Yield gap review of plantain production systems in West and Central Africa

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CRP-RTB Workshop

“Intensification of mixed RTB systems with plantain in West and Central Africa: Tools for improved cropping systems intensification”

Abidjan, Côte d’Ivoire

11-14 November 2013
Introduction: Plantain in West and Central Africa (WCA)

- Secondary centre of plantain diversification
- ~100 cultivars identified (Blomme et al. 2013)
- Production confined to humid forest & moist savanna zones
- Potential for improving productivity considered high (Jagtap & Chan 2000, Temple et al. 2007)
General yield constraints

- **Limited fertilizer use:** In most of WCA, combined NPK < 2 kg ha$^{-1}$ (Henao & Baanante, 2006)

- **Black sigatoka aka BLSD:** most important global constraint (De Lapeyre de Bellaire 2010). In Nigeria, more severe in HF (severity 32%) than in MS (10%) (Zandjanakou-Tachin et al. 2013)

- **Endoparasitic nematodes:** most important in WCA are *Pratylenchus coffeae, Radopholus similis, Helicotylenchus multicinctus, Meloidogyne spp.* (Udzu 1997, Adiko 1988, Speijer et al. 2001, Osei et al. 2013).

- **Weevils:** *Cosmopolites sordidus*
Yields gaps

- Potential yield ($Y_p$): theoretical yield obtained when grown 1) without restrictions of light, nutrients or water and 2) where biotic stresses (pests, diseases, weeds) are fully controlled (Van Ittersum & Rabbinge, 1997).
- Attainable yield ($Y_t$): yield achieved in farmers' fields with best management practices and without nutrient limitation.
- Actual yield ($Y_a$): yield actually achieved in farmers’ fields in the region under most widely used management practices (van Ittersum et al. 2013).

![Chart showing yields gaps]

- Potential yield of plantain difficult to calculate (light response)
- Focus here on attainable yield & Gap 1
Aims

- Describe smallholder systems in WCA
- Estimate actual yields ($Y_a$) in WCA, if possible separated by ecoregion & soil type
- Assess research conducted in WCA and estimate attainable yields ($Y_t$)
- Define scenarios to increase on-farm yields by applying combinations of innovations
Methods

- Screened > 350 articles (English/French), dated 1976 – 2013, predominantly from peer-reviewed literature, for descriptions of plantain systems or data on plantain yield in WCA
- For descriptions, only papers quoting original observations where the authors had visited fields were included
- For yield assessments, only articles containing original data, either given as bunch mass, bunch yield per hectare and/or bunch yield per hectare per year, were included
- Locations classified into 3 soil groups by 3 rainfall areas (9)
- Referred to FAO data (FAOSTAT)

Constraints

- Little access to in-country grey literature
- Short time period
Results

Description of smallholder systems in WCA

23 references, division into 5 categories following Akinyemi et al. (2010)

- **Food intercropping systems**: Cassava, egusi, yam, taro & tannia, okra, beans, groundnut, cowpea, maize, rice, sugarcane, sorghum

- **Homegarden (compound) systems**: Defined by proximity to homestead, diverse with trees/shrubs and a large range of annual crops, high levels of organic inputs

- **Plantain – cacao systems**: as shade crop for cacao saplings

- **Other agroforestry systems**: taungya systems with timber saplings, fruit trees, oil palm

- **Monoculture systems**
## Systems and countries where they have been described

<table>
<thead>
<tr>
<th></th>
<th>Food intercropping systems</th>
<th>Homegarden (compound) systems</th>
<th>Plantain – cacao systems</th>
<th>Other agroforestry systems</th>
<th>Monoculture systems</th>
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</thead>
<tbody>
<tr>
<td>Ghana</td>
<td>x</td>
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<td>x</td>
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<tr>
<td>Cameroon</td>
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<td>Nigeria</td>
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<td>Côte d'Ivoire</td>
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<td>DR Congo</td>
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<tr>
<td>Liberia</td>
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</tbody>
</table>
### Summary of trials quoting yields from WCA, classified into regions by soil group and rainfall.

Of 41 trials, 2 were interregional, one with 2 regions, one with 3.

<table>
<thead>
<tr>
<th>country / region</th>
<th>soil group</th>
<th>annual rainfall (mm)</th>
<th># experiments</th>
<th>locations per country / region</th>
<th>relative soil fertility classification</th>
<th>relative rainfall classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ghana</td>
<td>Oxisol</td>
<td>1280</td>
<td>2</td>
<td>1</td>
<td>Low (S1)</td>
<td>Low (R1)</td>
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<tr>
<td>SW Nigeria</td>
<td>Alfisol</td>
<td>1200-1367</td>
<td>10</td>
<td>4</td>
<td>High (S3)</td>
<td>Low (R1)</td>
</tr>
<tr>
<td>SW Nigeria, Ayepe</td>
<td>Alfisol</td>
<td>1780</td>
<td>1</td>
<td>1</td>
<td>High (S3)</td>
<td>Medium (R2)</td>
</tr>
<tr>
<td>E Nigeria</td>
<td>Oxisol</td>
<td>1500</td>
<td>4</td>
<td>2</td>
<td>Low (S1)</td>
<td>Medium (R2)</td>
</tr>
<tr>
<td>SE Nigeria</td>
<td>Ultisol</td>
<td>2200 - 2500</td>
<td>17</td>
<td>13</td>
<td>Medium (S2)</td>
<td>High (R3)</td>
</tr>
<tr>
<td>SW Cameroon</td>
<td>Andisol</td>
<td>2500</td>
<td>2</td>
<td>2</td>
<td>High (S3)</td>
<td>High (R3)</td>
</tr>
<tr>
<td>central Cameroon</td>
<td>Ultisol</td>
<td>1350</td>
<td>1</td>
<td>1</td>
<td>Medium (S2)</td>
<td>Low (R1)</td>
</tr>
<tr>
<td>southern Cameroon</td>
<td>Ultisol</td>
<td>1500</td>
<td>6</td>
<td>6</td>
<td>Medium (S2)</td>
<td>Medium (R2)</td>
</tr>
<tr>
<td>DR Congo</td>
<td>Oxisol</td>
<td>1800</td>
<td>1</td>
<td>1</td>
<td>Low (S1)</td>
<td>High (R3)</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td></td>
<td></td>
<td><strong>44</strong></td>
<td><strong>31</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Estimation of actual yields, $Y_a$, in WCA

- FAO statistics
- Reported on-farm yields in literature
- No input controls of researcher managed experiments
## Production and yield of plantain for 2000 and 2010 (FAOSTAT from 03.2013)

<table>
<thead>
<tr>
<th>Country</th>
<th>2000 Production (M Mg)</th>
<th>2010 Production (M Mg)</th>
<th>2000 Yield (Mg ha(^{-1}))</th>
<th>2010 Yield (Mg ha(^{-1}))</th>
<th>Change (%) During Decade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ghana</td>
<td>1.93</td>
<td>3.54</td>
<td>7.9</td>
<td>10.8</td>
<td>36</td>
</tr>
<tr>
<td>Cameroon</td>
<td>1.16</td>
<td>3.18</td>
<td>6.1</td>
<td>12.2</td>
<td>99</td>
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<td>Nigeria</td>
<td>1.97</td>
<td>2.68</td>
<td>5.1</td>
<td>6.0</td>
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<td>Côte d'Ivoire</td>
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<td>3.8</td>
<td>3</td>
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<tr>
<td>DRC</td>
<td>1.18</td>
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<tr>
<td>Guinea</td>
<td>0.43</td>
<td>0.46</td>
<td>4.3</td>
<td>5.2</td>
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<tr>
<td>Gabon</td>
<td>0.27</td>
<td>0.36</td>
<td>5.4</td>
<td>5.7</td>
<td>6</td>
</tr>
<tr>
<td>CAR</td>
<td>0.08</td>
<td>0.09</td>
<td>2.8</td>
<td>2.9</td>
<td>4</td>
</tr>
<tr>
<td>Congo</td>
<td>0.07</td>
<td>0.08</td>
<td>8.4</td>
<td>6.7</td>
<td>-21</td>
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<tr>
<td>Guinea-Bissau</td>
<td>0.04</td>
<td>0.05</td>
<td>2.9</td>
<td>3.1</td>
<td>7</td>
</tr>
<tr>
<td>Liberia</td>
<td>0.04</td>
<td>0.05</td>
<td>2.2</td>
<td>2.2</td>
<td>1</td>
</tr>
<tr>
<td>Eq. Guinea</td>
<td>0.03</td>
<td>0.04</td>
<td>5.1</td>
<td>5.8</td>
<td>15</td>
</tr>
<tr>
<td>Sierra Leone</td>
<td>0.03</td>
<td>0.04</td>
<td>5.3</td>
<td>5.3</td>
<td>1</td>
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</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>2000 Production (M Mg)</th>
<th>2010 Production (M Mg)</th>
<th>2000 Yield (Mg ha(^{-1}))</th>
<th>2010 Yield (Mg ha(^{-1}))</th>
<th>Change (%) During Decade</th>
</tr>
</thead>
<tbody>
<tr>
<td>WCA</td>
<td>8.86</td>
<td>13.36</td>
<td>4.9</td>
<td>5.7</td>
<td>17</td>
</tr>
</tbody>
</table>
Limitations of FAOSTAT

- FAO figures give general overview of where production is occurring
- Yield estimates likely to exhibit broad margins of error
- As they would also take into account large-scale systems, so might overestimate smallholder yields
On-farm yield data from WCA in peer-reviewed literature

Few data
Difficult to measure: intercropping, long and highly variable growth period, staggered harvest, high losses, heterogeneous planting densities

- Flinn & Hoyoux (1976) quoted yield data from older, difficult to obtain, publications but without reference to methodologies
- 0.1-3 Mg ha⁻¹ on poor soils, 1-4 Mg ha⁻¹ on fertile soils (Lescot & Ganry 2010)
- 4 Mg ha⁻¹ in Central Cameroon (Mutsaers et al. 1981) based on plantain occurrence and density measurements in intercropped food crop fields in two villages. Assumed average bunch weight 10kg (did not consider future plant losses)
- 4.8 Mg ha⁻¹ y⁻¹ in southern Cameroon (Kanmegne et al. 2006), based on farmer recall
Data from researcher-managed trials

- 13 publications had data on no-external input systems (proxy for smallholder “monoculture” systems)
- Only 2 quoted (negligible) yields of ratoons, so only PC data reported.
- Where authors assumed yields as mean bunch mass x planting density (i.e. assuming that 100% plants produce bunches), these data have been excluded
Mean PC bunch mass under no-input conditions in researcher-managed trials in WCA, separated by plantain type and zone.

<table>
<thead>
<tr>
<th>Plantain Type</th>
<th>French, S1.R3</th>
<th>French, S2.R2</th>
<th>False horn, S2.R2</th>
<th>False horn, S2.R3</th>
<th>False horn, S3R1 homegarden*</th>
<th>False horn, True Horn, S2R2</th>
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</thead>
<tbody>
<tr>
<td>n</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>mean bunch (kg)</td>
<td>9.5</td>
<td><strong>11.6</strong></td>
<td>8.6</td>
<td>6.9</td>
<td>9.1</td>
<td><strong>3.8</strong></td>
</tr>
</tbody>
</table>

*Homegarden reported separately, as it received local organic inputs
## Mean, minimum and maximum PC yields (Mg ha⁻¹) under no input conditions in researcher managed trials in WCA, separated by plantain type and zone

<table>
<thead>
<tr>
<th></th>
<th>French, S1.R3</th>
<th>French, S2.R2</th>
<th>False horn, S2.R2</th>
<th>False horn, S2.R3</th>
<th>False horn S2.R3 homegarden</th>
<th>False horn, True Horn, S3R1</th>
<th>S2R2</th>
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<tbody>
<tr>
<td>n</td>
<td>0</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>mean yield (Mg ha⁻¹)</td>
<td>-</td>
<td>7.8</td>
<td>7.4</td>
<td>4.7</td>
<td>-</td>
<td>3.2</td>
<td>-</td>
</tr>
<tr>
<td>minimum</td>
<td>-</td>
<td>4.5</td>
<td>6.2</td>
<td>3.3</td>
<td>-</td>
<td>2.9</td>
<td>-</td>
</tr>
<tr>
<td>maximum</td>
<td>-</td>
<td>10.2</td>
<td>8.9</td>
<td>6.2</td>
<td>-</td>
<td>3.5</td>
<td>-</td>
</tr>
</tbody>
</table>

- Data not available for all zones / plantain types
- Yields from **3.2 Mg ha⁻¹** to **7.8 Mg ha⁻¹** across zones (S2.R2, S2.R3, S3.R1)
- While French bunches were heaviest, French yields (Mg ha⁻¹) were similar to False horn, presumably as higher % False horn plants produce edible bunches
Topics investigated in trials in WCA.

- 41 trials, some inter-regional
- Some trials were multi-factorial
- * 2 controlled yield loss studies
- Most were based on “monoculture”

<table>
<thead>
<tr>
<th>location</th>
<th>cultivars</th>
<th>#</th>
<th>abiotic constraints</th>
<th>#</th>
<th>biotic constraints</th>
<th>#</th>
<th>agronomy</th>
<th>#</th>
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<tr>
<td>location</td>
<td>improved</td>
<td>11</td>
<td>fertilizer</td>
<td>9</td>
<td>sucker</td>
<td>5</td>
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<td>3</td>
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<td></td>
<td>burning</td>
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<td>inoculation*</td>
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<td>sucker</td>
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<td>field</td>
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</tbody>
</table>
Planting Density

- 5 studies
- For False horn, highest yield at $1600-1650 \text{ ha}^{-1}$.
- For French, highest yield at $1632 \text{ ha}^{-1}$
Intercropping with other food crops

- 7 trials
- Cassava, soybean, pumpkin, taro, tannia, maize
- Intercropping generally had a positive or neutral impact upon plantain yield
- However, in combination with cassava, the effect was negative, unless large amounts of K fertilizer were used
- Intercropping with pumpkin, taro and tannia was positive even without fertilizer application
Fertilization

- 9 trials
- Impacts of fertilizer rates, types or timing
- Of these, 3 trials assessed effect of K on False horn bunch mass, 1 trial on effects of K on % plants contributing to yield and planting to harvest time
Bunch mass change of PC (% change over 0 K control) due to K application across three zones in WCA.

\[
yield \text{ increase } (\%) = -0.0004K^2 + 0.32K
\]

\( R^2 = 0.67 \)
% plants contributing to yield and mean planting to harvesting time (days) as affected by application rate of K fertilizer.

\[ \text{\%py} = -0.0003K^2 + 0.17K + 64.89 \quad R^2 = 0.96 \]

\[ \frac{1}{PH} = -4E-09K^2 + 3E-06K + 0.0017 \quad R^2 = 0.99 \]
Added mulch trials

- 8 trials
- Factorial trials also incorporated fertilizer
- Elephant grass, wood shavings, sawdust, *Vigna*, rice husk, woodchips, oil palm bunch refuse, brewers' waste, cassava peel, plantain leaves
- Amounts up to 100 Mg ha\(^{-1}\) of fresh material, nutrient contents not given
- Mulching and fertilizing or not were treated categorically, i.e. levels disregarded
Bunch mass (kg) of non-mulched and mulched plants, whether fertilized or not, across 4 zones in WCA. False horn except where indicated.
Yields (Mg ha$^{-1}$) of non-mulched or mulched plants whether fertilized or not, across 2 zones in WCA. False horn.
Nematode inoculation and mulch interaction

- 1 trial, controlled yield loss experiment
Change (%) in yield parameters in False horns inoculated with nematodes and / or mulched relative to a non-mulched, non-inoculated control. S2R3 zone
- Mulch has positive effect on bunch mass & yield
- Where both fertilizer & mulch were added, effects were additive. However, given that mulch nutrient contents were not specified, it is not possible to make quantitative comparisons with fertilizer
- Inoculation with nematodes caused yield reduction (> -50%)
- Added benefit of mulch outweighed yield loss due to nematodes
Sucker sanitation

- 5 trials
- Ash coating, carbofuran (nematicide) application, paring, hot and boiling water treatment
Effects of sucker treatments of French plantain on yield change % as compared to a non-pared non-treated control in WCA. Not fertilized.
Scenarios of effects of innovations on yield

- Scenarios of combinations of boiling water treatment with mulching or K fertilizer on plantain landraces are outlined in following table
- Assumptions are conservative
- Mulch and fertilizer combinations have not been done as likely to be substitutional
## Attainable yield of landraces: effects of boiling water treatment, K fertilizer & mulch scenarios

<table>
<thead>
<tr>
<th></th>
<th>French landrace average</th>
<th>False horn landrace min.</th>
<th>False horn landrace max.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ya (Mg ha⁻¹)</strong></td>
<td>7.8</td>
<td>3.2</td>
<td>7.4</td>
</tr>
<tr>
<td><strong>1. + boiling water</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>yield increase factor</td>
<td>263%</td>
<td>149%</td>
<td>149%</td>
</tr>
<tr>
<td><strong>Yt (Mg ha⁻¹)</strong></td>
<td>20.5</td>
<td>4.8</td>
<td>11.1</td>
</tr>
<tr>
<td><strong>2. + 250 kg ha⁻¹ K</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bunch mass increase</td>
<td>155%</td>
<td>155%</td>
<td>155%</td>
</tr>
<tr>
<td>% plants contributing to yield</td>
<td>189%</td>
<td>189%</td>
<td>189%</td>
</tr>
<tr>
<td><strong>Yt (Mg ha⁻¹)</strong></td>
<td>22.8</td>
<td>9.4</td>
<td>21.7</td>
</tr>
<tr>
<td><strong>3. + mulch</strong></td>
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<td></td>
<td></td>
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<tr>
<td>yield increase factor</td>
<td>142%</td>
<td>177%</td>
<td>142%</td>
</tr>
<tr>
<td><strong>Yt (Mg ha⁻¹)</strong></td>
<td>11</td>
<td>5.7</td>
<td>10.5</td>
</tr>
<tr>
<td><strong>4. boiling water + mulch</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Yt (Mg ha⁻¹)</strong></td>
<td>23.7</td>
<td>7.2</td>
<td>14.1</td>
</tr>
<tr>
<td><strong>5. boiling water + K</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Yt (Mg ha⁻¹)</strong></td>
<td>35.5</td>
<td>10.9</td>
<td>25.4</td>
</tr>
</tbody>
</table>
Estimated attainable yields for French (solid) & False horn (striped). Boiling water trt + 250 kg ha$^{-1}$ K

- Conservative estimates of $Y_t$ of 35.5 Mg ha$^{-1}$
- Other fertilizer effects not considered so $Y_t$ likely higher
- $Y_a$ estimates from researcher-managed trials so may overestimate
- Large yield gap (at least 27 Mg ha$^{-1}$)
- $Y_p$ was highest yield found in WCA from Ekona, SW Cameroon
Summary, recommendations, limitations

Actual yield
- Lack of actual yield data from farmers’ fields and from no-input trials so calculating yield gaps difficult

- Information on ratoons rare and few yields quoted per yr

- Yield data only found for 3 / 9 zones defined

- Insufficient data to differentiate between zones

- Range of 3.2–7.4 Mg ha\(^{-1}\) for False horn and 7.8 Mg ha\(^{-1}\) for French from researcher-managed trials. Actual yields in smallholder fields probably lower
Universal recommendations

- Boiling water sucker treatment
- K fertilization up to 300 kg ha\(^{-1}\) elemental K.
- Mulching
- Intercropping according to farmer preference as no evidence of yield reductions for plantain, except for cassava, which should be avoided unless K fertilizer is used
- Optimal planting density under monocropping is 1600–1650 ha\(^{-1}\). No evidence was found on the requirement to reduce densities of plantain if intercropped
Limitations

- Lack and patchiness of yield data, particularly of cycle lengths, ratoons limits interpretation
- Little information on interactions, whether additive, synergistic or substitutional, if innovations combined
- Appropriateness, for e.g. of fertilizer rate will depend upon local conditions (access, price, labour costs)
Acknowledgements

Thank you for listening!

This presentation is based on a consultancy report for IITA. L. Norgrove is currently supported by the SNSF (Swiss National Science Foundation) through the awarding of a Marie Heim Vögtlin research fellowship.

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