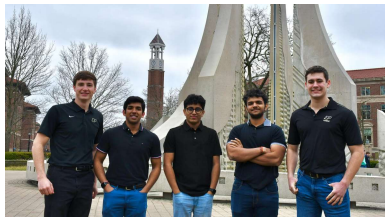
PURDUE UNIVERSITY
Mechanical Engineering

# TerraProbe – A Down2Earth Company

*Capstone Senior Design Project • Spring 2025*

***Down2Earth (D2E)***



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## Revolutionizing Soil Sampling

### Current State

Farming practices are evolving, but soil sampling remains outdated:

- Inconsistent Sampling & Contamination, No Depth Profiling
- Lab Testing of Soil Samples, Lack of **Real-Time Data** Testing
- Bulky, Manual, or Expensive Tools, Lack of an **intermediate** solution



### Future State

Intermediate solution that is affordable, automated, & actionable:

- Portable, Affordable, & Lightweight Soil Sampling Solution
- On-Demand, Real-Time Data Dashboard
- Multi-Depth Soil Core Sampling & Depth Profiling

## Critical Customer Requirements

| Benchmark Model(s) Limitations | TerraProbe's Design Response |
|---|---|
| High Cost ($3000-$6000) | Affordable ( <$1500 retail) |
| Bulky, Difficult to Transport | Compact & Lightweight (<25 kg) |
| Manual or Complex to Operate | Automated Operation & Burrowing |
| Inconsistent multi-depth sampling | Multi-Depth 4-layer sampling (up to 12") |
| No integrated data analytics | Testing Probe & Data (NPK & Moisture) |

## Market Potential & Opportunities

| | |
|---|---|
| **Primary Focus** | Agricultural |
| **Secondary Focus** | Research, Construction |

Global Soil Testing Market: **$5.5 Billion (2023)**

↓

Number (#) of US Farmers: **~1.8 million**

↓

Number (#) of Small-Mid Acreage Farms: **~670K**

↓

Target Market Adoption Rate: **20% (conservative)**

↓

Target Addressable Market (Units): **134K**

**Goal: Capture 20% of Market Over ~10 Years**

## Competitors & Market Gaps

**Low to High Complexity**

**AMS Soil Probe**

✓ Low Cost & Portable

✗ Manual, No Data

**WintexAgro 1000**

✓ Automated Sampling

✗ Vehicle Mount, Heavy

**Amity Technology**

✓ 3rd Party Data Analysis

✗ Heavy & Expensive

## Our Mission Statement

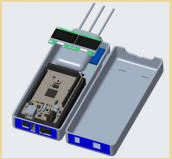
"TerraProbe aims to **bridge the gap** between manual probes and industrial sampling machines in the market, by offering an end-to-end **connected experience** through an **automated, portable soil sampling solution with real-time data insights** – allowing small/medium sized farmers to make informed decisions to improve crop health and yield."

## Introducing TerraProbe

### TerraProbe Soil Sampler

- ✓ Compact, **Portable** & Handheld Soil Sampling Device (9"x 12"x 17")
- ✓ Utilizes **Rack and Pinion Mechanism** for motorized power and downward movement (12" Deep)
- ✓ Contains **Replaceable Payload Tube** for each sampling event

### Soil Testing Probe (DAQ)



- ✓ Sensor Module for **on-site analysis** capturing key parameters
  - **Nitrogen, Phosphorous, Potassium (NPK)**
  - **Moisture**
- ✓ Readings taken at different intervals through **slits on the inner payload**
- ✓ **LED Display** and **Button** selectors guides user experience

### SoilIQ Dashboard

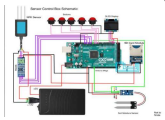
- ✓ Digital platform **to visualize NPK and moisture data** at various depth profiles
- ✓ Converts **SD card data from DAQ** into interpretable tables and charts
- ✓ Utilizes **neural network** to **predict** and recommend **potential crop type** based on NPK, Temperature and Humidity Parameters

## Engineering Details & Function

### Partially Exploded View – TerraProbe Soil Sampler

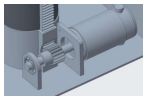
- ✓ **Shell & Payload**
  - Shell (outer tube) is welded to the racks
  - Payload (inner tube) houses soil
- ✓ **Rack & Pinion Mechanism**
  - Dual 12V DC motors power downward moment
- ✓ **Foot Pedals**
  - Adds grip, stability, and easier insertion of payload

### Soil Testing Probe (DAQ) Electrical Diagram



- ✓ **DAQ Electronics Architecture**
  - Arduino Mega 2650 for control
  - SD Card Module: Logs data
  - LED Display: Real-Time Feedback for User
  - Battery Powered for Portability
  - NPK & Moisture Sensors

### Motor-Pinion-Rack – TerraProbe Soil Sampler



- ✓ **Motor Driver System**
  - Controls power and direction (12V, 35W, 30 RPM Motor)
- ✓ **Bearings**
  - Prevents failure due to excessive stress, misalignment, or wear

### Soil IQ Dashboard System

- ✓ **Backend & Interface**
  - Built with Python + Streamlit
- ✓ **Data Processing**
  - SD card data -> Pandas DF
- ✓ **Predictive Analytics**
  - NN predicts best crop based on soil properties

## Innovation & Benefits

**Automated Burrowing & Multi-Depth Soil Profiling**

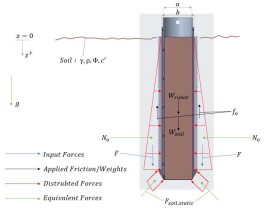
**Data-Driven Decision Support**

**Affordable & Efficient**

**Portable & Lightweight**

## Simulation & Validation

### Soil Burrowing - Modelling & Simulation

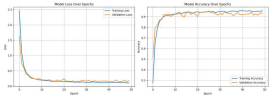


- ✓ **FBD Analysis**
  - Used Rankine theory and soil pressure forces to estimate downward force needed for soil penetration
- ✓ **Simulation on Clay & Loamy Soil**
  - Designed a 2-minute descent profile.
  - Required force calculated as 923.4 N for stiff cohesive soil
- ✓ **Motor Design & Sizing**
  - Selected a 35W, 12V motor at 30 RPM
- ✓ **Validation & Testing**
  - Tested on controlled soil field bed
  - Depth Consistency, Sampling Integrity (Tube fill, compaction), and Device Alignment

### Soil Burrowing - Validation

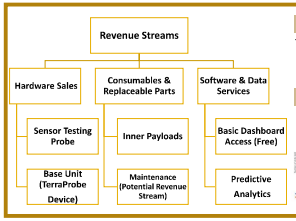
- **Penetration Force Test** ☑
  Success Criteria: Force to penetrate target soil types remains below motor torque limits (~923.4 N for stiff cohesive soil)
- **Burrow Time Test** ☑
  Success Criteria: Time that device reaches target depth (12 inches) is <= 2 min in loamy soil
- **Depth Accuracy Test** ☑
  Success Criteria: Burrow multiple times, measure depth each time (SD ≤ ±0.5")
- **Sensor Accuracy Test** ☑
  Success Criteria: Compare NPK, Moisture to known soil values and compare multiple sample values for variability (ME ≤ ±10%)

### Dashboard Recommendation Validation



- ✓ **Crop Recommendation Dataset**
  - Kaggle dataset augmenting rainfall, temperature, humidity, and NPK data
- ✓ **Neural Network Loss Function**
  - Low training and validation loss indicates high accuracy and generalizability of dashboard recommendations
- ✓ **Model Accuracy: 92% (Train-Test-Split)**

## Financials: Prototype to Product




| Production Cost | Sell Price & Margins |
|---|---|
| TerraProbe → $832.93 | TerraProbe → $1050 |
| Inner Tube → $84.24 | Inner Tube → $130 |
| | Software → Annually $100 |

| Production Cost | 10-Year ROI |
|---|---|
| $50M | 33% |

## Future Iterations & Considerations

- **Variable Depth Sampling**
  Enable programmable depth control
- **Plug & Play Modular Sensors**
  Attach/detach multiple sensors for testing (Modular)
- **Multi-Soil Adaptability**
  Motor speed control knob for torque control
- **Connectivity & Analytics**
  Bluetooth communication for real-time data and additional predictions/recommendation analytics