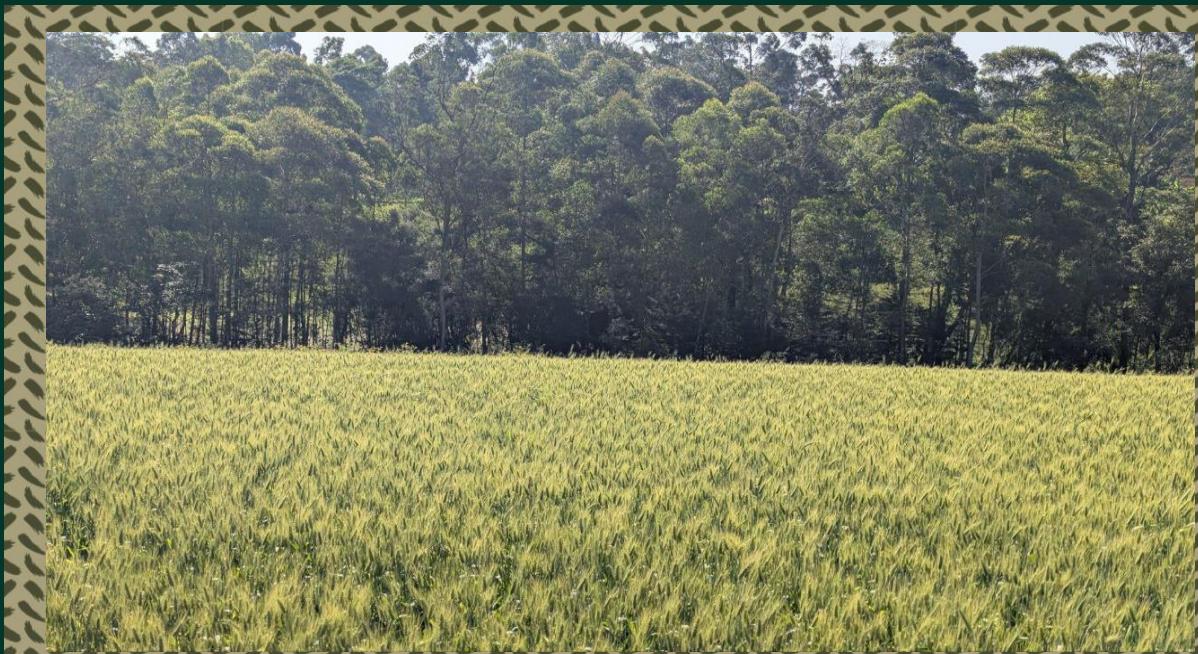


Hyper-Localized Fertilizer Advisory System

Precision Nutrient Management for Ethiopian Smallholder Farmers

December 2025



Authors:

Henok Desalegn, Gizaw Desta, Gizachew Legesse, Abiro Tigabie, Getachew Agegnehu

The Challenge: Blanket Fertilizer Recommendations

Current Fertilizer Use Situation

- Ethiopian agriculture uses uniform fertilizer recommendations; large areas are treated as homogeneous despite strong variation in soil, climate, and topography.
- Fertilizer is costly, and the climate is variable – farmers need field-level, data-driven guidance.

Consequences

- Over-application in nutrient-rich areas → wasted resources
- Under-application in deficient areas → limited yields
- Environmental degradation from nutrient runoff
- Economic losses for smallholder farmers

Need: Site-specific recommendations that account for local conditions

Our Solution: Two-Stage Recommendation Process

Stage 1: Site-specific Fertilizer Advisory

- User selects location on interactive map
- For a chosen farmer field, query Machine Learning (ML) driven N and P₂O₅ raster layers for the selected crop.
- Raster values are optimal fertilizer rates at ≈30 m resolution from the ML Decision Support Tool (DST).

Stage 2: Farmer Context-Based Fertilizer Adjustment

- Farmer reports site-specific conditions
- System applies percentage adjustments to baseline recommendations

Result

- Personalized fertilizer recommendation
- Transparent breakdown of each farmer context, farmer and extension knowledge, improving adoption and trust.

The screenshot displays the ICRISAT Soil & Landscape Portal interface. At the top, the ICRISAT logo and the text "Soil & Landscape Portal ICRISAT Ethiopia v1.0" are visible, along with navigation links for "Home", "Data Extraction", "Advisory", and "About".

The main content area features a section titled "About Hyper-Localized Advisory" with a brief description of the tool's purpose: "This tool adjusts baseline fertilizer recommendations based on your specific field conditions, farming practices, and resources. Select the factors that apply to your situation to get personalized nitrogen and phosphorus recommendations tailored to your farm." Below this is a "Select Location & Crop" form. It includes fields for "Latitude" (e.g., 9.0) and "Longitude" (e.g., 38.7), a "Select Crop" dropdown menu, and a "Get Baseline Recommendation" button. To the right of the form is a "Get Started" button with the text "Enter your location coordinates and select a crop to receive personalized fertilizer recommendations." At the bottom of the page is a "Map Selection" tool showing a map of the Horn of Africa region, with various locations labeled.

System Architecture

Technology Stack

- **Frontend:** JavaScript + Leaflet.js maps
- **Backend:** Python Flask REST API
- **Spatial Data:** GeoTIFF rasters (30m)
- **Processing:** Rasterio, PyProj, Pandas
- **Deployment:** Web-based, mobile-friendly

Data Flow

1. User clicks the location on the map
2. Coordinates sent to backend API
3. Raster values extracted at the point
4. User selects local adjustment conditions
5. Backend calculates adjusted values
6. Results are displayed with a breakdown

User Interface: Stage 1 - Site-specific Fertilizer Advisory (Baseline)

Interactive Map

- Map centered on Ethiopia
- Click to select field location
- Coordinates auto-populate input fields

Input Options

- Manual latitude/longitude entry
- Crop selection: Wheat, Sorghum, Tef, or Maize
- 'Get Baseline' button triggers raster extraction

Baseline Display

- Shows extracted N (kg/ha) and P₂O₅ (kg/ha)
- Values come directly from pre-computed raster maps

The screenshot displays the ICRISAT Soil & Landscape Portal interface for Ethiopia. At the top, the ICRISAT logo and 'Soil & Landscape Portal' are visible, along with 'ICRISAT Ethiopia v1.0'. The top navigation bar includes 'Home', 'Data Extraction', 'Advisory', and 'About'. The main content area is titled 'About Hyper-Localized Advisory' with a sub-section 'Select Location & Crop'. It shows coordinates (10200014, 38611056) and a 'Select Crop' dropdown set to 'Wheat'. A green button labeled 'Get Baseline Recommendation' is present. Below this is a 'Map Selection' section with a map of Ethiopia and a 'Click to select' button. To the right, two large boxes display fertilizer recommendations: 'NITROGEN (N) 240.0 kg/ha' (green box) and 'P₂O₅ 40.0 kg/ha' (blue box). The 'Wheat' crop is selected in the top right corner of the main content area.

User Interface: Stage 2 - Farmer Context-Based Fertilizer Adjustment

Soil & Terrain Factors

- Soil Fertility (poor to fertile)
- Soil Depth (shallow to deep)
- Soil moisture level (low to high)
- Landscape position (steep hill to bottomland)

Crop Management Factors

- Seed rate/plant density
- Crop rotation
- Organic inputs (compost/manure)

2 Adjust for Your Conditions
Select factors that apply to your land

Soil & Terrain

Soil Fertility ⓘ
Not specified

Landscape Position ⓘ
Not specified

Soil Depth ⓘ
Not specified

Soil Acidity ⓘ
Not specified

Soil Moisture ⓘ
Not specified

Liming Status ⓘ
Not specified

Crop & Farm Management

Crop Rotation ⓘ
Not specified

Seed Rate / Plant Density ⓘ
Not specified

Organic Inputs (Compost/Manure) ⓘ
Not specified

Intercropping ⓘ
Not specified

Weeding Method ⓘ
Not specified

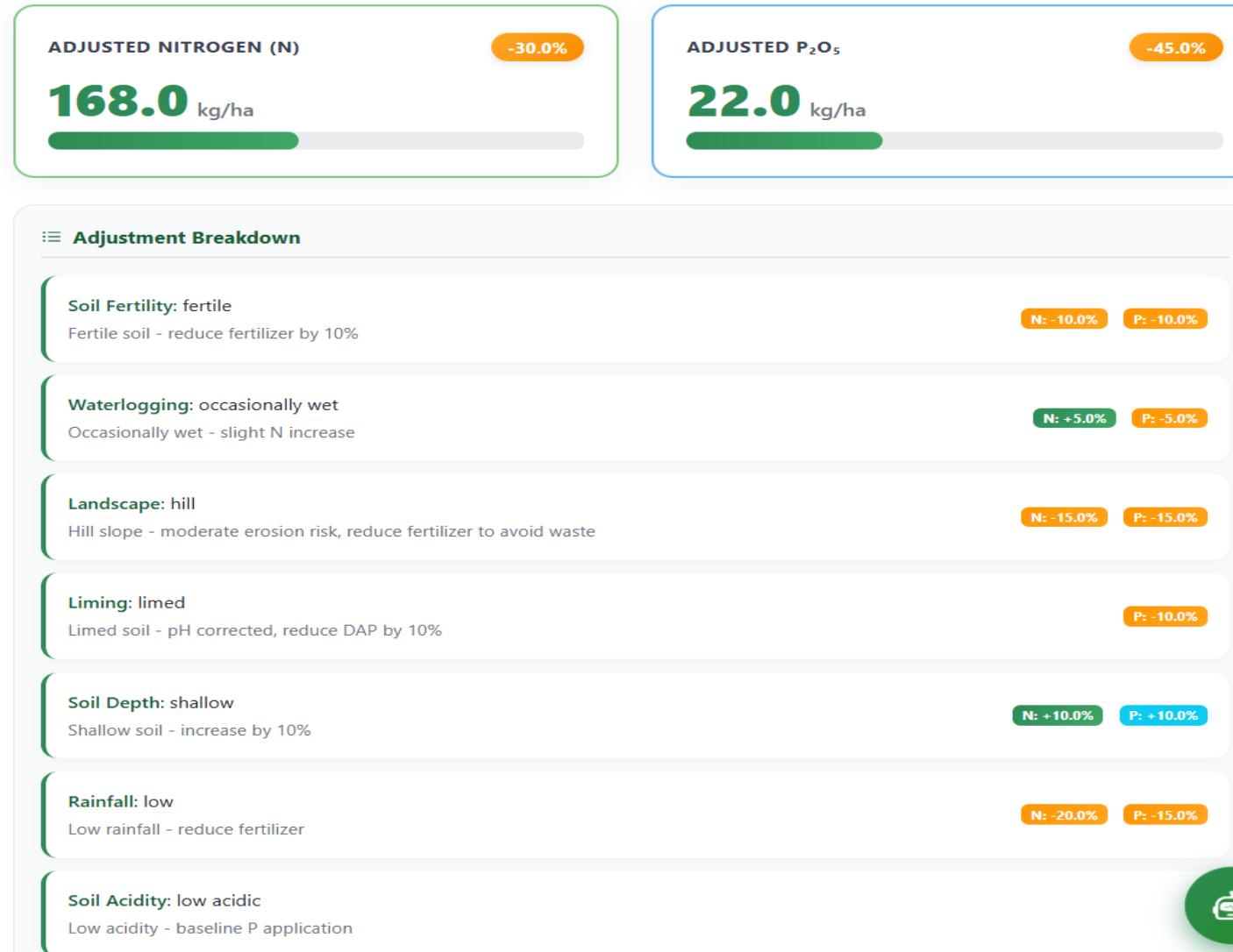
Advanced Options: Economic Constraints

Calculate Additional Recommendations

Personalized Recommendation

Final Recommendation Display

- Adjusted Nitrogen (N) in kg/ha with % change badge
- Adjusted P₂O₅ in kg/ha with % change badge
- Color-coded badges: green (+), orange (-), gray (0)



Core Implementation (Python Backend)

```
# script/routes/advisory.py

FERTILIZER_ADJUSTMENT_RULES = {
    "soil_fertility": {
        "very_fertile": {"N": -0.15, "P": -0.15, "description": "Reduce by 15%"},
        "poor": {"N": 0.10, "P": 0.10, "description": "Increase by 10%"},
        "very_poor": {"N": 0.20, "P": 0.20, "description": "Increase by 20%"}
    },
    "rainfall": {
        "very_low": {"N": -0.25, "P": -0.20},
        "high": {"N": 0.10, "P": 0.10}
    }
}

MAX_ADJUSTMENT = 0.50 # Safety cap at ±50%

# Apply adjustments
for factor, value in factors.items():
    rule = FERTILIZER_ADJUSTMENT_RULES[factor][value]
    total_adj_n += rule['N']
    total_adj_p += rule['P']
```

Expected Impact & Conclusion

Quantified Benefits

- Improved fertilizer-use efficiency and reduced costs for farmers.
- More equitable, field-specific fertilizer recommendations across heterogeneous landscapes.
- Higher and more stable yields due to better targeted N and P₂O₅ application.
- Reduced environmental pressure from over-application of fertilizers.
- Transparent and explainable recommendations that build trust among farmers and extension agents.

Key Innovations

- Combines geospatial precision with local knowledge
- A transparent, context-specific analysis for each farmer, explainable adjustments
- Safety-capped recommendations
- Mobile-friendly field deployment
- Bridges science and practical farming

The Hyper-Localized Fertilizer Advisory System transforms blanket recommendations into precision guidance, empowering farmers with actionable, site-specific insights.

Citation:

Desalegn, H., Desta, G., Legesse, G., Tigabie, A., and Agegnehu, G. 2025. Hyper-Localized Fertilizer Advisory System: Precision Nutrient Management for Ethiopian Smallholder Farmers

Acknowledgements

The CGIAR Sustainable Science Program forms a part of CGIAR's new Research Portfolio, addressing key challenges in agri-food systems by fostering efficient production of nutritious foods and safeguarding the environment to create fair employment opportunities, as we simultaneously tackle climate change, soil degradation, pests, diseases, and desertification. Its research is being implemented by CGIAR researchers from ICRISAT and ALLIANCE Bioversity International CIAT in close partnership with the Ministry of Agriculture, Ethiopian Institute of Agricultural Research, Regional Agricultural Research Institutes (Amhara, Oromia, South, Central, South West), Self Help Africa (SHA), Catholic Church South Synod, Sasakawa Africa Association (SAA), People in Need, Enhanced Rural Self Help Association (ERSHA), Precision Development (PxD), and Digital Green.

We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund: <https://www.cgiar.org/funders/>

About CGIAR Sustainable Science Program Report

This research was conducted as part of the CGIAR Sustainable Farming Science Program. This research is being implemented by CGIAR researchers from ICRISAT in close partnership with the Ministry of Agriculture, Ethiopian Institute of Agricultural Research, Regional Agricultural Research Institutes (Amhara, Oromia, South, Central, South West), Self Help Africa (SHA), Catholic Church South Synod, Sasakawa Africa Association (SAA), People in Need, Enhanced Rural Self Help Association (ERSHA), Precision Development (PxD), and Digital Green. CGIAR is a global research partnership for a food-secure future. Its science is carried out by 15 Research Centers in close collaboration with hundreds of global partners. www.cgiar.org

Disclaimer

This working paper has not been peer reviewed. Any opinions stated herein are those of the author(s) and do not necessarily reflect the policies or opinions of ICRISAT, donors, or partners.

This publication is copyrighted by the ICRISAT

It is licensed under a Creative Commons Attribution–NonCommercial 4.0 International License. To view this license, visit <https://creativecommons.org/licenses/by/4.0>. Unless otherwise noted, you are free to share (copy and redistribute the material in any medium or format), adapt (remix, transform, and build upon the material) for any purpose, even commercially, under the following conditions:

ATTRIBUTION: The work must be attributed, but not in any way that suggests endorsement by ICRISAT or the author(s).

For any reuse or distribution, the license terms of this work must be made clear to others. Any of the above conditions can be waived if permission is obtained from the copyright holder. Nothing in this license impairs or author's moral rights. Fair dealing and other rights are in no way affected by the above. The parts used must not misrepresent the meaning of the publication. (insert names of CGIAR Centers involved) would appreciate being sent a copy of any materials in which text, photos, etc., have been used.

©2025 ICRISAT

Key Words:

Hyper-Localized Advisory, Precision Nutrient Management, Site-Specific Fertilizer, Two-Stage Advisory Solution

Partners

Ministry of Agriculture, Self Help Africa (SHA), Catholic Church South Synod, Sasakawa Africa Association (SAA), People in Need, Enhanced Rural Self Help Association (ERSHA), Ethiopian Institute of Agricultural Research, Precision Development (PxD), Digital Green

About CGIAR Sustainable Farming Science Program

The CGIAR Sustainable Farming Science Program will address key challenges in agrifood systems by fostering efficient production of nutritious foods and safeguarding the environment to create fair employment opportunities, as we simultaneously tackle climate change, soil degradation, pests, diseases, and desertification.

About CGIAR Sustainable Farming Science Program

The CGIAR Sustainable Farming Science Program will address key challenges in agri food systems by fostering efficient production of nutritious foods and safeguarding the environment to create fair employment opportunities, as we simultaneously tackle climate change, soil degradation, pests, diseases, and desertification.

