

# Precision Soil Mapping for Better Crop Management

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## Abstract

Soil variability significantly influences crop performance, yet it is often overlooked in traditional farming practices. Precision soil mapping, utilizing digital tools, sensors, and geospatial technology, offers a transformative approach to understanding and managing this variability. Techniques such as grid soil sampling, remote sensing, and GIS-based analysis enable farmers to create high-resolution soil maps that guide precise input application. These maps facilitate site-specific fertilizer use, targeted irrigation, and informed crop selection, leading to higher yields, cost savings, and environmental protection. For instance, variable-rate technology (VRT) informed by soil maps can reduce fertilizer usage by up to 40% without compromising productivity. As agriculture becomes more data-driven, precision soil mapping is emerging as a cornerstone of sustainable and smart farming.

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## Introduction

Traditional farming often treats fields as uniform units, applying fertilizers, water, and seeds evenly across large areas. However, scientific research and farmer experience reveal that soil characteristics can vary significantly even within a few meters. These micro-variations impact nutrient availability, water retention, crop health, and ultimately, yield. To address this, farmers are increasingly adopting precision soil mapping—a technique that uses spatial data, sensors, and software to capture detailed soil information across different zones of a field. Unlike blanket treatments, precision soil mapping enables site-specific management, where each area of the field is treated according to its unique needs.

This approach is especially valuable in large farms where soil variability is common, but it's also gaining traction among smallholders using affordable

mobile mapping tools. A range of technologies support this practice: grid soil sampling, electromagnetic induction, remote sensing, GPS, and Geographic-information Systems (GIS). These tools help generate accurate digital soil maps that visualize pH levels, organic matter, moisture, salinity, and nutrient content across a farm.

For example, a farmer in Punjab using precision soil mapping reduced fertilizer usage by 30% while increasing wheat yields by 20%. In the U.S. Corn Belt, farmers equipped with variable-rate technology (VRT) apply inputs only where needed, saving thousands of dollars annually in input costs. In this article, we explore how precision soil mapping works, its real-world applications, and why it's becoming essential for profitable, sustainable farming in the era of climate change and resource scarcity.

## Precision soil mapping

Precision soil mapping involves collecting and analyzing spatially-referenced soil data to assess variability within a field. The goal is to enable site-specific crop management—applying inputs like fertilizers and water where and when they are most needed.

#### Key Components:

- **Data Collection:** Soil samples, sensor readings, aerial imagery.
- **Analysis:** Using GIS software to interpret spatial variations.
- **Mapping:** Generating visual maps showing soil properties across zones.
- **Decision Support:** Tailoring field operations based on the maps.

#### Technologies used in precision soil mapping

**Table 1.** Various technologies and their functions

Technology	Function
Grid Soil Sampling	Soil sampled at regular intervals (e.g., 1 sample/2.5 acres) to assess pH, NPK, etc.
Remote Sensing	Satellite or drone images to detect crop and soil variations.
Electromagnetic Induction (EMI)	Measures soil conductivity, which relates to texture, salinity, and moisture.
Near-Infrared Spectroscopy (NIRS)	Analyzes soil organic matter and mineral content rapidly.
GPS and GIS Mapping	Spatial tools to visualize and analyze data points.

#### Benefits of precision soil mapping

**Improved Fertilizer Efficiency:** Apply nutrients only where they are deficient, reducing waste and cost.

**Higher Crop Yields:** Uniform growth is promoted by addressing variability, increasing productivity by 10–25%.

**Water Conservation:** Targeted irrigation reduces water usage, especially important in drought-prone regions.

**Environmental Protection:** Reduces nutrient runoff into water bodies, limiting pollution and eutrophication.

**Better ROI (Return on Investment):** Although initial costs may be high, long-term savings and yield gains often offset expenses.

#### Case studies

**India:** Punjab Farmers Use Soil Health Cards. Using government-provided soil health reports and digital mapping, farmers reduced DAP fertilizer use by 25% and saw improved paddy yields.

**USA**

Corn Belt Precision Programs Farmers using VRT based on soil maps report \$15–\$30 per acre in savings on fertilizer alone, while boosting yields.

#### Australia

Moisture Mapping for Dryland Farming. Sensors mapped subsurface moisture, enabling better sowing time decisions and improving crop establishment in arid zones.

#### Challenges to adoption

**High Initial Costs:** Advanced sensors and mapping software can be expensive.

**Technical Knowledge:** Requires training to collect, interpret, and act on data.

**Limited Access for Smallholders:** Not all farmers have access to GPS/GIS tools or soil labs.

**Data Integration Issues:** Combining data from various sources into a usable map can be complex.

#### Conclusion

Precision soil mapping is transforming the way farmers understand and manage their fields. By making invisible soil variability visible, it empowers farmers to make smarter, data-driven decisions that benefit both their productivity and the planet. Though adoption challenges remain, the technology is rapidly evolving and becoming more affordable. As digital agriculture expands, precision soil mapping will be a cornerstone in building resilient and efficient farming systems for the future.

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