Integrated soil fertility management: definition and impact on productivity and soil C

ABSTRACT

Traditional farming systems in sub-Saharan Africa depend primarily on mining soil nutrients. The African Green Revolution aims at intensifying agriculture through dissemination of Integrated Soil Fertility Management (ISFM). In this paper we develop a robust and operational definition of ISFM, based on detailed knowledge of African farming systems and their inherent variability and of optimal use of nutrients. We define ISFM as ‘A set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles.’

Issues that will be covered in this paper include: (i) the use of mineral fertilizer and expected responses under varying soil conditions, (ii) the use of locally available organic inputs in combination with fertilizer, and (iii) the integration of legume species in rice-based systems, including aspects of improved agronomy. Examples are given for specific African farming systems with high potential for adoption of ISFM, including sorghum and millet based systems in the Sahel, legume-maize systems in the savanna, and cassava-based systems in the humid forest. For each above theme, both issues of crop productivity and soil carbon stocks and dynamics will be covered. Finally, the conditions that enable the adoption of ISFM, including access to markets and appropriate policy, are also discussed.
Integrated Soil Fertility Management: definition and impact on productivity and soil C

B Vanlauwe
TSBF-CIAT
Kenya, Nairobi
b.vanlauwe@cgiar.org
Background
The context
ISFM definition
Steps towards complete ISFM
Dissemination of ISFM
Final comments
Finally, fertilizer is back on the African research for development agenda! [though the pro-organic agriculture voice & no-to-fertilizer voices are still heard!]

Statement in 1996 (Research Director, IITA): ‘You can’t include fertilizer in your work since farmers in Africa are not using fertilizer’

The Alliance for a Green Revolution in Africa (AGRA) (headed by K Anan): ‘By 2015, increase fertilizer use from 8 to 50 kg fertilizer nutrients/ha’

Soil health program of AGRA [50% improved plants, 50% improved soils]
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Production environment in Africa

- Soils are old; limited rejuvenation
Only about 10% of the arable land in use
Only about 10% of the arable land in use [limited areas with large population densities]
Production environment in Africa

→ Lack of infrastructure, market organization
Production environment in Africa

→ Lack of infrastructure, market organization

- Mombasa (264 USD)
- Masaka (Uganda) (421 USD)
- Bukavu (DRCongo) (900 USD)
- International market (165 USD)
Production environment in Africa

Farming God’s Way

CCK is working to promote a biblical perspective on farming that connects the Christian faith with the most common vocation on the continent.

Based on the proven techniques of conservation agriculture, this is a program originally developed in Zimbabwe that uses scientifically sound, no-till agricultural techniques combined with strong biblical teaching to radically transform farming practices and bring hope to farmers (read more about farming God’s way here).

In many areas, Farming God’s Way has produced dramatic increases in yield. The beauty of this technique is that it protects and improves the productivity of the land at the same time, reducing the need for chemical fertilizer or pesticide application.
→ Lack of favorable policy [e.g., Nigeria: subsidies have been on/off over the past 30 years]
→ Declining capacity in R&D for soil fertility mgt
→ Insufficient investment in agricultural R&D
→ Brain drain
→ Climate change, drought
→ Civil strife
→ HIV/AIDS, malnutrition
→ Land tenure insecurity
→ High inflation, low salaries
→ Etc, etc, etc
Current status of agriculture in Africa

FAO Index of Net Food Output per Capita, 1961-2000

- World
- E SE Asia
- South Asia
- Sub-Saharan
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Necessary components of ISFM

1. Fertilizers are indispensable
Necessary components of ISFM

2. Organic resources are limited but necessary

- Crop residues
- Oilpalm leaves
- Imperata
- Manure

Availability? Acceptability? Quality?
Necessary components of ISFM

3. Improved germplasm enhances nutrient uptake
Necessary components of ISFM

4. Fields are heterogeneous

Good soil – same farm

Poor soil – same farm
Definition of ISFM

“The application of soil fertility management practices, and the knowledge to adapt these to local conditions, which maximize fertilizer and organic resource use efficiency and crop productivity. These practices necessarily include appropriate fertilizer and organic input management in combination with the utilization of improved germplasm’
Agronomic efficiency = \frac{\text{Increase in yield}}{\text{Fertilizer nutrients applied}}
Agronomic efficiency = \([\frac{\text{Increase in yield}}{\text{Fertilizer nutrients applied}}]\)

**Definition of ISFM**
Background

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Current practice

- Average of 8 kg nutrients/ha
- Relatively poor AE due to poor fertilizer management
- Lack of use of improved germplasm
Step 1: Fertilizer and germplasm

Management intensity (planting date, crop density and time of phosphorus application), Tinfouga, Mali (Bationo et al., 1997).

Maize grain yield (kg/ha)

Management regime

- control (no fertilizer applied)
- fertilizer applied

- low
- medium
- high
Step 1: Fertilizer and germplasm

- Early Specific variety
- Dual purpose variety
Step 1: Fertilizer and germplasm

Yield/ Agronomic efficiency

Current practice  Germplasm & fertilizer
Step 1: Fertilizer and germplasm

Source: Vanlauwe et al, PLSO, 2010
Step 1: Fertilizer and germplasm

Soil C issues

Zimbabwe, clayey soils

Source: Zingore al, EJSS, 2005
## Important research issues

### Soil C issues

<table>
<thead>
<tr>
<th>Site (country)</th>
<th>Fert</th>
<th>Duration (years)</th>
<th>Organic C (g kg(^{-1}))</th>
<th>Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Fert</td>
<td>+ Fert</td>
</tr>
<tr>
<td><strong>Zaria (Nigeria)</strong></td>
<td>AS</td>
<td>15</td>
<td>3.1</td>
<td>3.4</td>
</tr>
<tr>
<td><strong>Ife (Nigeria)</strong></td>
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<td>7</td>
<td>8.0</td>
<td>8.5</td>
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<td>AS</td>
<td>5</td>
<td>8.7</td>
<td>10.5</td>
</tr>
<tr>
<td><strong>Ife (Nigeria)</strong></td>
<td>AS</td>
<td>14</td>
<td>5.7</td>
<td>3.5</td>
</tr>
<tr>
<td><strong>Bouaké (Côte d’Ivoire)</strong></td>
<td>Urea</td>
<td>20</td>
<td>13.5</td>
<td>8.3</td>
</tr>
<tr>
<td><strong>Ibadan (Nigeria)</strong></td>
<td>Urea</td>
<td>5</td>
<td>8.7</td>
<td>9.0</td>
</tr>
<tr>
<td><strong>Ibadan (Nigeria)</strong></td>
<td>Urea</td>
<td>14</td>
<td>5.9</td>
<td>5.8</td>
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<tr>
<td><strong>Ife (Nigeria)</strong></td>
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<td>14</td>
<td>5.7</td>
<td>8.0</td>
</tr>
<tr>
<td><strong>Ibadan (Nigeria)</strong></td>
<td>CAN(^{a})</td>
<td>5</td>
<td>8.7</td>
<td>10.4</td>
</tr>
<tr>
<td><strong>Mokwa (Nigeria)</strong></td>
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<td>3.3</td>
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<tr>
<td><strong>Ife (Nigeria)</strong></td>
<td>CAN</td>
<td>14</td>
<td>5.7</td>
<td>6.5</td>
</tr>
</tbody>
</table>
Step 2: Combining fert and OM

Total millet dry matter yield as affected by long-term application of crop residues and fertilizer, Sadore, Niger

- Control
- Crop residues
- Fertilizer
- Crop residues + fertilizer

Dry matter / N applied (kg ha\(^{-1}\))

- without crop residues
- with crop residues
Step 2: Combining fert and OM

Yield/ Agronomic efficiency

Current practice  Germplasm & fertilizer  Germplasm & fertilizer’ + Organic resource mgt
Step 2: Combining fert and OM

Source: Vanlauwe et al, PLSO, 2010
## Step 2: Combining fert and OM

### Soil C issues

<table>
<thead>
<tr>
<th>Site (years)</th>
<th>Source of organic matter</th>
<th>Organic C (g kg⁻¹)</th>
<th>None</th>
<th>Fert</th>
<th>OM</th>
<th>Fert +OM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ibadan (10)</td>
<td>AC&lt;sup&gt;a&lt;/sup&gt; with <em>Leucaena</em></td>
<td>5.9</td>
<td>5.8</td>
<td>9.7</td>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td>Ibadan (10)</td>
<td>AC with <em>Senna</em></td>
<td>5.9</td>
<td>5.8</td>
<td>10.0</td>
<td>9.7</td>
<td></td>
</tr>
<tr>
<td>Ibadan (10)</td>
<td>Rotation + <em>Mucuna</em></td>
<td>5.9</td>
<td>5.8</td>
<td>7.4</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>Zaria (45)</td>
<td>External Manure</td>
<td>3.3</td>
<td>2.9</td>
<td>5.0</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>Saria (18)</td>
<td>External Manure</td>
<td>2.5</td>
<td>2.4</td>
<td>NA</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td>4.7</td>
<td>4.5</td>
<td>8.0</td>
<td>7.2</td>
<td></td>
</tr>
</tbody>
</table>
Soil C issues

Soil C contents of three aggregate size fractions (macroaggregates (>250 µm), microaggregates (53-250 µm), and silt and clay (<53 µm)) after 3 years of 4 Mg litter-C ha-1 yr-1 input (no input, *T. diversifolia*, *C. calothyrsus*, and *Z. mays*) in a maize cropping system in Central Kenya.

*Source: Gentile et al, 2010*
Step 3: Adaptation to local conditions

(a) Control maize yield (kg ha\(^{-1}\))

(b) N-AE (kg grain kg\(^{-1}\) N)

Source: Vanlauwe et al, PLSO, 2010
Step 3: Adaptation to local conditions

IF acid soil         THEN apply lime
IF soil crusting     THEN superficial tillage
IF plow layer        THEN deep tillage
IF drought           THEN water harvesting
IF ...               THEN ...

IF ...               THEN ...
Step 3: Adaptation to local conditions

Yield/ Agronomic efficiency

Current practice  Germplasm & fertilizer  Germplasm & fertilizer’ + Organic resource mgt  Germplasm & fertilizer + Organic resource mgt + Local adaptation ‘Full ISFM’
Step 3: Adaptation to local conditions

Occurrence of non-responsive soils!
Step 3: Adaptation to local conditions

- Current practice
- Germplasm & fertilizer
- Germplasm & fertilizer’ + Organic resource mgt
- Germplasm & fertilizer + Organic resource mgt + Local adaptation
- ‘Full ISFM’

- Responsive soils
- Poor, less-responsive soils

Yield/ Agronomic efficiency
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Increase in complexity

Yield/ Agronomic efficiency

Current practice  Germplasm & fertilizer  Germplasm & fertilizer' + Organic resource mgt  Germplasm & fertilizer + Organic resource mgt + Local adaptation

Responsive soils

Poor, less-responsive soils

Move towards ISFM

‘Full ISFM’
Agronomic efficiency

Current practice

Germplasm & fertilizer

Germplasm & fertilizer + Organic resource mgt

Germplasm & fertilizer + Organic resource mgt + Local adaptation

‘Full ISFM’

Move towards ISFM

Increase in complexity

- Increased knowledge
- Responsive soils
- Poor, less-responsive soils

Complete ISFM???
- Improved fallows
- Agroforestry systems
- Biomass transfer systems
- ???
- ???
Increase in complexity

‘Simple’ approaches
- Demonstrations
- Information folders
- Diagnosis non-responsive fields
- Supply chain issues
- [Partial] subsidy

Move towards ISFM

Responsive soils
- Poor, less-responsive soils

Yield
- Current practice
- Germplasm & fertilizer
- Germplasm & fertilizer' + Organic resource mgt
- Germplasm & fertilizer + Organic resource mgt + Local adaptation

‘Full ISFM’
The Malawi fertilizer subsidy programme
- Fertilizer + seed starter packs
- From net importer to net exporter (2006)
  - AE is 14 kg grain/kg fertilizer nutrient

Increase in complexity:
- Move towards ISFM
  - Increase in knowledge
  - Yield
    - Current practice
    - Germplasm & fertilizer
    - Germplasm & fertilizer + Organic resource mgt
  - Responsive soils
  - Poor, less-responsive soils
  - ‘Full ISFM’
Increase in complexity

‘Simple’ approaches
- Demonstrations
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Intensive approaches
- Farmer capacity
- Farmer field schools
- Interactive learning
- Diagnosis SF status
- Best-fit options
- Extension training

Yield
Current practice
Germplasm & fertilizer
Germplasm & fertilizer
+ Organic resource mgt
+ Local adaptation
+ Organic resource mgt

Move towards ISFM
‘Full ISFM’
An enabling environment for ISFM

Legend:
- System movers
- Effort pathways
- Income chains
- Supply chains
- Benefits flow

Key:
- CR = Community Regulator
- CCI = Community Cottage Industry
- HSLC = Household Level Consumption
- T = Tier Number

- STRATEGIC ALLIANCE
- AWARENESS CREATION
- TRAINING AND CAPACITY BUILDING
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Limitations to the AE concept

AE within the ISFM is based on short term gains

Focus on productivity… but indications that soil C can also be increased (soil-based ecosystem services)

It is difficult to achieve complete ISFM; probably a realistic goal should be to ‘move towards’ rather than achieving complete ISFM everywhere

Local diagnosis is crucial for local adaptation
1. **This is the time** for soil science and plant nutrition to show impact in Africa; **ISFM** will drive investments in soil fertility focusing on resource-use efficient agriculture!
Take home messages

1. **This is the time** for soil science and plant nutrition to show impact in Africa; **ISFM** will drive investments in soil fertility focusing on resource-use efficient agriculture!

2. The **AE concept** works; fertilizer as an entry point towards agricultural intensification in SSA
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2. The AE concept works; fertilizer as an entry point towards agricultural intensification in SSA

3. Moving towards complete ISFM: immediate impact is possible while investments in capacity building for complete ISFM are happening
Take home messages

1. **This is the time** for soil science and plant nutrition to show impact in Africa; **ISFM** will drive investments in soil fertility focusing on resource-use efficient agriculture!

2. The **AE concept** works; fertilizer as an entry point towards agricultural intensification in SSA

3. **Moving towards complete ISFM:** immediate impact is possible while investments in capacity building for complete ISFM are happening

4. Creating an **enabling environment** for ISFM is at least as crucial as developing ISFM practices.
1. Under **which conditions** (population, soil, markets, etc) can ISFM be the model for intensification?
Questions for a fruitful debate

1. Under **which conditions** (population, soil, markets, etc) can ISFM be the model for intensification?

2. **Is fertilizer a valid entry point** to improve soil fertility and soil C status and ensure longer term productivity increases?
Questions for a fruitful debate

1. Under **which conditions** (population, soil, markets, etc) can ISFM be the model for intensification?

2. **Is fertilizer a valid entry point** to improve soil fertility and soil C status and ensure longer term productivity increases?

3. How do we diagnose and manage **non-responsive soils**?
Questions for a fruitful debate

1. Under **which conditions** (population, soil, markets, etc) can ISFM be the model for intensification?

2. **Is fertilizer a valid entry point** to improve soil fertility and soil C status and ensure longer term productivity increases?

3. How do we diagnose and manage **non-responsive soils**?

4. At **which scale** should ISFM recommendations be developed (variation at different scales)?
Thank you!
Merci beaucoup!
Asante sana!