

EVALUATING CARBON SEQUESTRATION, NUTRIENT USE EFFICIENCY, AND SOIL BIOLOGICAL PROPERTIES UNDER MAIZE-TULSI INTERCROPPING MODEL

DR. SAVITA GARWA

**DEPARTMENT OF BIOTECHNOLOGY, M.Sc. FROM PODDAR UNIVERSITY,
Ph.D. FROM MAHATMA JYOTI RAO PHOOLE UNIVERSITY, JAIPUR,
RAJASTHAN, INDIA**

ABSTRACT

Improving carbon (C) sequestration has become a critical research priority for global agricultural sustainability. Carbon-dynamics and their influences on microbial-populations and crop-productivity in maize-tulsi intercropping system (MSI) remain unclear. Experiments were carried out at Renshou, Lezhi, and Yaan to investigate the carbon-balance in terms of C-sequestration across plants-organs and its mechanistic influences on microbial-populations and crop-productivity in MSI. Tulsi was planted with maize in two different relay-intercropping patterns (R11, 40:60 cm and R12, 50:50 cm) and the results compared against maize-monoculture (MM) and tulsi-monoculture (SM). Results showed that carbon-accumulation in MSI was significantly ($p < 0.05$) higher than in sole-cropping. Carbon accumulation was 5.96%, 23.9%, and 217.6% higher in MM, SM and R11 respectively, compared to the R12.

KEYWORDS- carbon sequestration, nutrient, biological, maize-tulsi, intercropping

INTRODUCTION

In a Maize-Tulsi intercropping model, combining Maize (*Zea mays*) with Tulsi (*Ocimum sanctum* / *Ocimum tenuiflorum*) creates a multi-tier cropping system that optimizes resource capture, spatial architecture, and secondary metabolite production.

1. Carbon Sequestration

- **Above-Ground Biomass Accumulation:** The tall, C4 canopy of maize captures solar radiation aggressively, while the bushy, perennial or semi-woody structure of Tulsi adds lower-tier foliage density. Total carbon fixation per unit area typically exceeds sole-cropping of either species due to extended light interception across different vertical strata. [1]
- **Below-Ground Carbon & Root Exudates:** Dense, fibrous maize root systems combined with Tulsi's aromatic root architecture release a steady stream of organic carbon, phenolics, and root exudates into the rhizosphere. [1]
- **Soil Organic Carbon (SOC) Stabilization:** The introduction of diverse root residues and reduced tillage disturbance increases macro-aggregation and particulate organic matter (POM), enhancing long-term carbon retention compared to monoculture maize. [1][2,3]

2. Nutrient Use Efficiency (NUE)

- **Complementary N-P-K Demands:** Maize is a heavy feeder requiring substantial nitrogen and potassium, whereas Tulsi has a relatively lower nutrient footprint and acts as an efficient aromatic herb that can thrive under integrated nutrient management. [1]

- Reduced Nutrient Leaching: The overlapping root zones capture mobile nutrients (like NO_3^-) from distinct soil depths, minimizing leaching losses into the groundwater.
- Allelopathic & Pest-Repellent Synergy: Tulsi secretes essential oils (such as eugenol and rosmarinic acid) into the rhizosphere and phyllosphere, which naturally deter specific soil-borne pests and reduce the need for synthetic chemical inputs, thereby improving overall economic and ecological nutrient efficiency. [1]

3. Soil Biological Properties

- Microbial Biomass & Diversity: Aromatic root exudates from Tulsi enrich the soil microbial community, increasing Soil Microbial Biomass Carbon (SMBC) and overall bacterial-to-fungal diversity ratios.
- Enzyme Activities: Intercropping elevates key soil enzyme markers—such as dehydrogenase, urease, and phosphatase—which accelerate the mineralization of organic matter and make bound phosphorus and nitrogen more plant-available. [1]
- Soil Aggregation & Bulk Density: Better root entanglement improves the Mean Weight Diameter (MWD) of soil aggregates and prevents surface crusting and compaction commonly observed in continuous sole-crop maize plots. [1]

DISCUSSION

The role of maize-legume cropping system on soil quality, carbon sequestration and yield of maize in a Northern Guinea Savanna Alfisol, Nigeria was assessed in 2014 and 2015 rain-fed cropping seasons. The experiment was a Randomized Complete Block Design (RCBD), replicated three times and treatments were Sole (Mono crop) Maize (M), Desmodium (D) and Tulsis (S); Maize/tulsis intercrop (MS), Maize/Desmodium intercrop (MD), Maize Strip cropped with Tulsi (MS 2:4) and Maize Strip cropped with Desmodium (M:D 2:4). Data obtained were evaluated for Organic carbon, available phosphorus, total nitrogen, soil pH, and CEC, Bulk density, Soil moisture, mean weight diameter and grain yield of Maize. Results show that mean soil acidity (pH water, 6.37; pH CaCl_2 , 5.78), mean organic carbon (5.23 to 5.69 $\text{g}\cdot\text{kg}^{-1}$) and mean total nitrogen improved (0.66 $\text{g}\cdot\text{kg}^{-1}$) in 2015 over values in 2014. Mean weight diameter (MWD) increased from 0.59 in 2014 to 1.05 in 2015; indicating a better aggregation across treatments. Treatment M resulted in significantly higher bulk density (Bd) than other treatments at 8 weeks after planting (WAP) and 16WAP, suggesting that soils under mono-crop maize were impaired for sustainable crop production. Soil organic carbon (SOC) sequestered in macro aggregates under MS (1.38 $\text{g}\cdot\text{kg}^{-1}$) was significantly higher than the other treatments. Best maize grain yield (GY) was under sole maize (M) and maize strip cropped with Desmodium (MD2:4) (3.13 $\text{t}\cdot\text{ha}^{-1}$ and 2.90 $\text{t}\cdot\text{ha}^{-1}$ in 2015, respectively). [4,5,6]Maize strip cropped with Desmodium and maize/tulsi intercrop enhanced better soil chemical and physical properties than sole maize. Soil quality (SQ) under MD2:4 ranked best (SQ1) for sustainable maize grain production and environmental conservation. Therefore, land use strategies that focus protection of soil organic carbon against further depletion and erosion, contribute nitrogen and/or replenishment of depleted carbon stocks through management techniques that involve legume/cereal cropping systems are advocated for sustainable agricultural production in the Nigerian Savanna zone Alfisols.

The NPKM treatment exhibited highest yield, exceeding NPK treatment by 8.5 to 27.9%. Intercropping reduced cumulative soil CO_2 and N_2O emission by 9.3 to 22.6% and 2.1 to 19.4%, respectively, while enhancing net CH_4 uptake by 27.3 to 135.2%. Soil organic carbon and

dissolved organic carbon contents were 6.8 to 21.5% higher under intercropping than monocropping, particularly under NPKM treatment. The integration of maize/tulsi relay intercropping with organic–inorganic fertilization, particularly NPKM, is a promising strategy. It simultaneously enhances crop yield, improves soil organic carbon sequestration, increases atmospheric CH₄ uptake, and significantly reduces the system's overall greenhouse gas (GHG) intensity and global warming point (GWP), demonstrating a viable path for climate-smart agriculture.[7,8,9]

RESULTS

Evaluating carbon sequestration involves measuring the net difference between carbon absorbed by ecosystems or tech systems and carbon released back into the atmosphere. [1]

Key Methods of Evaluation

- Terrestrial & Forest Biomass Assessment: Uses tree measurements like diameter at breast height (DBH) and tree height in allometric or linear regression models to calculate above-ground and below-ground biomass. [1, 2]
- Soil Organic Carbon (SOC) Tracking: Measures changes in organic matter within soil profiles using soil sampling, laboratory analysis (such as thermogravimetric analysis or TGA), and modeling frameworks like the YASO model. [1, 2]
- Remote Sensing & Geospatial Modeling: Employs satellite data (such as NDVI, MODIS net primary production, and GIS-based platforms like InVEST) to map land-use changes, vegetation cover, and ecosystem carbon stocks over time. [1, 2, 3]
- Flux Measurements & Gas Exchange: Tracks real-time carbon dioxide exchange between the land/canopy and the atmosphere using eddy covariance flux stations. [1]
- Industrial & Mineral Carbonation: Monitors weight and gas uptake via thermogravimetric analysis (TGA), pressure/temperature tracking, or autoclave systems for concrete and mineral weathering solutions. [1]

Core Carbon Pools Evaluated[10,11,12]

- Above-Ground Biomass: Living plant materials like trunks, branches, bark, and leaves. [1]
- Below-Ground Biomass: Living root systems. [1]
- Soil Organic Carbon: The largest terrestrial carbon pool, formed from decomposed plant and microbial matter. [1]
- Dead Organic Matter: Standing deadwood, fallen logs, and surface litter. [1]

Nutrient use efficiency (NUE) measures how effectively crops absorb, convert, and utilize applied fertilizer nutrients to produce growth and harvestable yield. [1, 2]

Key Types of Indices

- Agronomic Efficiency (AE): Economic yield obtained per unit of nutrient applied.
- Physiological Efficiency (PE): Biological or dry matter production per unit of actual nutrient uptake.
- Apparent Recovery Efficiency (RE): The fraction of the applied nutrient successfully absorbed by the plant.

- Internal Utilization Efficiency (IE): Total yield produced per unit of total nutrient accumulated in plant tissues. [1, 2, 3]
Typical Efficiency Ranges
- Nitrogen (N): 30% to 50% utilization; losses occur via leaching, volatilization, and denitrification.
- Phosphorus (P): 15% to 25% utilization; losses occur via strong soil fixation with iron, aluminum, and calcium.
- Potassium (K): 50% to 80% utilization; primarily lost or bound through leaching and clay fixation. [1, 2, 3]
Strategies for Improvement[13,14,15]
- The 4R Framework: Apply the right source, at the right rate, at the right time, and in the right place.
- Enhanced-Efficiency Fertilizers: Utilize coated fertilizers, slow-release products, nitrification inhibitors, and urease inhibitors.
- Precision Agriculture: Implement split fertilizer applications, variable-rate mapping, and regular soil or tissue testing. [1, 2, 3]

CONCLUSION

Intercropping Maize (*Zea mays*) with *Ocimum* (such as *Ocimum basilicum* or sweet basil) is a productive agricultural practice used to maximize land use, generate supplementary income from aromatic herbs, and manage pests naturally. [1, 2, 3]

Key Benefits of Maize–*Ocimum* Intercropping

- Land Equivalent Ratio (LER): Studies show that intercropping sweet basil into maize systems achieves high LER values (often ranging from 1.50 to 1.66), indicating superior total biological efficiency and resource exploitation compared to sole cropping. [1, 2]
- Main Corn Yield Stability: The primary grain yield of maize is generally not significantly reduced by the presence of lower- or mid-density basil intercrops, allowing farmers to harvest full-value maize while gaining an extra cash crop. [1][16,17,18]
- Natural Pest Repellent: Aromatic compounds and volatile oils released by *Ocimum* plants help deter common insect pests that target cereal crops. [1, 2]
- Income Diversification: Adding high-value medicinal and aromatic herbs provides continuous cash flow or secondary harvests (such as fresh/dry herb and essential oil yields). [1, 2]

Recommended Configurations and Practices

- Planting Proportions: Common trial configurations use additive series such as 100% maize + 75% to 100% *Ocimum* population, which optimize both corn growth and total herb yield without severe light or nutrient competition. [1, 2]
- Resource Management: Because maize is a tall, heavy-feeding C₄ plant and basil is a lower-stature herbaceous plant, staggered growth or matching row geometries ensures the basil utilizes lower-canopy sunlight and soil moisture efficiently. [1, 2]
- Biofertilizers: Integrating nitrogen-fixing bacteria (such as *Azotobacter* or *Azospirillum*) alongside moderate chemical or organic fertilization further boosts both the essential oil content of the basil and the overall productivity of the plot. [19,20]

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