Integrated Soil Fertility Management [ISFM] in Sub-Saharan Africa: principles and practice

B Vanlauwe
TSBF-CIAT
Kenya, Nairobi
b.vanlauwe@cgiar.org
Background
The context
ISFM definition
Steps towards complete ISFM
Dissemination of ISFM
Final comments
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Final comments
→ Finally, fertilizer is back on the African agenda!
→ Statement in 1996 (Research Director, IITA):
  ‘You can’t include fertilizer in your work since farmers in Africa are not using fertilizer’
The opportunity…

→ The African Green Revolution (KAnan)

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

→ Soil health program of AGRA [50% improved plants, 50% improved soils]
The challenge…

→ What are ‘best soil fertility management practices’?

→ How can these be deployed over a relatively large scale in a relatively short period of time?
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Final comments
Production environment in Africa

- Soils are old; limited rejuvenation
Production environment in Africa

→ Only about 10% of the arable land in use
Production environment in Africa

→ 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

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

- Lack of favorable policy \([e.g., \text{Nigeria: subsidies have been on/off over the past 30 years}]\)
- 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 Africa
The challenge…

→ What are ‘best soil fertility management practices’?

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Final comments
Necessary components of ISFM

1. Fertilizers are indispensable
Necessary components of ISFM

1. Fertilizers are indispensable
Necessary components of ISFM

2. Organic resources are limited but necessary

<table>
<thead>
<tr>
<th>Crop residues</th>
<th>Oilpalm leaves</th>
<th>Imperata</th>
<th>Manure</th>
</tr>
</thead>
</table>

Availability?  Acceptability?  Quality?
Necessary components of ISFM

3. Improved germplasm enhances nutrient uptake
Necessary components of ISFM

4. Fields are heterogeneous
Necessary components of ISFM

4. Fields are heterogeneous
Necessary components of ISFM

4. Fields are heterogeneous

Ring management (Prudencio et al, 93)  
Clustered farms (Titonnell et al, 05)  
Shifting plots (AfricaNuances, 07)

- House
- Fields; lighter colors refer to less fertile plots
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’
Definition of ISFM

Agronomic efficiency
= \frac{\text{Increase in yield}}{\text{Fertilizer nutrients applied}}

Constant fertilizer application rate
Definition of ISFM

Agronomic efficiency
= [Increase in yield]/[Fertilizer nutrients applied]
**Definition of ISFM**

Agronomic efficiency

\[ \text{Agronomic efficiency} = \frac{\text{Increase in yield}}{\text{Fertilizer nutrients applied}} \]
Definition of ISFM

Agronomic efficiency
= [Increase in yield]/[Fertilizer nutrients applied]
Definition of ISFM

Agronomic efficiency
= [Increase in yield]/[Fertilizer nutrients applied]

\[
\frac{\text{Value}}{\text{Cost}} = \frac{\text{Extra grain} \times [\$_{\text{grain}}]}{\text{Fertilizer} \times [\$_{\text{fertilizer}}]}
\]
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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
Soils do respond to fertilizer in SSA!

Maize-based systems in sub-Saharan Africa

$N$ applied $< 100$ kg/ha

Chivenge et al, 2010

Fertilizer alone

AE (kg grain/kg N added)

- All: $n=268$
- Sand: $n=69$
- Loam: $n=90$
- Clay: $n=109$
Step 1: Fertilizer and germplasm

- Crop yield
- Organic matter production
- Biomass yield
- Nutrient uptake
- Utilization efficiency
- Uptake efficiency

Diagram showing the relationship between fertilizer application and crop yield, biomass yield, nutrient uptake, and utilization efficiency.
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)

control (no fertilizer applied)
fertilizer applied

‘The 5th R’

Management regime

low medium high
Necessary components of ISFM

Soybean, West Kenya

Grain yield with P (kg dry matter/ha) vs. Grain yield without P (kg dry matter/ha)

- 93-19/35
- TGx 1835-10E
- Gazelle
- TGx 1448-2E
Step 1: Fertilizer and germplasm

![Graph showing yield and agronomic efficiency improvement]

Current practice
Germplasm & fertilizer

Move towards ISFM

Responsive soils
Poor, less-responsive soils

Responsive soils
Poor, less-responsive soils

Germplasm & fertilizer

Local adaptation
Step 2: Combining fert and OM

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

![Graph showing the effect of long-term application of crop residues and fertilizer on total millet dry matter yield from 1982 to 1996.](image)

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

![Bar graph showing dry matter N applied with and without crop residues.](image)
Step 2: Combining fert and OM

Maize-based systems in sub-Saharan Africa

$N$ applied $< 100 \text{ kg/ha}$

- Fertilizer alone
- Fertilizer + organic matter

AE (kg grain/kg N added)

- All: $n=268$, $n=82$
- Sand: $n=69$, $n=25$
- Loam: $n=90$, $n=22$
- Clay: $n=109$, $n=46$
Step 2: Combining fert and OM

- **Crop yield**
- **Utilization efficiency**
- **Organic matter production**

- Biomass yield
- Nutrient uptake
- Fertilizer application

- **A**
- **B**
- **C**
- **D**
- **E**
Step 2: Combining fert and OM

Early Specific variety

Dual purpose variety
Step 2: Combining fert and OM

- Current practice
- Germplasm & fertilizer
- Germplasm & fertilizer’ + Organic resource mgt

Yield/ Agronomic efficiency

Germplasm & fertilizer

Responsive soils

Poor, less-responsive soils

Move towards ISFM

Local adaptation
Step 3: Adaptation to local conditions

Maize grain yield

SED (control)

Shinyalu, Western Kenya
Step 3: Adaptation to local conditions

Maize grain yield

- SED (control)
- SED (with PPK)
- Shinyalu, Western Kenya

Comparison of yield under different conditions:
- Control
- With NPK
Step 3: Adaptation to local conditions

Carsky et al., 1998

Soil Organic C (%) vs. Maize grain yield (t/ha)
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 ...
New soil map for African farmers

By James Morgan
Science reporter, BBC News

The first detailed digital soil map of sub-Saharan Africa is to be created.

The £12m project will offer farmers in 42 countries a "soil health diagnosis" and advice on improving crop yields.

Scientists from the International Center for Tropical Agriculture (CIAT) will take soil samples from across the continent and analyse nutrient levels.
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

Responsive soils

Poor, less-responsive soils

Current practice

Germplasm & fertilizer

Germplasm & fertilizer’

+ Organic resource mgt

+ Local adaptation

‘Full ISFM’
Priority cropping systems

**QUADRANT D – ‘Low-high’**
- Tree and herbaceous improved fallows
- Alley farming
- Biomass transfer systems
- Fallows with indigenous trees
- Slash-and-burn (low population densities)

**QUADRANT A – ‘High-high’**
- Fertilizer micro-dosing in sorghum-millet-based systems
- Soybean – maize rotations with fertilizer targeted to different phases of the rotation
- Improved cereal-legume intercrops with targeted fertilizer application

**QUADRANT C – ‘? ?’**
- ISFM for cassava-based systems
- ISFM for banana-based systems
- ISFM for upland rice (e.g., NERICA)
- ISFM in conservation agriculture

**QUADRANT E – ‘Low-low’**
- Composting, household waste
- Bio-solids

**QUADRANT B – ‘High-low’**
- ‘Seeds and fertilizer’
- Crop residue utilization
- Animal manure
- Grain legume - cereal rotations without fertilizer
- Cereal - grain legume intercrops without fertilizer
Priority cropping systems

QUADRANT A – ‘High-high’
- Fertilizer micro-dosing in sorghum/millet – cowpea rotations
- Soybean – maize rotations with fertilizer targeted to different phases of the rotation

QUADRANT D – ‘Low-high’
- Tree and herbaceous improved fallows
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Adoption potential vs Relative increases in yield/AE
The challenge...

→ What are ‘best soil fertility management practices’?

→ How can these be deployed over a relatively large scale in a relatively short period of time?
Increase in complexity

- Responsive soils
- Poor, less-responsive soils

Yield/ Agronomic efficiency

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

Move towards ISFM ‘Full ISFM’
Increase in complexity

- Improved fallows
- Agroforestry systems
- Biomass transfer systems
- ???
- ???

Move towards ISFM

'Full ISFM'

Yield/ Agronomic efficiency

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

Current practice
Germplasm & fertilizer
Germplasm & fertilizer
Germplasm & fertilizer

Move towards ISFM

‘Full ISFM’
Increase in complexity

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

Responsive soils
- Poor, less-responsive soils

Yield
- Current practice
- Germplasm & fertilizer

Germplasm & fertilizer
- + Organic resource mgt
- + Local adaptation

Move towards ISFM

‘Full ISFM’
Increase in complexity

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

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

Move towards ISFM

'Full ISFM'

Yield

Current practice

Germplasm & fertilizer

Germplasm & fertilizer' + Organic resource mgt

Germplasm & fertilizer + Organic resource mgt + Local adaptation
An enabling environment for ISFM

- Access to input and output markets
- Nutrition and health benefits
- Conducive policy environment
- Capacity of extension services
- Etc
Important research issues

1. How can stakeholders in the field of soil fertility management diagnose the soil fertility status?

<table>
<thead>
<tr>
<th>Farmer class</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>57%</td>
<td>33%</td>
<td>10%</td>
</tr>
<tr>
<td>Medium</td>
<td>22%</td>
<td>61%</td>
<td>17%</td>
</tr>
<tr>
<td>High</td>
<td>18%</td>
<td>34%</td>
<td>48%</td>
</tr>
</tbody>
</table>

Organic C measurements
Important research issues

2. Rehabilitation of non-responsive soils

Move towards ISFM

Responsive soils

Poor, less-responsive soils

Current practice

Germplasm & fertilizer

Germplasm & fertilizer’ + Organic resource mgt

Germplasm & fertilizer + Organic resource mgt + Local adaptation

‘Full ISFM’

Increase in knowledge

Agronomic efficiency
2. Rehabilitation of non-responsive soils


![Graph showing maize grain yield (kg/ha) vs N fertilizer applied (kg N/ha)](Zingore et al, 2007)
Important research issues

2. Rehabilitation of non-responsive soils

→ Chemical/physical degradation: use of high rates of Org. Res.

(Zingore et al, 2007)
### Important research issues

3. Can fertilizer as an entry point to ISFM provide sufficient OM for increasing the soil C pool?

<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>Zaria (Nigeria)</td>
<td>AS</td>
<td>15</td>
<td>3.1</td>
<td>3.4</td>
</tr>
<tr>
<td>Ife (Nigeria)</td>
<td>AS</td>
<td>7</td>
<td>8.0</td>
<td>8.5</td>
</tr>
<tr>
<td>Ibadan (Nigeria)</td>
<td>AS</td>
<td>5</td>
<td>8.7</td>
<td>10.5</td>
</tr>
<tr>
<td>Ife (Nigeria)</td>
<td>AS</td>
<td>14</td>
<td>5.7</td>
<td>3.5</td>
</tr>
<tr>
<td>Bouaké (Côte d’Ivoire)</td>
<td>Urea</td>
<td>20</td>
<td>13.5</td>
<td>8.3</td>
</tr>
<tr>
<td>Ibadan (Nigeria)</td>
<td>Urea</td>
<td>5</td>
<td>8.7</td>
<td>9.0</td>
</tr>
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<td>Ibadan (Nigeria)</td>
<td>Urea</td>
<td>14</td>
<td>5.9</td>
<td>5.8</td>
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<td>CANa</td>
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<td>8.7</td>
<td>10.4</td>
</tr>
<tr>
<td>Mokwa (Nigeria)</td>
<td>CAN</td>
<td>12</td>
<td>3.1</td>
<td>3.3</td>
</tr>
<tr>
<td>Ife (Nigeria)</td>
<td>CAN</td>
<td>14</td>
<td>5.7</td>
<td>6.5</td>
</tr>
</tbody>
</table>
Limitations to the AE concept

- AE within the ISFM is based on short term gains; what about the soil fertility status?
- Focus on productivity; soil health deals with 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
Take home messages

1. **This is the time** for soil science and plant nutrition to show impact in Africa!
Take home messages

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2. **ISFM** will drive investments in soil fertility focusing on resource-use efficient agriculture
Take home messages

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3. **Moving towards complete ISFM**: immediate impact is possible while investments in capacity building for complete ISFM are happening
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4. **Important research issues** required addressing before complete ISFM is possible
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2. **ISFM** will drive investments in soil fertility focusing on resource-use efficient agriculture

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

4. **Important research issues** required addressing before complete ISFM is possible

5. Creating an **enabling environment** for ISFM is at least as crucial as developing ISFM practices
Take home messages

IPNC and Africa

1. The main challenge in Africa is the need for a substantial increase in productivity in an environment with multiple stresses (low nutrient stocks, drought, acidity, etc)
Take home messages

IPNC and Africa

1. The main challenge in Africa is the need for a substantial increase in productivity in an environment with multiple stresses (low nutrient stocks, drought, acidity, etc).

2. Strategic plant nutrition research is going to be required to develop improved, stress-resistant germplasm adapted to these conditions.
Take home messages

IPNC and Africa

1. The main challenge in Africa is the need for a substantial increase in productivity in an environment with multiple stresses (low nutrient stocks, drought, acidity, etc)

2. **Strategic plant nutrition research** is going to be required to develop improved, stress-resistant germplasm adapted to these conditions

3. **Exposure of African scientists** to new developments and approaches including participation in the IPNC meetings is crucial...
Take home messages

IPNC and Africa

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2. Strategic plant nutrition research is going to be required to develop improved, stress-resistant germplasm adapted to these conditions.

3. Exposure of African scientists to new developments and approaches including participation in the IPNC meetings is crucial...

4. … eventually resulting in tangible cooperation.
Thank you!
Merci beaucoup!
Asante sana!