the technology in addition to infrastructure development and the development of fertiliser markets.

**Key words: ISFM; germplasm; organic resources; inorganic fertiliser; soil fertility.**

# Gestion Intégrée de la Fertilité des Sols au Ghana: Défis et Opportunités

**Résumé**

La fertilité des sols reste un défi au Ghana et dans d'autres pays d'Afrique subsaharienne. La plupart des bilans de nutriments dans les champs des agriculteurs sont négatifs en raison de l'extraction de nutriments résultant de la culture continues des champs des agriculteurs. Les principaux systèmes agricoles de la région sont caractérisés par une faible utilisation d'intrants et dépendent fortement de la matière organique présente dans le sol, qui est très faible en raison de facteurs environnementaux et socio-économiques. Le Ghana a l'un des taux d'application d'engrais les plus faibles de la sous-région, car les agriculteurs n'ont pas les moyens d'acheter cet intrant. L'introduction de pratiques de gestion intégrée de la fertilité des sols (GIFS), qui repose sur la combinaison de ressources organiques et d'engrais organiques pour lutter contre le déclin de la fertilité des sols, en association avec un matériel génétique approprié, est présentée comme une technologie susceptible de réduire l'infertilité des sols. Cette étude jette un regard critique sur la mise en œuvre de l'ISFM au Ghana, en mettant l'accent sur les défis posés à l'adoption et à la mise en œuvre. Les résultats indiquent que la plupart des succès de cette technologie ont eu lieu dans les régions du nord du pays; cependant, une mise en œuvre adéquate nécessitera plus d'efforts pour relever des défis tels que les flux d'information dans la chaîne de valeur. L'autre solution est la nécessité d'un changement de politique en faveur de la mise en œuvre de la technologie, en plus du développement de l'infrastructure et des marchés des engrais.

**Mots Clés: ISFM; germoplasme; ressources organiques; engrais inorganiques; fertilité des sols.**

## Introduction

Generally, wherever farming has depended on traditional practices (slash and burn) with intervening fallow periods between cropping, the mining of soil nutrients is prevalent and sustainable farming is difficult (Baah-Ofori & Amoakohene, 2021; Vanlauwe *et al.,* 2015). This is particularly common in sub-Saharan Africa (SSA), where crop cultivation has intensively depended on traditional practices such as land clearing, bush burning, and tilling of the topsoil using hoe and rudimentary implements; resulting in negative nutrient balances on most farmers fields as a result, most nutrient balances are negative on farmers' fields. This traditional practice has been cited in literature as one of the main causes of the current deterioration of soil fertility in most parts of the developing world (Snoeck *et al.,* 2010).There is an urgent need to adopt modern agricultural practices which thrive on the use of system innovation and improved farming.

The green revolution initiated by Nobel laureate Norman Borlaug at the International Centre for Maize and Wheat Improvement (CIMMYT) in Latin America and Asia in the 1940s was very successful because it relied on technology such as improved crop varieties, irrigation, and input of fertilisers and pesticides (Ramson *et al*., 2003) . These successes were, however, not realised in Africa, especially SSA, because of the high costs of agrochemicals, which are beyond the purchasing power of many farmers in the region. These challenges have led to the development of innovative ways of farming, taking into consideration the socio-economic and other external influences on farming in the sub-region. One such technology has been the introduction of the *integrated soil fertility management* (ISFM) concept. Drawing its roots partly from the integrated crop and pest management concept among other technologies, the focus of this model is the combination of organic and inorganic resources with appropriate input and germplasm to increase yields and break poverty (Baah-Ofori & Amoakohene, 2021).

Agriculture contributes significantly to the gross domestic products (GDPs) of many economies in the sub-region, and in a country such as Ghana, 54% of GDP is from agriculture with an annual growth rate of 5.5% and accounts for over 40 % of export earnings, while at the same time providing over 90 % of the food needs of the country (MoFA/SRID, 2011). It is no wonder that when agricultural productivity declines in Ghana and most countries of the sub-region, there is a drop in foreign direct investments (FDIs) and standards of living of the populace. Innovations in agriculture have been seen as the panacea to poverty reduction in the sub-region (Kuivanen *et al.,* 2016).

Integrating soil fertility management in SSA has been met with mixed success. While certain countries such as Kenya, Tanzania, Zambia and Rwanda have enjoyed relatively high successes in the implementation of the concept, countries such as Ghana, Nigeria and Niger have not achieved much. In Ghana, for example, the concept had a fair success only in the northern parts of the country, while the other parts barely practised it (Vanlauwe *et al.,* 2015).

The focus of this review is to examine the concept of ISFM in Ghana from theory to practice and why it has failed to live up to expectations. In this paper, the authors focused on ISFM, a hybrid form of technology which has become essential for the agricultural sector. The case of Ghana is particularly presented even though the practice is yet to capture the interest of more farmers. The focus on ISFM is necessary for several reasons, but mainly because the prerequisite for agricultural intensification is investments in soil fertility and that both organic and mineral fertilisers are needed to sustain soil health and increase crop production (Vanlawue *et al*., 2010). Although the practice of ISFM is based on key thematic areas, modifying the practice to specific agro-ecologies is necessary for a successful implementation of the principles of the technology (Vanlauwe *et al*., 2006).

As described above, ISFM as a practice underscores the need for complementary roles by combining a number of technologies (Ailincăi *et al.,* 2012) for higher crop productivity and increasing the sustainability of farmers' income. One way of ensuring increased productivity, sustainable agricultural development, and food security, as well as increased incomes among small-scale farmers, is through a proper and efficient transfer of knowledge of ISFM, the provision of incentives and access to input and output markets, which lies in the realms of national stakeholders. This paper explores literature, with the aim of establishing the benefits of ISFM in Ghana. More specifically, it hopes to contribute to the policy debate by advising stakeholders on reassuring farmers of the benefits of adopting ISFM practices because not much research on ISFM has been conducted in the country. Examples and best practices will be drawn from Africa and other developing countries from other regions.

This paper focuses on the need for ISFM in Ghana and the challenges facing the agricultural sector in terms of the efficiency of implementation in the various agroecologies of the country. Such an exercise will aid in informing policy decision and exploring challenges with the technology, which needs review, especially when advanced machinery is involved.

**Materials and Methods**

The review relied heavily on publications on technologies introduced to farmers in Ghana over the years, with particular emphasis on ISFM using the search engines “Scopus” and “Google Scholar”. The authors did an online search using the terms “ISFM” and “soil fertility”, “channels of ISFM information”, and “sources of information on ISFM”. “Communication strategies for ISFM dissemination”, “challenges to ISFM adoption”, and “using communication to address ISFM”. The search was done from June to August 2022 and was limited to the period between the years 2000 and 2022; however, annual reports, databases such as the CABI database (*https://cgspace.cgiar.org)*, _CGIAR database (https://www.cabidigitallibrary.org), *sciencedirect.com* and publications of institutions in the agriculture value chain were also consulted.

The search generated 121,000 results, which included journal articles, published theses, conference proceedings and technical reports from across the globe. Several of these publications were excluded from the review due to criteria set by the authors, which are shown in Table 1. The reviewers excluded studies outside SSA. For publications appearing in journals and reports, only the journal article option was selected. In the end, 63 documents met the set criteria and were subsequently selected for analysis. A seven (7) item coding scheme in Table 1.0 was developed to aid the content analysis of documents acquired to elicit answers to the review questions. The main review questions were: What is the state of ISFM in Ghana? Is inorganic fertiliser the limiting factor in the implementation of ISFM? Is information on the practice of ISFM available to farmers? Some of the items on the coding scheme were descriptors and captured essential articles such as 'title', 'authors', and 'year of publication' and the focus of the research. Annual reports of agricultural related organisations such as Alliance for a Green Revolution in Africa (AGRA), CSIR-Crops Research Institute (CRI) and Ministry of Food and Agriculture (MOFA), Ghana were also reviewed. Studies involving ISFM and rice and maize were included in the review because they are two major staples consumed in Ghana.

## Results

### Definition of ISFM

The need for sustainable intensification of agriculture and the increasingly high cost of inorganic fertiliser in SSA and Ghana, in particular, has informed the need to encourage farmers to adopt a hybrid soil management practice that has the potential to improve farm productivity and thereby provide higher income given the availability of market for the farm produce. A new and promising hybrid practice of the one described above is ISFM, which promises to support poverty reduction programmes. Although it is a relatively new technology that supports soil fertility improvement, ISFM has already attracted several definitions. In general, ISFM can be

Table 1.0. Inclusion and exclusion criteria

| Inclusion criteria for study | Exclusion criteria for study |
|---|---|
| Studies inside sub-Saharan Africa | studies outside sub-Saharan Africa |
| Studies on soil fertility management (SFM) strategies with emphasis on ISFM | which focused on non-ISFM strategies |
| Fertiliser/germplasm interactions | non-germplasm/fertiliser interactions of |
| Conference proceedings | duplicated conference proceedings |
| Studies with crop and animal manure | non-animal and crop manure studies |
| Ghana fertiliser subsidy program | non-fertiliser subsidy programs of Ghana |
| Field trials with maize and rice | fertiliser trials with non-cereal crops |

described as a soil fertility management practice that uses mineral or inorganic fertiliser, in combination with organic inputs and germplasm applied in a local environment, where local knowledge on how to adapt the practice or technology is followed. By this definition it suggests that ISFM aims at optimizing agronomic use efficiency of the applied nutrients and to improve crop productivity. While this definition is generic, the combinations of the various elements have varied in many locations. This variation in the definition of the technology is critical and should be emphasized (Vanlauwe *et al*., 2006).

According to some authors, such as Breman (2011) and Fofana *et al*. (2008), ISFM refers to an integrative use of inherent soil nutrient stocks, locally available soil amendments, and mineral fertilisers to increase the productivity of the land while maintaining or enhancing soil fertility. This suggests that any agricultural intensification policy aiming at increasing yield would require using mineral fertilisers, which, when not properly used, may lead to serious damage to soil fertility, and in the long term, yield may decline due to acidification processes. It has also been realized that the nutrient content of organic sources is relatively low and not abundantly available to the farmer (Vanlauwe *et al*., 2006).

The International Fertiliser Development Centre (IFDC) has attempted to define and explain the technology. According to the IFDC, integrated soil fertility management (ISFM) comprises a set of agricultural practices adapted to local conditions to maximize the efficiency of nutrient and water use and improve agricultural productivity (IFDC, 2010). The central tenant of the ISFM focuses on the combined use of inorganic fertilisers and organic manure (crop residues, compost and green manure) to replenish lost soil nutrients. According to IFDC, this technology improves soil quality and the efficiency of fertilisers and other agro-inputs. A combination of inorganic and organic fertilisers has been suggested as a superior remedy for soil infertility in most parts of SSA, including Ghana.

Like some SSA countries, some institutions' programs, such as AGRA's Soil Health Program in Ghana, have ISFM as a framework for boosting crop productivity.

**The agriculture policy environment and ISFM in Ghana**

A literature survey suggests that although evidence exists to show the potential of soil fertility management in improving crop yields in the country, there is a dearth of information on ISFM. Research has shown that, in general, the adoption of any soil management practice, such as, ISFM is highly influenced by the availability and accessibility of the appropriate components of the technology (Whalen, 2012) Examples exist in some SSA countries, such as Kenya, Uganda, Tanzania, Malawi and Ghana, suggesting that sustained input availability has worked well in the sub-region. This means that when there are workable policies to support private-public partnerships, such as governments partnering with input dealers to execute a fertiliser policy, achieving good results from agricultural innovations and interventions is possible. Successful implementations of ISFM, however, have faced some challenges in Ghana, with poverty being the most prominent as it limits people's accessibility to the products or various components of the technology. This situation will likely continue into the foreseeable future as poverty remains prevalent among farmers in SSA (Vanlauwe *et al.,* 2015). Technological dissemination needs to be complemented by a financing facility such as subsidies to stabilize input supply and demand. This is possible if the policy environment is favourable. Policy interventions should aim at lowering input costs. The successful implementation of policies such as ISFM is also linked to a well-trained extension service since most farmers lack the technical capacity to implement ISFM without technical support (Patricia & Tawiah, 2001).

In most African countries the agriculture extension officer: farmer ratio is about 1:13,000 against the recommended ratio of 1:400 (Anang *et al*., 2020). This challenge is further exacerbated by the unavailability of logistics for extension agents to effectively implement their tasks, necessitating private sector involvement in equipping the Extension Services Department of MoFA (Morris *et al.,* 1999). Policies that could boost the capacity and quality of extension services must aim at improved recruitment rates, in-service training and provision of tools for extension personnel (Weiske & Soren, 2006).

**Opportunities for ISFM development in Ghana**

One of the aspects of employing ISFM is the simultaneous application of organic and inorganic resources based on the assumption that there will be positive interactions between the two which will benefit farmers. In recent years, the focus of soil fertility research has shifted towards combining organic and inorganic resources to arrest the declining soil fertility levels in SSA. ISFM is a soil fertility technology that uses inorganic fertiliser, organic inputs and germplasm combined with local knowledge on how to adapt the practice or technology to local conditions (Plate 1). ISFM approach embraces local resources or materials and external resources (fertilisers) applied in a local context or a particular combination into a single technology depending on availability of resources, local or scientific knowledge and crop demands (Figure 1).

These organic resources include crop residues (such as groundnut leaf, rice straw, maize and sorghum stovers; prunings of cowpea and soybean; and cassava litter), green manures (such as *Mucuna pruriens, Chromolaena odorata, Crotalaria juncea, Panicum maximum,* etc.) and agro-industrial by-products (e.g., coffee husk, rice husk, sugar cane bagasse, etc.).

Table 2 presents the nutrient composition of some selected green manures in Ghana. These low-cost organic resources are obtained through cultivation or from nature, which can be applied as manure or compost. The green manures sources (*C. odorata, P. maximum* and *C. juncea*) contain appreciable quantities of nutrients which can potentially improve soil fertility; however, accessibility is constrained in many farming systems and could perhaps also be a challenge in the ISFM practice, Governmental interventions such as the national seeds program is sorting these challenges out (Fening *et al*., 2011).

Meanwhile, alternative uses of these resources, such as for fuel, feed and fibre and the labour needed to gather and process these resources limit their potential use. Also, it is quite expensive to transport compost made from these materials to farm plots. Converting these residues to biochar is faced with constraints of technology and yield from residues that contain low recalcitrant carbon.

Moreover, animal manures are valuable sources of nutrients which have the potential to increase crop yields when applied. They are also known to improve soil organic matter content and soil structure. These organic resources are widely available in Ghana in

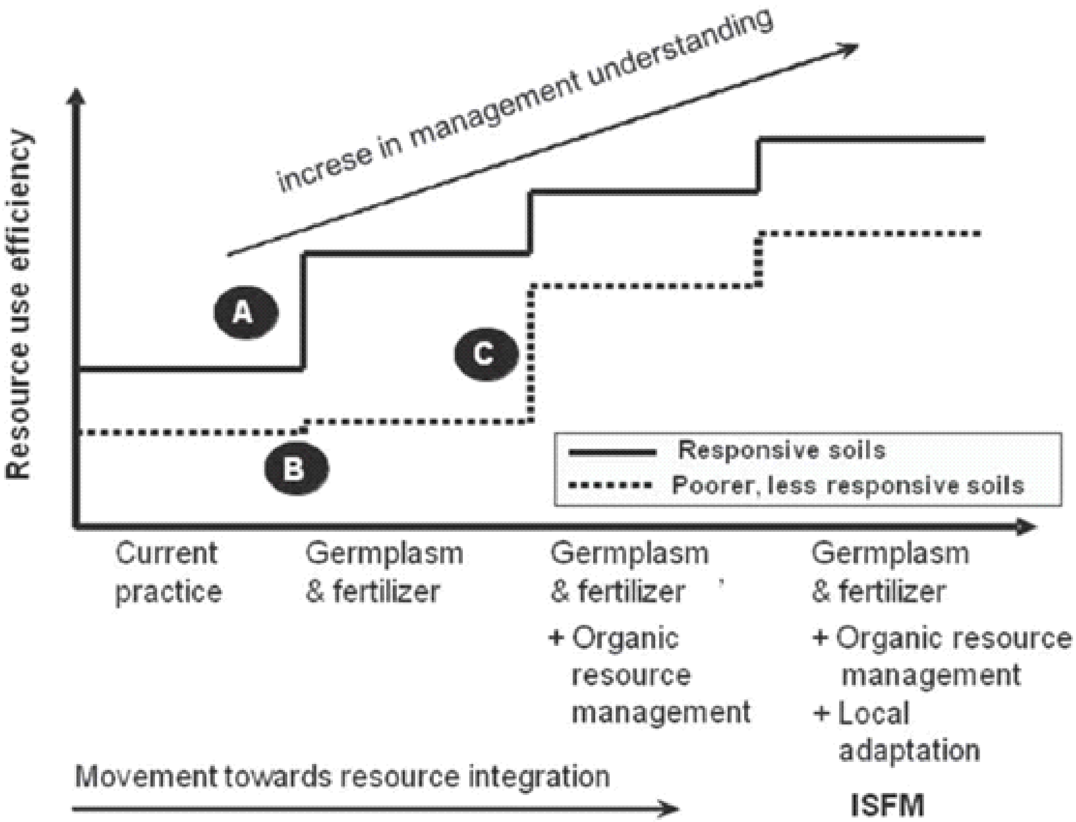


Figure 1. Conceptual relationship between the efficient use of resources as one moves from current practice to achieve ISFM. Source: Vanlauwe *et al*. (2010)

Table 2. Nutrient and proximate composition of selected green manures in Ghana

| *Green manure* | N | P (mg/g) | K | Ca | Mg (%) | Lignin | Polyphenol |
|---|---|---|---|---|---|---|---|
| C. odorata | 24.6 | 4.2 | 25.6 | 32.1 | 23.3 | 10.8 | 1.6 |
| C. juncea | 10.7 | 3.8 | 13.8 | 27.4 | 24.2 | 12.4 | 0.73 |
| P.maximum | 24.9 | 3.3 | 26.1 | 26.0 | 20.2 | 13.2 | 1.5 |

Source*: Fening et al. (2011)*

Table 3. Nutrient content of poultry, cattle, and sheep manures

| Animal Manure | Average nutrient content (% wt/wt) | | | | |
|---|---|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ | CaO | MgO |
| Poultry | 2.20 | 1.80 | 1.10 | 2.40 | 0.70 |
| Cattle | 1.20 | 0.17 | 1.10 | 2.40 | 0.13 |
| Sheep | 1.55 | 0.31 | 0.15 | 0.46 | 0.15 |

Source: FAO (2005b) (based on CSIR-SRI, 1997)

livestock farming communities. The two most important animal manures are poultry and cattle manure. Manure from cattle is abundant in the Sudan and Guinea savannah agro-ecological zones because cattle rearing is a popular activity there. Poultry manure is popular in the forest zones where poultry farms abound.

Table 3 presents nutrient content of animal manures. It is clear from the table that poultry manure contains the highest nutrient content compared to cattle and sheep manure.

In some instances, it has been established that organic resources are poor in nutrient quality and insufficient in quantity terms to meet the nutrient needs of crops when solely applied (Roy *et al.,* 2022; Zhang *et al.,* 2021; Cayuela & Rasse, 2019; Wang *et al.,* 2017). Alternatively, application of inorganic fertilisers in combination with organic resources have the potential to yield the desired results. This is through a synergistic interaction between the inorganic fertiliser and the organic resource, leading to agronomic efficiency and increased soil nutrient buffering capacity (Linquist & Phengsouvanna, 2007).

Ghana is endowed with significant reserves of limestone and some marginal reserves of sulphur (S) – bearing minerals that can be utilized directly as nutrient sources or as raw materials for processing into fertiliser, although the potential for economic development is small (Saidou *et al.,* 2010). Liming materials contain calcium and magnesium carbonates that can neutralize soil acidity, stimulate soil microbial activity and supply essential nutrients such as Ca and Mg. In cases where the liming potentials of the applied organics are low and where liming materials are not available, external sources of lime can be included in the technology. Similarly, sulphur, a component of fertiliser, can be obtained domestically (De Luca *et al.,* 2012). However, fertiliser is not manufactured domestically; Ghana imports huge tons annually (FAO, 2005). Fertilisers are available on the domestic market but are expensive due to poor distribution mechanisms, local marketing margins and trade tariffs. The government of Ghana, for example, introduced the Ghana fertiliser subsidy program in 2008 to improve fertiliser usage among farmers; however, as at the time of this writing the program is not being implemented well and has not alleviated the low levels of fertilization adoption in the country (Jayne *et al.,* 2015). The current (2023) fertiliser subsidy may be helpful to ensure that the fertilisers are affordable and within the reach of smallholder and poor farmers.

Poor infrastructure, such as poor roads, lack of marketing facilities, and inadequate communication infrastructure, can lead to prohibitive transaction costs with negative consequences on household participation in markets. The feeder road networks in rural areas are bad and lack maintenance, which can render these communities inaccessible during rainy seasons. In Ghana, poor road networks, poor tariff infrastructure, and poor distribution mechanisms result in high transaction costs, which could sometimes make up about 50% of the fertiliser price, as is the case for many other countries in the sub-region(Kanza *et al.,* 2022)

Farmers in rural areas, especially in very remote communities, find it difficult to access fertiliser markets; when they finally get it, it is at a higher price, further driving them into debts and becoming a disincentive to procure fertilisers (Kanza *et al.,* 2022). Poor road networks also hinder the transport of organic resources such as compost from the production site to farmlands. Bellwood-Howard *et al*. (2015) reported that farmers in Northern Ghana overwhelmingly indicated poor transportation facilities as their primary barrier to composting. Therefore, improvements in road infrastructure by the government will contribute to ensuring the proper functioning of transportation systems with reduced transaction costs. Opening up rural communities will be essential to scaling up ISFM as it will facilitate the distribution of fertilisers, transport of organic resources, farmers' access to improved germplasm and access to extension services. Thus, improvements in infrastructure will affect the movement of the various components of ISFM and ensure the adoption of ISFM technology. Therefore, the ongoing infrastructural development by Government coupled with the fertiliser subsidy will help address the issue of high transaction costs. Bellwood-Howard *et al*. (2015) recommended that state and private investments to improve infrastructure are essential for sustainable ISFM.

**Technologies**

ISFM embraces a combination of existing and new technologies to maximise agronomic efficiency. Currently, a plethora of technologies have been developed and released in Ghana including improved crop varieties, input technologies and farm management practices (Afrifa *et al.,* 2010a) . These technologies come with distinctive characteristics which make them adaptable to particular local conditions. These make most of the existing technologies applicable within the ISFM context, and this is what has been done in the Northern regions of Ghana where ISFM is being practised (Bloem & Hopkins, 2006). This implies that a nationwide upscale of ISFM technology is possible, given that these technologies are used in other parts of the country but adapted to suit local conditions. Table 3 presents selected technologies in Ghana which can be mainstreamed into ISFM. For instance, Northern Ghana is characterised by a long dry season, so improved drought tolerant and early maturing varieties can be integrated into ISFM technology. Results indicate that farmers in Northern Ghana prefer crops with high yield, large grain size and drought resistance (Oppong-Anane, 2013). Ghana's research institutions, especially CSIR and the universities, are still contributing to the development of appropriate technologies adaptable to the various agro-ecological conditions, and this have intensified over the years (Frimpong Manso *et al.,* 2019).

Input technology is another vital component of ISFM. Issues related to input unavailability are many and range from socio-economic to political interference, with at least three standing out: (1) inorganic fertilisers are delivered in different formulations and may not resolve local nutrient deficiencies , (2) nutrient deficiencies of soils vary from one locality to another necessitating different optimal fertiliser application rates between farms in the same locality or on the same field, and (3) fertiliser is expensive and therefore optimal application rates vary with variations in the fertiliser-output price ratio (FAO, 2005), necessitating a thorough understanding of the complexities arising with this technology. The good news is that research and initiatives taken over the years have overcome the bottlenecks associated with fertiliser technology and made it more attractive and accessible. Following several on-farm trials, fertiliser recommendation rates have been made simple for various crops grown in the various agro-ecological zones. For example, the Ghana Grains Development Project (GGDP) recommendation for maize (Aflakpui & Dapaah, 2011), and CSIR-CRI and SARI's recommendation for rice (CSIR-SARI, 2011). Implementing the fertiliser subsidy program has also helped increase the adoption of inorganic fertiliser technology in the country. The awareness and adoption of technologies have been increasing among farmers in Northern Ghana largely because of the continued interaction between farmers, extension agents and research institutions (Wood, 2013), suggesting more collaborations between stakeholders will generate more benefits. The same holds for the Southern sector of Ghana.

Germplasm is an important component towards complete ISFM practice and full realization of resource use efficiency (Plate 1). Maize yield increases have been reported when improved maize germplasm plus inorganic fertilizer addition were compared with local variety plus inorganic fertilizer application (Vanlauwe *et al*., 2010). Tables 4a and 4b shows maize and rice germplasm in Ghana that have been released over the past years that can support ISFM practice. As new varieties are released, it is imperative to evaluate their superiority when the full compliment of ISFM is applied.

**Development and promotion of soil fertility initiatives in Ghana.**

***The use of crop-specific right fertiliser and organic resource combinations for various crops in the various agro-ecosystems***

It is important to use the right fertiliser for efficient utilization by crops (Koala *et al.,* 2010; Woomer *et al.,* 1990). Therefore, inorganic fertilisers applied to crops should meet the crops nutritional needs. According to (Bloem & Hopkins, 2006) knowledge of soil characteristics and processes regulating nutrient availability and supply to crops is essential for increasing crop output per unit of fertiliser nutrient applied. The most commonly applied fertilisers are NPK (15-15-15 or 20-20-0 or 20-20-20), Sulphate of ammonia and Urea. They are recommended to farmers by MoFA/CSIR, taking into consideration agro-ecological zone, soil type and cropping history because crop response to applied fertiliser is location specific.

For maize, compound fertilisers such as NPK 15-15-15 or NPK 20-20-0 is recommended, and the starter fertiliser should be applied about 5 cm away from the hills at planting or one to two weeks after planting; however, due to volatilization losses of nutrients, especially N, basal application or application at planting is no longer recommended and must be reviewed as part of the revised protocol for

Table 4a. Characteristics of improved maize varieties released in Ghana

| Variety | Year released | Source of germplasm | Selected distinctive characteristics |
|---|---|---|---|
| | Improved maize varieties | | |
| Aziga (yellow) | 2007 | [1]CIMMYT | High yielding, quality protein maize (QPM), good for poultry and livestock industry, contains carotene which imparts yellow color to egg yolk. |
| Akposoe | 2007 | CIMMYT/IITA | Extra early, QPM, drought tolerant (DT) excellent taste, when boiled or roasted |
| Etubi (hybrid) | 2007 | CIMMYT/IITA | QPM hybrid, DT, lodging tolerance |
| Abontem | 2010 | CIMMYT/IITA | QPM hybrid, DT, lodging resistant |
| Omankwa | 2010 | [2]IITA | DT, Striga tolerant, QPM |
| Aseda | 2012 | IITA | DT Striga tolerant, QPM |
| | 2012 | | Hybrid white, DT, very good for domestic purposes |
| Opeanburoo | 2012 | | Hybrid white, DT |
| Tintim | 2012 | | Hybrid white, DT |

[1] The International Maize and Wheat Improvement Centre, [2]International Institute of Tropical Agriculture

ISFM (Baah-Ofori & Amoakohene, 2021). About 4-5 weeks after planting, sulphate of ammonia or NPK 20-20-0 or NPK 20-20-20 should be applied as a side dressing at the soil surface except on sloping farm plots, depending on the available moisture contents of the soil. Urea is another fertiliser that can be applied; however, it is best to incorporate it into the soil rather than surface apply it to avoid losses through volatilization. Recommended fertiliser types and rates for maize production have been developed across different cropping systems in Ghana (Table 5). Several on-farm trials by GGDP researchers have led to these recommendations (Afrifa *et al.,* 2010a). In the forest zones, no fertiliser application rate is recommended for fields that had been fallowed for five years or more because the soils are assumed to be fertile and hence are less responsive to fertilisation while application of compound NPK fertiliser at a rate of 90-40-40 is recommended for the transition and savannah agro-ecological zones under at least two years cultivation (Morris *et al.,* 1999). It is important to note that these recommendations are revised based on market prices for maize and fertiliser (Snoeck *et al.,* 2010). Further, combining organic and inorganic amendments are preferred for soils in the Northern regions of Ghana because of their sandy nature, low soil

Table 4b. Characteristics of improved rice varieties released in Ghana

| Variety | Year released | Source of germplasm | Selected distinctive characteristics |
|---|---|---|---|
| | Improved maize varieties | | |
| DIGANG | 2002 | [3]IRRI | early maturing, DT, grains break easily |
| NERICA 1&2 | 2009 | AfricaRice | Aromatic, long grain, good taste, |
| JASMINE 85 | 2009 | IRRI | preferred by consumers |
| | | | high yield, blast resistant, long and |
| EMO TEAA/IDSA 85 | 2009 | [4]CRNA | slender, no aroma |
| | | | High yield, blast tolerant, aromatic, |
| Amankwa/Marshall | 2010 | [5]UG | long grain, less broken |
| | | | High yield, blast tolerant, no aroma, |
| Wakatsuki (Bouake 189) | 2010 | AfricaRice | not very tasty, grains break easily |

[3]International Rice Research Institute, [4]Centre Nationale de Recherche Agronomique. [5]University of Ghana, Legon

organic matter (SOM) and soil organic carbon (SOC) levels. In this case, the organic fertiliser or compost will add organic matter to the soil and help in the water retention capacity of the savannah soils.

For rice production in Ghana, fertiliser recommendations by CSIR-CRI and SARI regarding the optimal timing, method of application, and rates of application are presented in Table 6. Following extensive on-station and on-farm trials, split fertiliser application recommendations were made for rice production: basal application with a compound fertiliser and top dressing with sulphate of ammonia or urea at the reproductive stage. About 200–400 kg/ha of compound fertiliser (NPK 15-15-15) has been recommended for the basal application, while 150 kg/ha of sulphate of ammonia (SOA) or 95 kg/ha of urea is recommended based on cropping history. Regarding the timing of fertiliser application, it is recommended that the first application should be made one week after transplanting of seedlings and 2-3 weeks under direct seeding (in all agro-ecological zones), and the second application should be carried out 5-6 weeks after planting in all zones except the Northern savannah which can be done 7-8 weeks after planting (Tsujimoto, 2009).

Cassava cultivation occurs in the Forest, Transition and Guinea Savannah agroecological zones. Cassava responds to fertiliser application in all the cassava producing areas (Michael *et al.,* 1999), with the recommended application rate being 68kg N/ha, 45kg $P_2O_5$/ha and 68kg $K_2O$/ha (Morris *et al.,* 1999). Even though the recommended application rates from scientists are available, there is a disconnect between recommended rates by scientists and farmers' adoption of these application rates. Fertiliser application in the country is more under the control of farmers' income level, other socio-economic

Table 5. Recommended rate of fertiliser application for maize production across Ghana

| Cropping system | Starter (50kg/ha) | Side dress (50kg/ha) | Nutrient application N (kg/ha) | P | K |
|---|---|---|---|---|---|
| Coastal savannah and Northern savannah zones | | | | | |
| Land fallowed for 5 or more years | 1 | 1 | 45 | 19 | 19 |
| Land fallowed for < 5 years or Continuously | 2 | 2 | 90 | 38 | 38 |
| Land is continuously cropped plus hybrid | 3 | 3 | 134 | 56 | 56 |
| Forest and transition zones | | | | | |
| Land fallowed for 5 or more years | 0 | 0 | 0 | 0 | 0 |
| Land fallowed for less than 5 years | 1 | 1 | 45 | 19 | 19 |
| Land continuously cropped | 2 | 2 | 90 | 38 | 38 |
| Land continuously cropped plus hybrid | 3 | 3 | 134 | 56 | 56 |

Source: CSIR- SARI (2011); West Africa Agricultural Productivity Programme (WAAPP) and MOFA/SRID (2013)

Table 6. CSIR/MoFA recommended rate and timing of fertiliser application for rice production in Ghana

| Planting method | First application NPK 151515 Rate (kg/ha) | Second application SOA or Urea Rate (kg/ha) | Nutrients (kg/ha) N | P | K |
|---|---|---|---|---|---|
| **Lowland** | | | | | |
| Transplanted | 400 | SOA;150 or Urea 75 | 95 | 60 | 60 |
| Direct seeding | 300 | SOA:150 or Urea 75 | 80 | 45 | 45 |
| **Northern Savannah** | | | | | |
| Transplant/Direct seeding | 200-300 | SOA:150 or Urea 75 | 60-80 | 30-45 | 30-45 |

Source: MoFA/SRID (2013)

Note: SOA = Sulphate of ammonia

Table 7. Fertiliser use and application by maize farmers across agroecological zones in Ghana

| Fertiliser type | All zones | forest | Transitional | Northern | Coastal |
|---|---|---|---|---|---|
| | | | --------Savannah------- | | |
| Inorganic fertiliser (% maize area) | 47 | 17 | 74 | 81 | 37 |
| **Plots with fertiliser(kg/ha)** | | | | | |
| Nitrogen | 47 | 27 | 48 | 57 | 29 |
| Phosphorus | 20 | 16 | 16 | 27 | 17 |
| Potassium | 20 | 16 | 15 | 27 | 17 |
| **Plots with fertiliser (% of farmers)** | | | | | |
| NPK 15-15-15 | 83 | 73 | 77 | 95 | 72 |
| Sulphate of ammonia | 71 | 52 | 63 | 88 | 67 |
| Urea | 5 | 2 | 12 | 2 | 0 |

Source: Marschner (2003)

Table 8. Fertiliser use and application on paddy fields across different ecological zones in Ghana

| Fertiliser type | All | Irrigated | Lowland rainfed | Upland rainfed |
|---|---|---|---|---|
| Inorganic fertiliser (% farmers) | 77 | 98 | 68 | 82 |
| **Plots with fertiliser (kg/ha)** | | | | |
| Nitrogen | 64 | 84 | 54 | 43 |
| Phosphorus | 31 | 43 | 25 | 19 |
| Potassium | 30 | 43 | 25 | 19 |
| **Plots with fertiliser (% of farmers)** | | | | |
| NPK 15-15-15 | 90 | 99 | 87 | 71 |
| Sulphate of ammonia | 77 | 84 | 75 | 61 |
| Urea | 12 | 17 | 10 | 4 |

Source: Marschner (2003)

factors and experience, where fertilisers apply fertiliser based on soil fertility gradient. A typical case in point is the fertiliser applied on maize and rice farms(Morris *et al.,* 1999).

Fertiliser use and application rates by maize farmers have been studied across the agro-ecological zones in Ghana (Table 7). The Northern Savannah zone recorded the highest nitrogen application rate (57 kg/ha N), followed by the Transition zone (48 kg/ha N) and the Forest zone (27 kg/ha N). The frequency of fertiliser application, however, differs from farmer to farmer. Dume *et al.* (2017) reported that majority of farmers applied fertiliser in a split (at least twice), while some applied it only once. Overall, the amount of fertiliser nutrients applied was 47 kg/ha N, and about 20 kg/ha each of phosphorus and potassium, which is about half the recommended rate of nitrogen (90 kg/ha), phosphorus (38kg/ha) and potassium (38kg/ha) for continuously cropped fields.

Fertiliser use and application rates by rice farmers were also studied across the agro-ecologies zones (Table 8). The CSIR and MoFA recommended rates of application are 65 kg/ha N for rice fields in the forest zone with less than five years of fallow period and 100 kg N/ha for rice fields that are continuously cropped (Marschner, 2003). Their findings showed that the N application rate used by the farmers was lower than the recommended rates (Table 8). Analysis across the rice growing ecologies showed that fertiliser use in the rainfed lowland and upland production systems was much lower than the recommended rates (Marschner, 2003). The fertiliser application rate is higher in irrigated production systems compared to lowland and upland production systems. For example, the average application rate at the Kpong irrigation sites was 126 kg N/ha, which is higher than the recommended rate, while the application rate was lowest in the North with 71 kg/ha N in Tono, 54 kg/ha N in Vea, and 56 kg/ha N in the Botanga irrigation schemes(Marschner, 2003).

Even though the national subsidy may have incentivized farmers to use more fertilisers on their maize and rice farms, the rates of application still remain lower than recommended since even the subsidized rates are beyond the affordability of many farmers in addition to the unavailability of subsidized products (e.g., NPK and SOA ) to farmers (Weiske & Petersen, 2013). Results from the surveys indicated that most farmers prefer NPK 15-15-15 as it was applied to 83% of maize field, followed by sulphate of ammonia (71%) and urea (5%). A similar trend was observed among rice farmers, too. Other fertilisers used but in marginal quantities are Sulfan, Actyva, foliar fertilisers and NPK 20-20-0 (Afrifa *et al*., 2010b)

**Improved germplasm of major food crops**

Improved germplasm is a key component of the Green Revolution technologies, along with fertilisers, pesticides, and irrigation. Improved germplasm usually means crop varieties bred for disease resistance, high yields, and the ability to use fertiliser efficiently. An improved germplasm enhances nutrient use efficiency (NUE) and reduces nutrient mining in soils. Improved germplasms could lead to increased biomass production which can be added to improve soil organic matter. Improved cereal (maize, rice, etc.) and other crop germplasms abound in Ghana. The major sources of maize germplasm to breeders in Ghana are the International Maize and Wheat Improvement Centre (CIMMYT) and the International Institute of Tropical Agriculture (IITA) (Ragasa *et al*., 2013). Some of the improved maize germplasm and the sources of their parental lines are presented in Table 9. Maize breeders at CSIR-CRI use the parental lines obtained from CIMMYT and IITA for the

Table 9. Improved germplasm of maize varieties in Ghana (1984-2010)

| Variety | Year released | Germplasm | Source of germplasm |
|---|---|---|---|
| Dobidi | 1984 | Ejura (1) 7843 | CIMMYT |
| Kawanzie | 1984 | 4Tocumen (1) 7931 | CIMMYT |
| Gold crystal | 1984 | | CIMMYT |
| Safita-2 | 1984 | Pool 16 | CIMMYT |
| Okomasa | 1984 | EV8343-SR | CIMMYT/IITA |
| Abelechi | 1990 | Ikenne 8149-SR | CIMMYT/IITA |
| Dorke SR | 1990 | Pool 16-SR | CIMMYT/IITA |
| Obatanpa | 1992 | Pop 63-SR | CIMMYT/IITA |
| Mamaba | 1996 | Pop 62, Pop 63-SR | CIMMYT/IITA |
| Dadaba | 1996 | Pop 62, Pop 63-SR | CIMMYT/IITA |
| Cidaba | 1996 | Pop 62, Pop 62-SR | CIMMYT/IITA |
| Dodzi | 1997 | | CIMMYT/IITA |
| Aziga (yellow); | 2007 | | IITA |
| Golden Jubilee and Etubi (Yellow) | 2007 | | CIMMYT |
| Akposoe | 2010 | | CIMMYT/IITA |
| Aburohema; Abontem and | | | IITA |
| Omankwa | 2010 | | |
| Enihi (hybrid) | | | CIMMYT/IITA |

Source: Morris *et al.* (1999) and Regassa *et al.* ( 2013)

genetic improvement of grain quality and yield and yield-related traits for high yield of local adaptable varieties. Genetically improved progenies are evaluated on-station first and then in multi-growing environments across the different agro-ecological zones and finally with farmers. Maize breeders at CIMMYT and IITA also collaborate with breeders from CSIR-CRI to evaluate selected experimental varieties in multi-growing environments and on-farm with farmers across the country. The most promising varieties selected from these trials are released as commercial varieties through the national varietal release system. The seeds of the commercial varieties are multiplied and sold to farmers.

Rice breeding in Ghana used to be mainly evaluation of improved genotypes obtained from AfricaRice and International Rice Research Institute (IRRI) (see Table 4b) under multi-growing environments to test the resilience and adaptability in diverse environments. However, since 2017 CSIR-CRI has started releasing commercial varieties of its own genetically improved rice varieties in the country (Asante *et al*., 2017).

**Sustainability (residual and long-term effects)**

Integrating organic inputs such as compost into ISFM improves the physico-chemical properties of soils. Such benefits include the supply of N, P and K to crops and the enhancement of soil structure and aggregate stability in addition to the supply of energy to soil microbiota and the enhancement of soil water retention capacity while reducing evaporation from soils, which resonates the concept of strong sustainability (Bellwood – Howard, 2014). Organic resource management in ISFM delivers greater crop productivity under low or high rainfall due to improved water use efficiency, enhanced resilience of cropping systems to climate change impacts and mitigation of greenhouse gas (GHG) emissions (Mu *et al.,* 2017). Diversifying the crop base by planting annual and perennial crops together significantly reduces the impacts of climate change on farm production while addressing food insecurity. Aside from increasing total biomass yield dramatically, using local materials such as stover residues in some cropping systems in ISFM as an organic resource management strategy has proven to neutralize acidity and reduce the export of potassium, calcium and magnesium(Bationo, 2004). The stover on the land also serves to protect the soil against wind erosion. Therefore, the development and promotion of ISFM will lead to sustainable land use and increased food production and development. While problems such as eutrophication and acidification exist in other parts of the world, in SSA, the problem of eutrophication does not exist; however, acidification is possible in cases where sulphur fertilisers are used in large quantities, then the application of organic residues can be a panacea. However, the more significant issue is the indirect effects of low soil organic matter reincorporation, resulting in lower soil moisture and nutrient retention (Bellwood-Howard, 2014). The low soil moisture and nutrient retention status must be addressed if crop productivity in the Northern Savanna eco-ecological agro-ecological zone has to be increased (Braimoh & Vlek, 2006).

**Socio-economics and cultural issues**

The socio – economic and cultural contexts affect a farmer's ability and need to compost. there is a direct and indirect relationship between various components of the social economy and in the context of farming, money, labour and livestock interact to affect soil fertility (Bellwood-Howard *et al.,* 2015). Due to poverty, most farmers cannot afford fertiliser, leaving them with compost as the only alternative. In Northern Ghana, wealthy farmers do not only have financial resources to purchase more fertiliser but also the ability to transport compost to their farms (Njoh *et al.,* 2018) because compost is not always produced where it is required for application, necessitating transportation. Farmers have used different means of transport including hand-pulled trucks, wheelbarrow and animals (ox or donkey) to transport organic resources or compost to farms. However, access to these resources through either ownership or hire depends on having financial capital. According to Bellwood-Howard *et al.* (2015), a lack of finance limited the ability of farmers to apply compost and fertiliser to their crops. Livestock is an important form of physical capital; however, cultural and religious factors influence which type of livestock manure to use. For example, Christian farmers have access to pig manure, ruminant manure and other organic inputs thereby increasing the chances of meeting their compost needs. On the other hand, Muslims use ruminant manure together with plant residues. Composting is labour intensive; Therefore, social capital helps farmers enlist human capital, implying that larger households are more likely to compost

(Waqas *et al.,* 2018). Bellwood-Howard *et al.* (2015) also found no evidence of larger households (with more people to carry the product) adopting compost in Northern Ghana because households apply compost for different reasons, which range from acceptability to socio-cultural issues. They further noted that larger households have lower opportunity costs of labour, and although many could afford fertiliser because they are richer, they used compost in addition to inorganic fertiliser to reduce drought risk. Ghana's fertiliser subsidy program has enabled farmers to purchase fertiliser at lower cost. Since the inception of the national fertiliser subsidy program, fertiliser use has increased considerably, suggesting this may have encouraged more farmers in that regard '(Jayne *et al.,* 2015).

**Development and production of the right fertilisers and access to these fertilisers**

Ghana does not produce mineral fertilisers and, therefore, resorts to importing inorganic fertilisers to satisfy domestic demand. In contrast, organic fertilisers are produced on a minimal scale, while private companies, the Agricultural Development Bank and some commercial banks import inorganic fertilisers into the country. That notwithstanding, the private sector also does local blending of fertiliser types using imported active ingredients, constituting about 45% of fertiliser requirement (MoFA/SRID, 2011). Due to the significance of blending fertilisers locally, enhancing the private sector's capacity of blending appropriate straight fertilisers based on the ecology, soil type and crop variety to be adopted by farmers is being considered(MoFA/SRID, 2011) .

Compound fertilisers make up the larger proportion of the total fertiliser imported into Ghana. The other essential fertilisers imported are ammonium sulphate, muriate of potash, triple superphosphate, single superphosphate and only marginal amounts of urea (in terms of quantity applied to fields even though it is the most commonly used) (FAO, 2005). With the assistance of MoFA, CSIR-CRI, CSIR-SARI and agricultural extension agents (AEA's) farmers can use the right fertilisers that address the nutrient needs of their crops. Evidence from literature indicates that farmers have access to the right fertilisers (Nations *et al.,* 2008). For example, AGRA helped create 28 networks of agro-dealer/farmer's organisation in 8 districts of the Northern region through which the farmers access fertiliser(MoFA/SRID, 2011). Although the fertiliser subsidy program introduced in 2008 may have increased fertiliser availability, its distribution, access and affordability to smallholder farmers remain a fundamental policy challenge (Lele & Goswami, 2020; MoFA/SRID, 2011; Kolawole, 2007)

**Access to markets and financial institutions / credits**

Access to markets by farm households is crucial because it ensures the availability of the inputs needed for sustainable soil management practices and markets for harvests. However, farmers face high transaction costs when selling produce or purchasing inputs due to poor roads, inadequate market facilities and imperfect information limiting their market engagements. For ISFM to succeed, there must be well-structured and functioning input and output markets where farmers can purchase inputs and sell their produce. This calls for developing market centres and road infrastructure to promote market integration and ensure farmers' market participation–. (Lele & Goswami, 2020). With increased efficiency in the distribution system and greater access to inputs and output markets, ISFM would be a better and more sustainable technology because farmers would be assured of regular supply of inputs and ready market for harvest (Baah-Ofori & Amoakohene, 2021).

Evidence from literature indicates that farm households engage in markets. In Northern Ghana, farm households who have adopted the ISFM to some extent engage in input market by owning tractors which they use to provide mechanised services to neighbouring farmers in their community (Njoh *et al.,* 2018). In return, they received a portion (a tenth) of their harvests as repayment and resold them during the lean season when prices were high (Njoh *et al.,* 2018). Input dealers are the leading market source for inputs such as fertiliser for farm households in Ghana. The AGRA's project (2010-2013) Increasing maize-legume cropping system productivity through scaling out of integrated soil fertility, partnered with a network of agro-dealers organized by International Fertiliser Development Centre (IFDC) to ensure regular supply of farm inputs (AGRA, 2014). The project created 28 networks of agro-dealer/farmer's organisation in about eight districts of the Northern region through which the agro-dealers delivered fertiliser to farmers' groups. In facilitating access to output markets, market information on output prices is made available through broadcast using radio, mobile phones and leaflets through collaborative efforts among AGRA, IFDC and local FM radio stations in the Northern region. This collaboration also facilitated linkage between the farmer groups and bulk produce buyers (AGRA & IIRR, 2014).

Credit is an important source of capital resources in agriculture. Without credit, poor and smallholder farmers cannot make meaningful farm investment. The sources of credit include formal (e.g. banks), semi-formal (e.g. credit unions), informal (e.g. *susu*) as well as family members. Farmers' access to credits is important for their farming operations as it enables them to purchase improved crop varieties, fertilisers, compost and other farming inputs on time. Moreover, credit access by farmers ensures sustainable ISFM. Credit drives the uptake of costly technologies such as inorganic and organic fertiliser (Bellwood-Howard *et al.,* 2015). Thus, access to credit boosts the financial endowment of farmers and has positive spillover effects on farming activities. In Ypilgu, Tarakpaa, Zugu, Satani and Yirikpani communities in Northern Ghana, farmers who accessed credits used more fertiliser and compost, achieved higher crop yields and were able to sell more of their maize (Bellwood-Howard *et al.,* 2015). In a study on the ex-post impact of AGRA Soil Health Project 005 in Northern Ghana, it was revealed that farmers or households had access to credit in the form of inputs (fertiliser, seed), service and cash (Martey *et al.,* 2013) The Centre for Agricultural and Rural Development (CARD), a non-governmental organisation (NGO), in partnership with the AGRA Soil Health Project provided input credit (a cashless credit facility) to farmers at a relatively lower interest rate (AGRA and IIRR, 2014). Farmers sold their produce to CARD to repay the acquired loan, a strategy that ensured farmers did not default and were assured market for their produce. Martey *et al*. (2013) noted that non-cash credit in inputs and services to farmers elicited better outcomes than cash credit. Other sources of credit for farmers come from informal sources such as money lenders and family members, as well as NGOs who help promote input credits to farmers.

Several formal financial institutions, such as Agricultural Development Bank, commercial and rural banks, offer loans to farmers at exorbitant interest rates. Although these banks are willing to give out loans to farmers, their requirements and modalities for accessing loans restrict the farmers, who then resort to the aforementioned informal sources (Martey *et al*., 2013).

**Access to knowledge and information on ISFM**

For farmers to derive the benefits of ISFM (for example, enhanced yield of staple food crops), they need the proper knowledge of ISFM and skill sets related to ISFM, which may vary from place to place due to disparities in soil nutrient contents (fertility status), type of farmer/household and gender of farmer (AGRA & IIRR, 2014). Knowledge and information on ISFM are multiple; important are information on inputs use (e.g. improved seeds, fertiliser, pesticides, and weedicides), farming systems, appropriate crop management methods, effective soil and water management practices. The range of available information must be adapted to address the needs of farmers in their localities. For instance, the needs and interests of a farmer in the Sudan Savannah agro-ecological zone in Northern Ghana will differ from that of a farmer in the Transition or Forest zones. Also, input dealers and service providers need information to be able to address farmers' concerns.

Access to information on ISFM is essential for its uptake. In Northern Ghana, where ISFM is practiced farmers depend on a wide range of knowledge and information. They rely on research scientists, extension agents, NGOs and neighbouring farmers for information regarding inorganic and organic fertiliser technology, improved crop varieties, fertiliser prices and fertiliser application rates. Bellwood-Howard (2013) found that knowledge influences farmers' composting decisions in Northern Ghana. The farmers who had acquired knowledge and information on composting from NGOs, MoFA and neighbouring farmers could prepare and apply compost and recognize the higher water retention capacity of soils treated with compost (Bellwood-Howard, 2013, 2014). Further, observable technologies (for example, composting) are easily disseminated through participatory farmer-to-farmer methods (Kalnins *et al*., 2015) For example, NGOs like OIC (Opportunity Industrialization Centre) introduced composting to farmers in Ypilgu in Northern Ghana (Bellwood-Howard, 2013). Wiredu et al. (2014) in their study on the adoption of ISFM practices in Ghana, found the adoption rate for inorganic fertiliser use to be 96%, followed by adoption of improved maze varieties (89%) and adoption of organic fertilisers (60%). They further found that about 51% of farmers had adopted the ISFM technology on 57% of their maize fields. ISFM technology is widely practiced by households, as captured in a study conducted by Martey *et al*. (2013), suggesting that farmers have access to knowledge and information on ISFM, contributing to the reported adoption rates of the various components and their entirety.

The AGRA funded Project in Ghana "Improving food security of small holder producers through middle level manpower capacity building in soil health" implemented between 2011and 2014, sought to overcome the lack of staff knowledgeable about ISFM in the country's extension service system, to enhance nationwide capacity building (AGRA & IIRR, 2014). The main focus of the project was to revise the curricula of the Diploma in Extension programmes of four agricultural colleges (Kwadaso, Ohawu, Ejura and Damango) and three farm institutes (in Wenchi, Asuansi and Adidome), which train students and farmers to include ISFM concepts. Moreover, the Universities for

Development Studies and Cape Coast (the implementing universities) also revised their Soil Science curricula to incorporate ISFM at the bachelor's level. The aim of the project was to train 60 staff of the colleges, farm institutes and extension agents in ISFM, soil testing, among others. During the project implementation phase, 21 demonstration sites were established to train students and farmers in ISFM in the communities around the colleges and farm institutes. Radio programmes were also undertaken as part of the outreach activities by partnering with ten radio stations across Northern and Southern Ghana to disseminate information on soil fertility to farmers. Information on ISFM was disseminated in the local languages on radio, and farmers called into the programme to ask questions, which experts addressed. These activities ensured that farmers had access to enough information to speed up the adoption of ISFM practices.

**Challenges to ISFM**

- **Funding for ISFM Research:** There is a need to identify and address research gaps in ISFM to improve the current state of results and adoption. Funding, however, for this, as is often the case in research activities, is not available. With increase in funding allocated to ISFM related research, there will be improved technologies and varied dissemination and adoption promotion methods. Most studies on ISFM in Ghana have centered on the northern region. With increased resources, further studies can be carried out in other areas of the country facing soil fertility depletion to obtain varied experiences that will influence the dissemination of information as well as the creation of technologies. An ex-post impact assessment of AGRA Soil Health Project in Northern Ghana by Martey *et al*. (2013), noted that funds provided by AGRA to soil scientists at CSIR-SARI to test various ISFM technology options to identify and promote those that enhance crop yields of smallholder farmers. In northern Ghana, approximately 2,300 smallholder farmers are still supported by a revolving fund that was established in 2011, and which has significantly improved access to financing and quality-certified inputs for farmers. As a result, agro-dealers trained and supported by the SHP are reporting an annual year-on-year increase in demand for fertilizers in the range of 10 percent, with the traded volumes now exceeding 200,000 tons of inorganic fertilizers. This accounts for 48 percent of total fertilizer usage in Ghana in 2019. This led to increased crop yields on farmers' fields (AGRA, SHP, 2020).This is a step in the right direction and should be followed by other bodies, especially the Government and related Ministries.

- **Poverty State of Farmers:** Several studies have pointed to a relationship between the income or resource of the farmer and his inclination towards ISFM adoption. Farmers' ability to hire labour positively influenced the adoption of ISFM practices (Mugwe *et al*., 2007; Kelly *et al*., 2005; Okuro *et al*., 2002). Thus, if the farmer is well-endowed and can afford to hire labour, he is more likely to adopt ISFM since organic fertiliser application is considered laborious. In contrast, Ransom *et al*. (2003), reported a significant negative effect of hired labour on the adoption of improved varieties. Martey *et al*. (2013) further reported that the occupational status of a farmer is related to the probability of adoption; those who had farming as their primary occupation were less likely to adopt ISFM, in contrast, those who had other non-farm activities as their primary occupation were more likely to adopt ISFM because they can plough profit from those activities into the farm.

The authors suggested that adoption of ISFM was associated with cost, and low-income farmers had no incentive to do so. These findings point to the complexity of farmers' attitudes and choices.

- **Limited quantities of organic components:** ISFM applies the concept of both organic and inorganic fertilisers. The challenges encountered cover the high cost of inorganic fertilisers and the limited quantities of organic fertilisers. In Donkor & Awuni (2011), 11.2% of respondents said they chose local organic materials because they were cheaper and available in their communities. Thus, with adequate quantities of organic matter, more farmers who cannot afford inorganic fertilisers can use organic fertilisers to improve the soil fertility of their farms. While implementing participatory action research (PAR) in the context of ISFM as an adaptation tool for smallholder farmers, one major challenge was the low availability of organic resources since most farmers were resource constrained. In addition, Alhassan (2009) and Bellwood-Howard (2013), found that transportation of compost to farms is another challenge limiting compost availability for use on farms. Measures to solve issues of limited organic matter must also consider how to transport them to farms easily.

- **Inadequate resources for dissemination:** In a baseline survey, the Ghana Soil Health Consortium noted that, though the usefulness of the ISFM is recognized in the country, most institutions lacked an ISFM Database. The significance of extension services in determining the adoption of farming techniques has been discussed in many studies (Morris *et al.,* 1999). Frequent contact with extension staff allows the farmer the opportunity to learn about the availability and use of new farming techniques. The problems with the extension delivery system in Ghana, like in many other developing countries, are that the staff is woefully inadequate and not properly motivated. Staff from NGOs are better motivated, but they are not enough to make up for the deficiency (Donkor & Awuni, 2011). Pooling together key agricultural stakeholders to consolidate, synthesize and develop effective messages on ISFM technologies can help obtain detailed, up-to-date and spatially explicit information for dissemination (AGRA-SHP-2002) (AGRA country level Soil Health Consortia Issue 02). Dealing with issues of attitudinal nature require more education, sensitization and effective dissemination, encompassing a myriad of measures. For example, the AGRA Soil Health Program ( AGRA, SHP005) implemented to promote the use of ISFM practices among farmers in Northern Ghana used several interventions, notable among them are farm demonstrations, capacity building of Farmer Based Organisations (FBOs) and facilitating input credit to farmers.

- **Access to knowledge and information:** Inadequate access to information and knowledge on ISFM results in misconceptions and, as such, has a negative impact on the adoption rate. A study by Donkor & Awuni (2011) on farmers' perceptions and adoption of improved farming techniques in lowland rice production systems in Northern Ghana showed that farmers had a misconception of ISFM and entertained fears that the use of organic fertilisers on their rice fields will gradually turn the area into an upland, hence their reluctance to adopt the technique, particularly on their lowlands. Education of the household head has been reported to be associated with a lower probability of ISFM adoption (Dang, 2007), suggesting that though education is often linked with increased depth of knowledge and awareness level, it is not in all cases that education can promote the adoption of new technologies. It is often anticipated that participation in projects and training programs organised by organisations such as AGRA would promote the adoption of technologies. On the contrary, the study by CSIR- SARI on ISFM in the northern parts of the country suggested that non-participant households are more likely to adopt ISFM technologies than participating ones (Martey *et al*. 2013). Thus, participation in training programs does not necessarily lead to increased adoption since individuals have different motivations for participation in such programs, and non-participating ones could be more risk-loving. According to Martey *et al*. (2013), fertiliser use intensity was positively influenced by membership of associations. According to the authors, the associations served as a platform for accessing and disseminating information and technology. Most projects in the Northern regions such as Northern Rural Growth Programme (NGRP), Millennium Challenge Account (MCA) Programme and AGRA Soil Health Project, target the farmer groups to enhance and build their business and technical capacities which have proved effective. However, this method of dissemination remains a challenge since the groups will be expected tosupport in cash and in-kind, as is always the case. Easy access to extension/ agricultural offices also hinders the dissemination of information because the distance from a farmer's location to the nearest office in their locality can hinder farmers from accessing information that might be available and, hence, prevent them from adopting and effectively using these technologies.

**Conclusion**

From the preceding discussions, research gaps exit in Ghana that need to be addressed to ensure the effective implementation and sustainable use of ISFM technologies. The major areas that need to be addressed include how to obtain a reliable ISFM Database for institutions and scale up research to the southern part of the country.

**Recommendation**

An essential condition for rapid ISFM adoption is access to farm inputs, produce markets, and financial resources. To a large extent, adoption is market-driven as commodity sales provide incentives and cash to invest in soil fertility management technologies, providing opportunities for community-based savings and credit schemes. Policies towards sustainable land use intensification and the necessary institutions and mechanisms to implement and evaluate these can also facilitate the adoption of ISFM. Policies favouring the importation of fertiliser or better, the establishment of local fertiliser companies, its blending and packaging, or smart subsidies are needed to stimulate the supply of fertiliser. It is recommended that policies for sustainable land-use intensification be rigorously implemented and encouraged.

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**Conflict of interests**

The authors have not declared any conflict of interests.

**References**

Aflakpui, G.K.S. & Dapaah H.K. 2011. Farmer participation in on-farm research: The experience of the Ghana Grains Development Project. *Ghana Journal of Agricultural Science* Vol.33(1): 99 -108

Afrifa, A. A., Ofori-Frimpong, K., Acquaye, S., Snoeck, D. & Abekoe, M.K. 2010a. Soil nutrient management strategy required for sustainable and competitive cocoa production in Ghana. Some key information on nutrient and their availability required for Cocoa. Proceedings of the 16th International Cacao Research Conference, Denpassar, Bali 16-21 November, 2009. pp 335 - 342.

——2010b. Soil nutrient management strategy required for sustainable and competitive cocoa production in Ghana. Some key information on nutrient and their availability required for cocoa. Proceedings of the 16th International Cacao Research Conference, Denpassar, Bali 16-21 November, 2009. pp 335 - 432.

AGRA & IIRR. 2014. Investing in Soil. Cases and lessons from AGRAs Soil Health Programme, Nairobi, Kenya : Alliance for Green Revolution in Africa (AGRA): International Institute of Rural Reconstruction (IIRR), 2014. pp 169

AGRA 2014. Integrated soil fertility management (ISFM). Promotional project implemented by Africare. Final report: end of project evaluation, November 2014. pp 93

Ailincăi, C., Jităreanu G.,. Bucur D. & Despina A. 2012. Long-term effect of fertiliser and crop residue on soil fertility in the Moldavian Plateau. *Cercetari Agronomice in Moldova* 45(2): 29 - 41.

Anang, B. T., Backman, S., & Sipilainen, T. 2020. Adoption and income effects of agricultural extension in northern Ghana. *Scientific African* 7: e00219.

Baah-Ofori, R. & Margaret, A. 2021. A review of soil fertility management communication in sub-Saharan Africa. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* 122(1): 1-12.

Bationo, A. 2004. Nutrient cycles to sustain soil fertility in sub-Saharan Africa Tropical Soil Biology and Fertility Institute of CIAT 2004.

Bellwood-Howard, I., Chimsi E., Abdul-Ganiya S., & van Veenhuisen, R. 2015. Urban and peri-urban agriculture in Tamale:URBANET UrbanFoodPlus RUAF Foundation Ghana WASH Programme University for Development Studies and International Water Management Institute. *A Policy Narrative* (January): 1-35.

Bloem J., Hopkins, W., & Benedetti A. 2006. Microbiological methods for assessing soil quality CABI Publishing. Website: www.cabi-publishing.org.

Braimoh A. K & Vlek, P.L.G. 2006. Soil quality and other factors influencing maize yield in northern Ghana. *Soil Use and Management* 22: 165-171. doi: 10.1111/j.1475-2743.2006.00032.x

Breman, A. 2011. Give more tomorrow: Two field experiments on altruism and intertemporal choice. *Journal of Public Economics* 95: 1349-1357

Cayuela, M.L. & Daniel, P. R. 2019. Biochars from mediterranean agroindustry residues: Physicochemical properties relevant for carbon sequestration and soil water retention. *American Chemical Society Sustainable Chemistry and Engineering* 7:

4724–4733.

CSIR- SARI. 2011. Council for Scientific and Industrial Research 2011 Annual Report.

DeLuca, T. H., Derek-MacKenzie M. & Michael J. G. 2012. Biochar effects on soil nutrient transformations. In: Biochar for Environmental Management. *Science and Technology* (Eds. J. Lehmann & S. Joseph) pp 251 - 270.

Donkoh, S.A. & Awuni J.A. 2011. Adoption of farm management practices in lowland rice production in Northern Ghana. *Journal of Agricultural and Biological Science* 2(4): 84-93

Dume, B., Ayele, D., Regassa, A., & Berecha, G. 2017. Improving available phosphorus in acidic soil using biochar. *Journal of Soil Science and Environmental Management* 8: 87-94. doi:10.5897/JSSEM2015.0540

Food and Agriculture Organisation (FAO) (2005). Fertiliser use by crop in indonesia.

Fening, J.O., Adjei-Gyapong, T., Ewusi-Mensah, N. & Safo, E.Y. 2011. Manure management, quality and mineralization for sustaining smallholder livelihoods in the Upper East Region of Ghana. *Journal of Science and Technology* (Ghana) 30 (2): 1-10

Frimpong Manso, E., Nartey, E. K., Adjadeh, T. A., Darko D. A., Lawson, I. Y. D. & Amoatey, C. A. 2019. Use of corn cob and rice husk biochar as liming materials in acid soils. *West African Journal of Applied Ecology* 27(2): 32-50.

Fofana, B., Wopereis, M. C. S., Bationo, A., Breman, A. H. & Mando, A. 2008. Millet nutrient use efficiency as affected by natural soil fertility, mineral fertilizer use and rainfall in the West African Sahel. *Nutrient Cycling in Agroecosystem* 81: 25-36

International Fertiliser Development Center (IFDC). 2010. Annual Report. https://hub.ifdc.org/handle/20.500.14297/1722

Jayne, T.S., Jordan, C., Lulama, T., Nicholas, S., Milu, M., Felix, K., Yeboah, W. A., Antony, C., Ayala, W., Chewe, N. & Richard, K. 2015. Africa's changing farm size distribution patterns: the rise of medium-scale farms. *Agricultural Economics* 47 (1): 197-214

Kalnins, H.J.R. & Jarohnovich, N. 2015 System thinking approach in solving problems of technology transfer process. *Procedia-Social and Behavioural Science* 195: 783-789.

Kanza, P., Vitale, J. & Vitale, P. P. 2022. Agriculture in sub-Sahara Africa developing countries and the role of government: Economic perspectives. *African Journal of Agricultural Research* 18 (7): 493 509

Kelly, K. B., Stockdale, C. R. & Mason, W. K. 2005. The productivity of irrigated legumes in northern Victoria. 2. Effect of grazing management. *Australian Journal of Experimental Agriculture* 45 (12): 1577-1585

Kolawole, O. P. & Ayodeji, L. S. A. 2007. Engineering research to improve cassava processing technology. *International Journal of Food Engineering* 3 (6): Article 9. pp 13

Kuivanen, K.S., Michalscheck, M., Descheemaeker, K., Adjei-Nsiah S., Mellon-Bedi, S., Groot, J. & Alvarez C.J. 2016. Characterising the diversity of smallholder farming systems and their constraints and opportunities for innovation: A case study from the Northern Region, Ghana. *NJAS - Wageningen Journal of Life Sciences* 78: 153-166. http://dx.doi.org/10.1016/j.njas.2016.04.003.

Lele, M. & Sambuddha, G. 2020.

Agricultural policy reforms: Roles of markets and states in China & India. *Global Food Security* 26 (April): 100371. https://doi.org/10.1016/j.gfs.2020.100371.

Linquist, B. A. & Vongvilay, P. 2007. Benefits of organic residues and chemical fertiliser to productivity of rain-fed lowland rice and to Soil nutrient balances. *Nutrient Cycling in Agroecosystems* 10: 59-72.

Marschner, H. 2003. Mineral nutrition of higher plants. 3rd Edition. Academic Press, Amsterdam

Martey, E., Nimo, A.W. & Bright, O. A. 2013. Factors Influencing Participation in Rice Development Projects. *International Journal of Development and Economic Sustainability* 1(2): 13-27.

MOFA-SRID. 2011. Agriculture in Ghana: Facts and Figures. Accra, Ghana.

MoFA/SRID. 2013. Ghana - Ghana agricultural production survey (Minor Season) 2013, Second Round GHA-MoFA-SRID-GAPS-2013-V1.0

Morris, M. L., Robert, T. & Dankyi, A. A. 1999. Adoption and impacts of improved maize production technology: A case study of the Ghana Grains Development Project Economics Program Paper 99-01. Mexico, D.F.: CIMMYT.

Mu, D., Naomi, H., Maeve, C. & Kimmera, J. 2017. Environmental and economic analysis of an in-vessel food waste composting system at Kean University in the U.S. *Waste Management* 59: 476-486. http://dx.doi.org/10.1016/j.wasman.2016.10.026.

Mugwe, J., Mugendi, D., Odee, D. & Otieno, J. 2007. Evaluation of the potential of using nitrogen-fixing legumes in smallholder farms of Meru south district. In: *Advances in Integrated Soil Fertility Management in Sub-Saharan Africa: Challenges and Opportunities* 503-510 (Eds A. Bationo, B. Waswa, J. Kihara and J. Kimetu). Netherlands: Springer.

Njoh, A.J., Bigon, L., Ananga, E.O. & Ayuk-Etang, R.A. 2018. Institutional, economic and socio-cultural factors accounting for gender-based inequalities in land title procurement in Cameroon. *Land Use Policy* 78: 116-125.

Okuro, J. O., Muriithi, F.M., Mwangi, W., Verjuikl, H., Gethi, M. & Groote, H. 2002. Adoption of maize seed and fertilizer technologies in Embu district, Kenya. Mexico, DF: CIMMYT.

Oppong-Anane, K. 2013. Cassava as Animal Feed in Ghana: Past, Present & Future http://www.fao.org/docrep/018/i3304e/i3304e.pdf.

Patricia, B. Y. & Tawiah A. 2001. Farmers access to agricultural extension services in the Dangme West District of Ghana. Agricultural and Food Sciences, Sociology. https://api.semanticscholar.org/CorpusID:131106967}

Ransom, J.K., Paudyal, K. & Adhikar, K. 2003. Adoption of improved maize varieties in the hills of Nepal. *Agricultural Economics* 29: 299-305

Regassa, H., Eyasu, E., Meron, T. & Gudima, L. 2013. The nitrogen fertilizer replacement values of incorporated legumes residue to wheat on vertisols of the Ethiopian highlands *Heliyon* 17:9 (11).doi: 10.1016/j.heliyon.2023.e22119

Roy, S., Bose, A. & Mandal, G. 2021. Modelling and mapping geospatial distribution of groundwater potential zones in Darjeeling Himalayan region of India using analytical hierarchy process and GIS technique. *Modelling Earth Systems and Environment 7* (01): 1-22.

Saidou, K., Patrick, N., Paul W., Nancy K., Fredrick, B., Kenton, D., Joseph M., Teressah, W., George, M. & Stanley, K. 2010. Advancing technical skills in rhizobiology : Training Report N2Africa. 25 October 2010.

Sheahan, M., Black, R. & Jayne, T. S. 2013. Are Kenyan farmers under-utilizing fertilizer? Implications for input intensification strategies and research. *Food Policy* 41: 39-52. doi: 10.1016/j.foodpol.2013.04.008.

Snoeck, D. 2010. Mapping Fertiliser Recommendations for cocoa production in Ghana using soil diagnostic and GIS Tools. *West African Journal of Applied Ecology* 17: 97-107.

Tsujimoto, Y. 2009. Soil Management: The key factors for higher productivity in the fields utilizing the system of rice intensification (SRI) in the central highlands of Madagascar. *Agricultural Systems* 100 (13): 61-71. http://dx.doi.org/10.1016/j.agsy.2009.01.001.

United Nations Development Programme (UNDP). 2008. Agriculture in Africa : Strategies to improve and sustain smallholder production systems. New York.

Vanlauwe, B. 2015. Integrated soil fertility management in Sub-Saharan Africa: Unravelling local adaptation. Soil 1: 491-508.

Vanlauwe, B., Bationo, A., Chianu, J., K. E., Merckx,R., Mokwunye, U., Ohiokpehai, O., Pypers, P., Tabo, R., Shepherd, K.D., E.M.A., Woomer, P.L. & Sanginga N. 2010. Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. *Outlook on Agriculture* 39:17-24

Vanlauwe, B, Tittonell, P. & Mukalama, J. 2006. Within-farm soil fertility gradients affect response of maize to fertilizer application in western Kenya. *Nutrient Cycling in Agroecosystems* 76: 171-182.

Wang, S., Gongxin D., Haiping, Y. & Zhongyang, L. 2017. Lignocellulosic biomass pyrolysis mechanism: A State-of-the-art review. *Progress in Energy and Combustion Science* 62: 33-86. http://dx.doi.org/10.1016/j.pecs.2017.05.004.

Wang, B. & Zhang, G.H. 2017. Quantifying the binding and bonding effects of plant roots on soil detachment by overland flow in 10 typical grasslands on the Loess Plateau. *Soil Science Society of America Journal* 81: 1567-1576.

Waqas, M. 2018. Optimizing the process of food waste compost valorizing; Its applications: A case study of Saudi Arabia. *Journal of Cleaner Production* 176: 426-438. https://doi.org/10.1016/j.jclepro.2017.12.165.

Weiske, A. & Soren, O.P. 2006. Mitigation of greenhouse gas emissions from livestock production. *Agriculture* 112 (2): 105-106.

Whalen, J. (Ed.). 2012. Soil fertility improvement and integrated nutrient management - A global perspective. InTech. Available at http;//dx.doi.org/10.5772/1401.

Whalen, J.K., Comte, I., Colin, F., Grünberger, O. & Caliman, J. P. 2012. Agricultural practices in oil palm plantations and their impact on hydrological changes, nutrient fluxes and water quality in Indonesia: A Review. *Advances in Agronomy* 116: 71-124.

Wiredu, A.N, Gyasi, K.O. & Abdoulaye, T. 2009. Characterization of maize producing households in the Northern Region. Drought Tolerant Maize for Africa (DTMA) Project Country Report Household Survey, Ghana.

Wood, T.N. 2013. Agricultural development in the northern savannah of Ghana. D.P.H. Doctoral document, University of Nebraska, Lincoln. http://digitalcommons.unl.edu/planthealthdoc/1.

Woomer, P., Singleton, P. W. & Bohlool, B.B. 1988. Reliability of the most-probable-number technique for enumerating rhizobia in tropical soils. *Applied and Environmental Microbiology* 54:1494-1497.

Woomer, P., James, B. & Russell, Y. 1990. Overcoming the inflexibility of most-probable-number procedures. *Agronomy Journal* 82(2): 349-353.

Zhang, H. 2011. Biomass fast pyrolysis in a fluidized bed reactor under N2, CO2, CO, CH4 & H2 atmospheres. *Bioresource Technology* 102(5): 4258-4264. http://dx.doi.org/10.1016/j.biortech.2010.12.075.

Zhang, W., Qian, C., Carlson, K. M, Ge, X., Wang, X. & Chen, X. 2021. Increasing farm size to improve energy use efficiency and sustainability in maize production. *Food and Energy Security* 10 (1), p. e271 . doi:10.1002/fes3.271