Integrating isolated trees improves the agricultural performance assessment of smallholder farming systems at landscape scale in the Senegalese peanut basin


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« Make our planet treed again »  (Montpellier Declaration, World Agroforestry Congress, 2019)
Agroforestry parklands in face of SDG’s

SUSTAINABILITY  EQUITY  RESILIENCE
An increasing scientific interest in understanding effects of parklands on soil and crop productivity ....

**Cumulative number of publications: trees vs soil fertility and crop yields in West Africa**

Félix et al., Agron Sustain Dev, 2018
Background & objectives

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SUPPORTING SERVICES
Ex. Increasing of SOC

PROVISIONING SERVICES
Ex. Increasing of cereal yields under F.albida

REGULATING SERVICES
Ex. Microclimate modification
Background & objectives

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SUPPORTING SERVICES
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... But still some challenges

1 – Most of studies are conducted at tree scale

2 – Limited knowledge on the impacts of parklands pattern (composition / structuring) on agricultural performance of farming system at landscape scale

3 – Models (crop process-based or statistical) accounting for trees in agricultural landscape remain scarce
Background & objectives
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At landscape scale:

1 - To evidence the contribution of parklands structuring on the agricultural performance of smallholder farming systems

2 - To estimate crop yields and its spatial heterogeneity

The « old » peanut basin: the Senegalese breadbasket

A agricultural landscape dominated by rainfed crops ...

**CLIMATE**

- Sudanian climate
- Annual rainfall: 500-650 mm
- Rainy season: July to Oct.

**FARMING SYSTEM**

- Agriculture dominated by:
  - Millet (on-farm consumption)
  - Groundnut (cash crop)
  - Livestock
- Low input

Ndao et al., 2019
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* Leguminous nitrogen-fixing specie
* ‘reverse phenology’
* ‘fertility hotspot’ at tree level
* And various other tree species

Ndao et al., 2019
At the nexus of remote sensing, landscape ecology and statistical modelling

**Data**

- **Agronomical Survey**
  - Millet – 50 fields
  - 4 classes of landscape
  - 2 cropping seasons

**Methods and Outputs**

1. Agricultural practices
2. Tree inventory
3. Yield components
At the nexus of remote sensing, landscape ecology and statistical modelling

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**Methods and Outputs**

- Linear Mixed model
- 1-TREE effect
METHODS AND OUTPUTS

DATA

AGRONOMICAL SURVEY
- [Millet – 50 fields]
- [4 classes of landscape]
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1. Agricultural practices
2. Tree inventory
3. Yield components

MULTI-SOURCES REMOTE SENSING

2017
- Sentinel 2B
- RapidEye
- Planet 2A

2018
- Sentinel 2B
- RapidEye
- Planet 2A

1. Parkland structuring proxies
   * Nbs of trees
   * Woody cover
   * Tree density

2. Vegetation productivity proxies
   * Phenological metrics
   * Vegetation indices
   * Water stress index
   * Nutrient stress index

Linear Mixed model

1-Tree effect

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**Methods and Outputs**

- Linear Mixed model
  - 1 - Tree effect

- Linear Regression model
  - 2 - Millet yield estimates
    - *Plot level

*WITH TREE* → *WITHOUT TREE*

At the nexus of remote sensing, landscape ecology and statistical modelling

**DATA**

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**METHODS AND OUTPUTS**

1. Tree effect
   - Linear Mixed model

2. Millet yield estimates
   - Linear Regression model
     - With tree
     - Without tree
     - Gradient Boosting Regression tree model

3. Analysis of yields heterogeneity
   - Soil information
     *Texture
     *Soil Org Carbon/Soil Org Nitrogen
**Results ~ from a ground perspective**

**Trees effect at landscape scale based on ground observations**

Type II Anova with Kenward-Roger ddf approximation for small sample

<table>
<thead>
<tr>
<th>Variable</th>
<th>Type II F</th>
<th>P-value</th>
</tr>
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<tbody>
<tr>
<td>Tree density</td>
<td>47.50</td>
<td>&lt;0.001</td>
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*Significant effects of parkland on millet yields*
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<th>Millet grain yield</th>
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<tr>
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*Significant effects of parkland on millet yields*

*The well-known ‘fertility hotspot’ of *F.albiba* can be mitigated at landscape scale by the tree species richness and proportion of *F.albida* within fields*
Results ~ from a plot perspective

From satellite information to yield estimates accounting for tree effects

1. Sensitivity to vegetation productivity proxy and tree information

*Integrating parklands structuring information improves millet yield model
*Best model: GDVI x Nb of trees ($R^2 = 0.70$ & $RRMSE = 0.28$)
From satellite information to yield estimates accounting for tree effects

1~Sensitivity to vegetation productivity proxy and tree information

2~Sensitivity to phenological development for GDVI

*Integrating parklands structuring information improves millet yield model
*Best model: GDVI x Nb of trees ($R^2 = 0.70$ & RRMSE = 0.28)
*Panicle initiation phase to mid of the grain filling phase are more sensitive periods
Results ~ from a landscape perspective

Millet yield heterogeneity analysis at landscape scale

*Median millet yield estimates = 730 kg/ha with high variability (coef.var = 61%)
*High spatial heterogeneity, with a clear spatial pattern

* Comparison with the 95th percentile
* 95th.p > 1912 kg/ha
What are drivers of spatial heterogeneity pattern?

Variable importance for the Gradient Boosting Tree

$R^2 = 0.77^{***}$

Yield heterogeneity drivers: soil fertility, parklands structuring & crop health

*Parkland structuring information and soil fertility as drivers of spatial heterogeneity*
What are drivers of spatial heterogeneity pattern?

Variable Importance for the Gradient Boosting Tree

- Total Organic Nitrogen
- Landscape Woody Cover
- Plot Woody Cover
- Nutrient Stress
- Soil Organic Content
- Crop Cover Heterogeneity
- Water Stress
- Landscape Number of Trees
- Soil Texture

Partial Variable Dependence Plot

Influence of woody cover in surrounding landscape

*Parkland structuring information and soil fertility as drivers of spatial heterogeneity

* Woody cover in field surrounding landscape decreases the YH till a certain level
Take home messages
Findings:

- Using parklands structuring information improves the agricultural performance assessment.
- The apparent benefits of individual trees on crop yield can be challenged at landscape scale with the parklands composition/structuring.
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What is new?
- To scaling up crop yields estimates in parklands using cutting edge multisources remote sensing images.
- To consider the landscape scale to explore & improve our understanding on the implication of trees on crop productivity.
Findings:
- Using parklands structuring information improves the agricultural performance assessment
- The apparent benefits of individual trees on crop yield can be challenged at landscape scale with the parklands composition/structuring

What is new?
- To scaling up crop yields estimates in parklands using cutting edge multisources remote sensing images
- To consider the landscape scale to explore & improve our understanding on the implication of trees on crop productivity

Next steps?
- To analyze the intra-field variability
- To map tree species to strenghthen the analysis of parklands impacts at landscape scale
- To combine with socio-economic information to consider tradeoffs and synergies between goods & services
THANKS FOR YOUR ATTENTION

QUESTIONS-REMARKS: louise.leroux@cirad.fr - https://louise.leroux.igeo.fr/

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