

Soil Moisture Sensor

Industrial Design Project- 3

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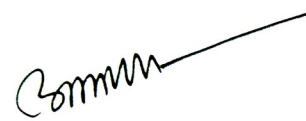
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Approval

Industrial Design Project 3
“Soil Moisture Sensor”

By: Juwin Thomas
M. Des Industrial Design 2015-2017

Is approved as a partial fulfillment of requirements of post graduate
Degree in Industrial Design at IDC, IIT-Bombay.



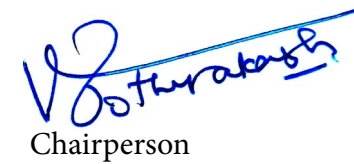
External Examiner



Internal Examiner



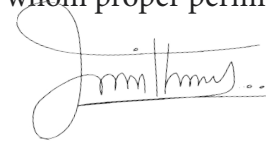
Project Guide



Chairperson

Declaration

I declare that this written submission represents my own ideas and where other's ideas or words have been used, I have adequately cited and referenced the original sources. I also declare that I have adhered to all the principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any ideas/source/fact in my submission. I understand any violation of the above will be the cause for a disciplinary action by the institute and can also issue penal action from the sources which has been thus not been properly cited or from whom proper permission has not been taken where required.

A handwritten signature in black ink, appearing to read 'Juwin Thomas', with a horizontal line underneath.

Juwin Thomas
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Acknowledgment

I take this opportunity to thank the entire faculty at IDC school of design for the inputs that helped me throughout the project.

I express my gratitude to my guide Prof. B.K Chakravarthy for giving me the opportunity to work with this project. I am deeply thankful to Rajul S Patkar, who entrusted me with this project. It is her Ph.D Thesis project on developed low cost piezoresistive cantilever platforms for agricultural applications, IIT Bombay. under Prof. V. Ramgopal Rao and Prof. M.S Bagini which paved the path for this project in first place.

I like to thank Nithin for his valuable insights at every stage of the project. I also like to thank Aniket for extending his support by helping in quickly making prototypes and test rigs. It was a great learning experience for me.

Last but not the least i am grateful to my classmates for contributing their valuable insights to this project.

Abstract

Agriculture is “The backbone of Indian economy”. In 2012-13 agriculture contributed to 13.9% of the total GDP , and employed 47% of the total workforce population. Due to increasing population, the basic need such as food and water is increasing day by day. Thus it is substantial to save these resources and utilize them in an efficient manner. Since water is one of the most important elements in our daily life, we must adapt to efficient ways to utilizing water and save it for future generations. One of method is efficient irrigation management practices for fields. Irrigation water management practices could greatly benefit by the knowledge of moisture in the soil. By knowing the moisture value, we can estimate when to water and how much to water the fields so that there is no over- watering or wilting of crops. Water holding capacity varies from soil to soil. Moreover different varieties of crop require different amounts of water for optimum growth.

Rajul S Patkar, (2016) has developed low cost piezoresistive cantilever platforms for agricultural applications as a part of her Ph.D.Thesis, IIT Bombay. under Prof. V. Ramgopal Rao and Prof. M.S Bagini. Through this project i aim to design a low cost soil moisture sensor by utilizing proposed sensor based technology developed at electrical department, IIT Bombay for small and medium scale farmers that helps them in providing optimum irrigation for crops and thereby increasing productivity.



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01 Introduction

Data collection

i. Understanding scenarios

Drought is one of the major problems faced by India. As available water resources become scarcer, more emphasis is given to efficient use of irrigation water for maximum economic return and water resources sustainability.

This requires appropriate methods of measuring and evaluating how effectively water extracted from a water source is used to produce crop yield. Inadequate irrigation application results in crop water stress and yield reduction. Excess irrigation application can result in pollution of water sources due to the loss of plant nutrients through leaching, runoff, and soil erosion.

The efficiency of irrigation water use varies across India. In areas where water is limited, available water is used more carefully. Whereas, in areas of abundant water, the value put on conserving water is less and the tendency to over irrigate exists. Efficient use of water is also influenced by cost of labor, ease of controlling water, crops being irrigated, type of irrigation system, and soil characteristics

Given this scenario, perhaps it is time to make a shift to micro irrigation so that the efficient and judicious use of scarce water resources can be made. A study conducted by the National Mission for Sustainable Agriculture on micro irrigation in 64 districts of 13 states (Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Haryana, Karnataka, Maharashtra, Odisha, Rajasthan, Tamil Nadu, Sikkim, Uttar Pradesh and Uttarakhand), reveals that there were significant reductions in the use of water and fertilizer but the yield of crops increased up to 45% in wheat, 20% in gram and 40% in soybean. However, high initial costs deter farmers to adopt this technology.

Field visit-Understanding existing interventions

Osmanabad

In order to better understand problems faced by farmers, it is necessary to understand rural culture and get acclimatized with village community. A 2 day visit was made to Osmanabad, Maharashtra. The area is one of the worst drought hit places in Maharashtra district.

We visited Krishi Vigyan Kendra at Tuljapur and had a fruitful discussion with the agricultural scientists. We had the opportunity to study and examine some of the frugal innovations in agricultural sector.

The facility served as a training centre for farmers and gave them free classes on using machineries and equipments developed at various agricultural universities across the country.





Insect catcher installed in field.
-Traps insects with UV light powered by a solar panel



Water wheel and low cost weed remover
-Interventions in field of water transport in rural areas and weed removing



Centrifugal grain separator
-Works by centrifugal force that separates grains from impurities

Field visit-Understanding farmer behavior

Mahabaleshwar

I also visited Mahabaleshwar and had the opportunity to study irrigation patterns adopted for strawberry cultivation. Mahabaleshwar attracts a lot of tourists especially during winter season. The high altitude of the hill-station provides perfect conditions for strawberry cultivation.

The hill-town alone produces over 85 per cent of the strawberries in the country. It is observed that the sweetness of strawberries is directly proportional to cool climate available in this region. Mahabaleshwar's strawberry season begins around November 15 and lasts till the middle of April. With nearly 2,300 acres under its cultivation, the varieties that reign supreme here are the Californian ones – Sweet Charlie, Camarosa and Winter Dawn, the first accounting for around half the production.

The farmers also tried growing blueberry and blackberry on a commercial scale, but with little success, reiterating that Mahabaleshwar will strictly remain strawberry territory.



Fresh strawberries collected in a tub after harvesting



Farmers adopt mixed farming by cultivating onions along with strawberries. Drip irrigation is followed and fields are covered with polythene sheets to prevent moisture loss. This also makes it easy to harvest while keeping the berries free from dirt and insects.



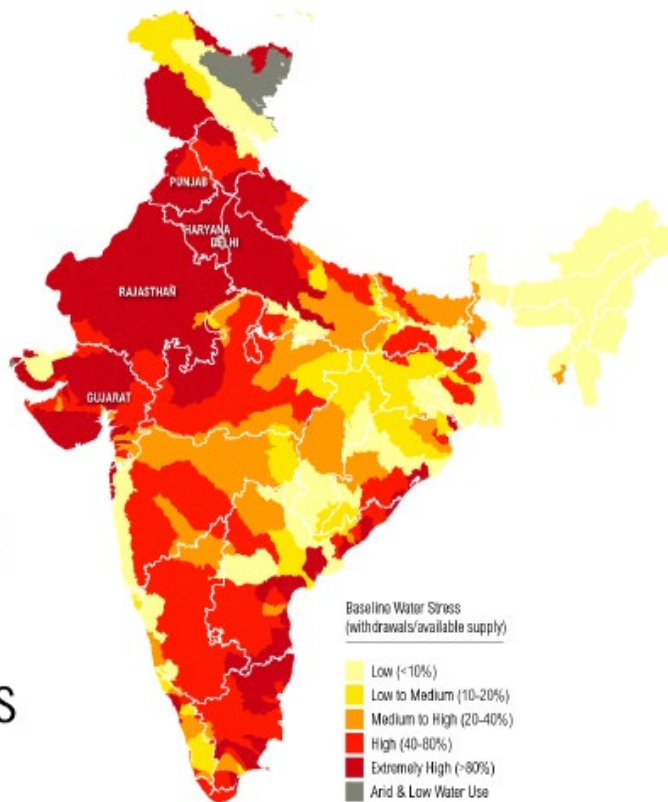
Strawberries have roots just below surface and propagates by runners. Mostly women are involved in cultivating, harvesting and even selling of the strawberries.



Water for drip irrigation is taken from a well nearby and is irrigated twice a week.

Water Distribution in India

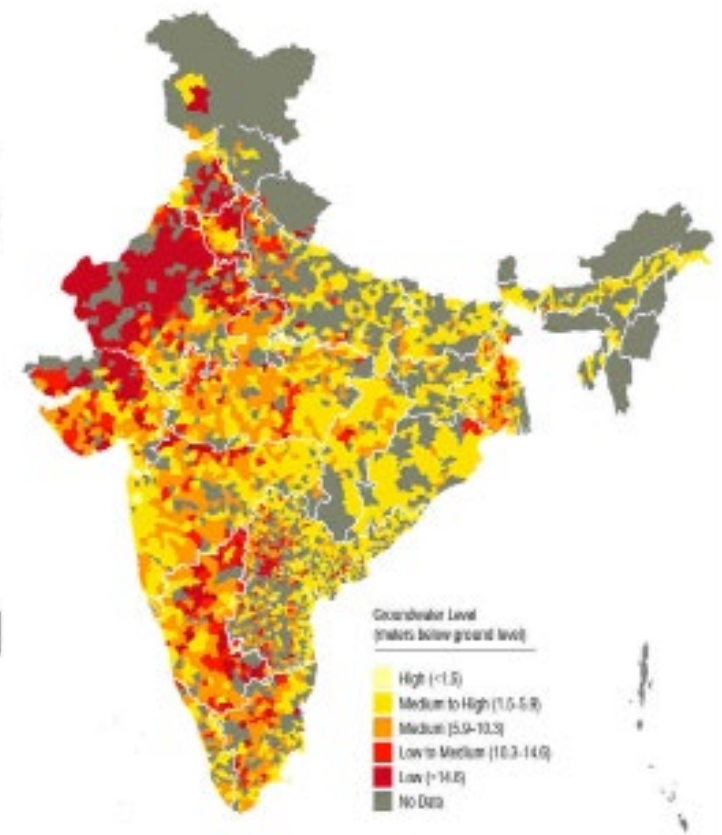
54%
of India
Faces
**High to
Extremely
High**
Water Stress



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54%
of India's
Ground-
water
Wells Are
Decreasing



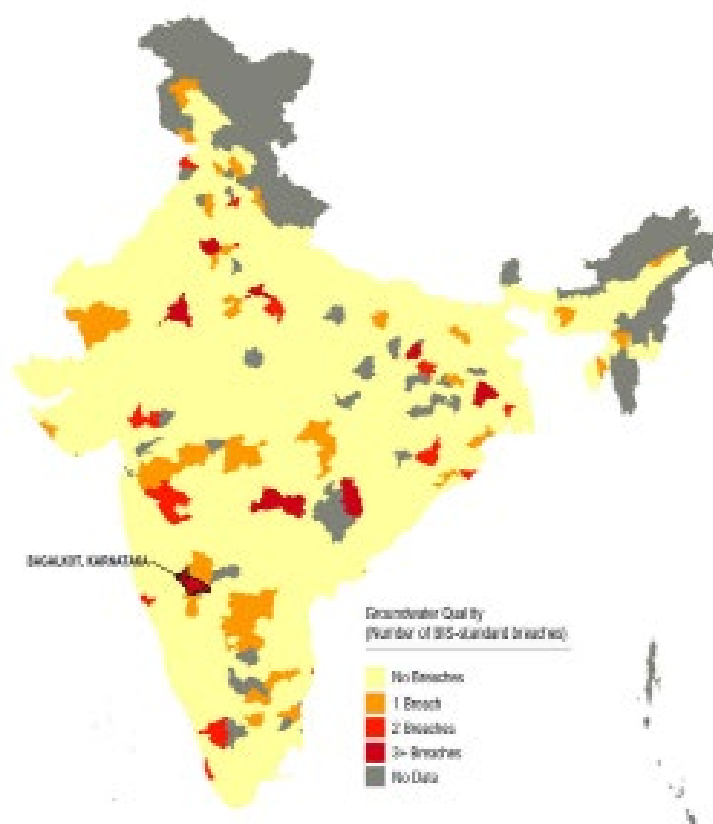
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With 54 percent of India's total area facing high to extremely high stress, almost 600 million people are at higher risk of surface-water supply disruptions.

Groundwater levels are declining across India. Of the 4,000 wells showing statistically significant trends, 54 percent dropped over the past seven years, with 16 percent declining by more than 1 meter (3.2 feet) per year.

More than
100
MILLION
People Live
in Areas of
Poor Water
Quality



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Farmers in arid areas, or areas with irregular rainfall, depend heavily on groundwater for irrigation. The Indian government subsidizes the farmers' electric pumps and places no limits on the volumes of groundwater they extract, creating a widespread pattern of excessive water use and strained electrical grids.

Northwestern India again stands out as highly vulnerable. Of the 550 wells studied in the region, 58 percent have declining groundwater levels.

Among the 632 groundwater quality districts, only 59 are above BIS limits. Whenever a particular pollutant concentration exceeds BIS limits, drinking water is considered unsafe. The yellow and red areas below indicate places where chlorine, fluoride, iron, arsenic, nitrate and/or electrical conductivity exceed national standards.

Methods of irrigation

1. Traditional Irrigation Methods:

- (i) Check Basin Method
- (ii) Furrow Irrigation Method
- (iii) Strip Irrigation Method

(i) Check Basin Method:

In this method, the whole field is divided into basins according to the capacity of water. Basins are connected through a 'Dhora' (A small drain type flow way), which has raised earthen walls on both sides. 'Dhora' is of two types, one is the main 'Dhora' and the other 'Dhora' is connected to basins. Size of basins are made according to the inflow of water.

Advantages:

1. It is the best method of irrigation for leveled fields.
2. It does not require any technical knowledge.
3. This method is more useful in soils having lesser infiltration.
4. In this method, rain water stays in basins, hence soil erosion is not caused.
5. It has lesser economic investment.
6. It irrigates more area.

Disadvantages:

1. Due to seepage in drains, wastage of water is caused.
2. Machines cannot be used in this method because during spray of insecticides or fertilizers, the earthen walls of basins are damaged.
3. Waterlogging.



(ii) Furrow Irrigation Method:

Furrow irrigation method is resorted to where crops are one grown in rows. Along the side of rows of crops, 'Dol' is formed, and in between two such 'Dols', a furrow is formed in which water flows for irrigation. The quantity of flow of water depends on demand of water by plants and the rate of infiltration.

Advantages:

1. Large areas can be irrigated at a time.
2. It saves labour since once the furrow is filled, it is not necessary to give water a second time.
3. It is a comparatively cheaper method.
4. Plants get suitable quantity of water by this method.

Disadvantages:

1. Due to imbalance in flow of water, wastage of water is caused in it.
2. It is not suitable in all types of crops.
3. Making 'Dol' for drains requires more labour information.



(iii) Strip Irrigation Method:

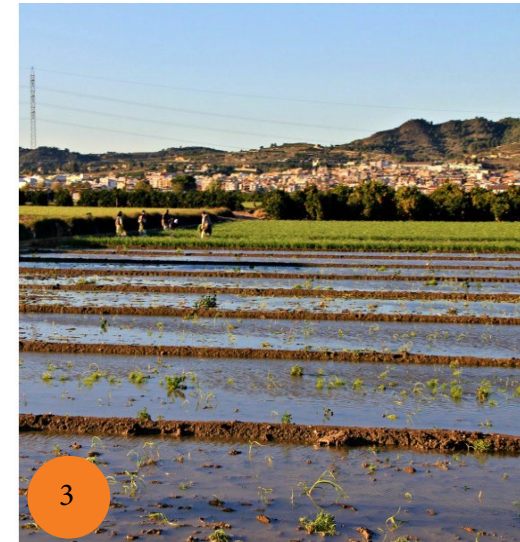
In strip irrigation method, fields are divided into strips of different size. A boundary called 'Med' is formed to separate the strips. These strips are constructed according to the slope. The source of water is situated at the highest place in the field from where the whole field can get the flow of water.

Advantages:

1. It is possible to irrigate more area at a lesser expenditure.
2. It requires less labour.
3. Method of irrigation is easy and it causes lesser erosion.

Disadvantages:

1. It is not suitable for all types of crops.
2. It is not possible to get balanced supply of water.
3. It is not suitable for all soil compositions.



2. Modern Irrigation Methods:

- (i) Sprinkler Irrigation Method
- (ii) Drip Irrigation Method

(i) Sprinkler Irrigation Method:

In sprinkler irrigation method, water is taken from source to the fields through pipes, whereas in surface irrigation methods only 30-45 per cent water reaches the crops. Such loss of water is avoided in sprinkler irrigation method. The problem of water logging which may be caused in case of excess water from surface irrigation, whereas no such problem is caused in sprinkler irrigation method. The balance of groundwater is also maintained.

Advantages:

1. There is increase in production and compactness.
2. Sprinkler system is considered more suitable in areas where slit is coagulated on surface of soil after rains, prevents growth of crop.
3. This system saves the crop from extreme frost or temperature.
5. Fertilizer application as well as insecticide spray can be done by sprinkle system.
6. Waste land can be improved by less water. Physical condition and composition of soil can be maintained in a balanced condition.

Disadvantages:

1. Sprinkler irrigation method is expensive.
2. It requires technical knowledge.
3. Sprinkler irrigation method cannot be used in all crops.
4. Crop is damaged by changing sprinkler system again and again.
5. Water to be used in sprinkler method should be clean.



Drip Irrigation:

A newly developed irrigation system known as drip irrigation or trickle irrigation, originally developed in Israel, is becoming popular in areas of water scarcity. In this irrigation system, a small amount of water is applied at frequent intervals in the form of water droplets through perforations in plastic pipes or through nozzles attached to tubes spread over the soil to irrigate a limited area around the plant.

A precise amount of water equal to the daily consumptive use or the depleted soil water needs to be applied. The soil water can be maintained at the field capacity during the crop growing period. Deep percolation losses can be completely prevented and the evaporation loss is also reduced.

The basic equipment for drip irrigation consists of a water supply head, a main pipe, lateral pipes and dippers. The water flow in the pipe system is controlled with control valves and fertilizers can be applied at the water source. As water passes through the very small outlets of dippers, it is filtered before it is distributed in the pipe system.



Advantages:

1. In this method, water directly reaches the roots of the plants, which take water to plants in balanced quantities.
2. Drip irrigation method saves 30 to 70 per cent water and it is possible to irrigate three times more area with the same amount of water.
3. In this method, weeds do not spread because water reaches only near plants and does not spread in the whole field.
4. Fertilizers and insecticides can also reach the plant directly by solution in the water and it saves 30 to 60 per cent chemical fertilizers as well as 40 to 50 per cent pesticides along with saving of water.
5. Even in case of uneven lands, drip irrigation method can do balanced irrigation.
6. Cultivation in saline and alkaline soil also can be done by this method of irrigation.
7. Crop production is higher by 20 to 40 per cent in drip irrigation method, because plants can get air and water in required quantities, resulting in regular growth of crops.
8. Lesser labourers are required for irrigation work.
9. Bacteria causing diseases in crops do not grow because of dry atmosphere near plants.

Disadvantages:

1. Drip irrigation method is expensive.
2. It requires special technical knowledge for successful operation of this method.
3. In heavy soils, it creates problems of flow and water blockages.
4. Plants are able to get nutritive elements in a very limited area.
5. It is not suitable for every crop.
6. Utmost care has to be taken for holes of drippers, because soil may come along with water at any time, which will prevent water dripping smoothing from holes.

Methods of soil moisture measurement

By measuring soil moisture at regular interval and at several depths within the root zones, information can be obtained as to the rate at which moisture is being used by the crops at different depths. This provides the base for determining when to irrigate and how much water to be applied.

For practical purpose, irrigation should be given when about 50 percent of available moisture in the root zone is depleted. The amount of water to be applied is directly related to the water already present in the soil. The methods of measuring soil moisture are divided in to:

A) **Direct method:** Measurement of moisture content in the soil (wetness)

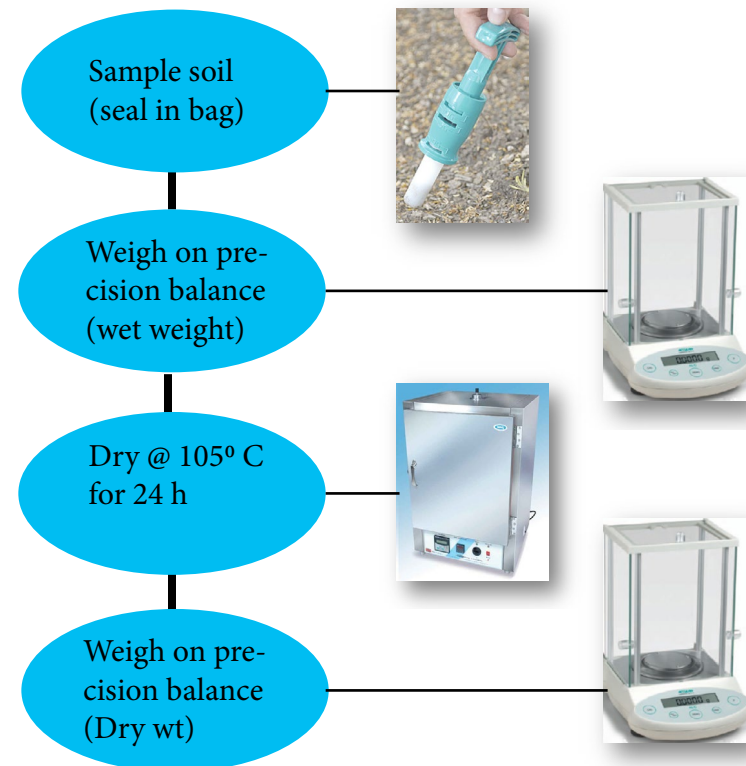
B) **Indirect methods:** Measurement of water potential or stress or tension under which water is held by the soil.

I) Gravimetric methods:

In the gravimetric method, basic measurement of soil moisture is made on soil samples of known weight or volume. Soil sample from the desired depths are collected with a soil auger. Soil sample are taken from desired depth at several locations of each soil type. They are collected in air tight aluminum containers. The soil samples are weighed and they are dried in an oven at 105°C for about 24 hours until all the moisture is driven off. After removing from oven, they are cooled slowly to room temperature and weighed

again. The difference in weight is amount of moisture in the soil. The moisture content in the soil is calculated by the following formula:-

$$\text{Moisture content On weight basis} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight}} \times 100$$



II) Volumetric Method:

Soil sample is taken with a core sampler or with a tube auger whose volume is known. The amount of water present in soil sample is estimated by drying it in the oven and calculating by following formula.

Moisture content = Moisture content (%) by weight x Bulk Density (%) by volume.

The method is though accurate and simple it is used mainly for experimental purpose. Sampling, transporting & repeated weighing give errors. It is also laborious and time consuming. The errors of the gravimetric method can be reduced by increasing the size and number of samples. However the sampling disturbs the experimental plots and hence many workers prefer indirect methods.

III) Using Methyl Alcohol: Soil sample is mixed with a known volume of methyl alcohol and then measure the change in specific gravity of soil with a hydrometer. This is a shot cut procedure but it is no in common use.

IV) Using calcium chloride: Soil sample is mixed with a known amount of calcium chloride. Calcium chloride reacts with water and removes it in the form of acetylene gas. The moisture is determined has come in common use.

B) Indirect methods:

In those methods, no water content in the soil is directly measured but the water potential or stress or tension under which the water is held by the soil is measured. The most common instrument used for estimating soil moisture by indirect method is:

- 1) **Tensiometer**
- 2) **Gypsum block**
- 3) **Granular Matrix Sensor**
- 4) **Neutron meter**
- 5) **Dielectric sensors**
- 6) **Dual-needle heat pulse**

In all these methods, the reading from above instruments and corresponding soil moisture content is determined by oven drying method are plotted on a graph. Subsequently, these calibration curves are used to know soil moisture content from the reading of these instruments.

1) Tensiometer:

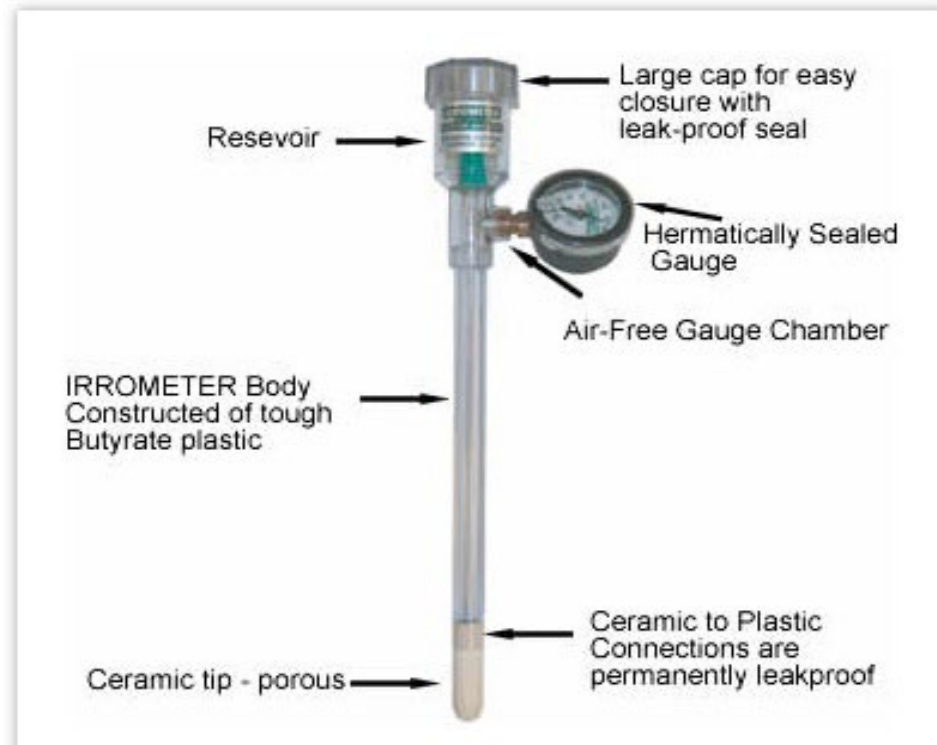
Tensiometer is also called irrometers since they are used in irrigation scheduling. Tensionmeters provide a direct measure of tenacity (tension) with which water is held by soil. It consist of 7.5 cm porous ceramic or clay cup, a protective metallic tube, a vacuum gauge and a hollow metallic tube holding all parts together. At the time of installation, the system is filled with water from the opening at the top and rubber corked when set up in the soil. Moisture from cup moves out with drying of soil, creating a vacuum in the tube which is measured with the gauge. Care should be taken to install tensiometer in the active root zone of the crop. When desired tension is reached, the soil is irrigated. The vacuum gauge is graduated to indicate tension values up to one atmosphere and is divided in to fifty divisions each of 0.2 atmosphere value. The tensiometer works satisfactory up to 0.85 bars of atmosphere.

Merits of tensiometer:

1. It is very simple and easy to read soil moisture in situ.
2. It is very useful instrument for scheduling irrigation to crops which require frequent irrigations at low tension.

Limitations:

Sensitivity of a tensiometer is only up to 0.85 atmospheres while available soil moisture range is up to atmosphere and hence is useful more on sandy soils wherein about 80% of available water is held within 0.85 ranges.



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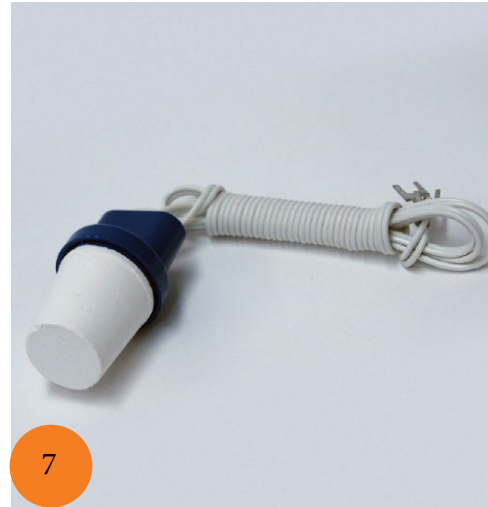
2) Gypsum Blocks:

Gypsum blocks or plaster of Paris resistance units are used for measurement of soil moisture in situ. These were first invented by Bouycos and Mick (1965). The blocks are made of various materials like gypsum, nylon fiber, glass, plaster of Paris or combination of these materials. The blocks are generally rectangular shaped. A pair or electronics is usually made of 20 mesh stainless steel wire screen soldered to copper lead wire. The common dimensions of screen electrodes are 33.75 cm long and 0.25 cm wide. The usual spacing between the electrodes is 2 cm. A similar block is 5.5 cm long, 3.75 cm wide and 2 cm thick.

Principal of working: It works on principal of conductance of electricity. When two electrodes A and B are placed parallel to each other in a medium and then electric current is passed, the resistance to the flow of electricity is proportional to the moisture content in the medium. Thus, when the block is wet, conductivity is high and resistance is low. Generally these read about 400 to 600 ohms resistance at field capacity and 50,000 at wilting point. the readings are taken with portable Wheatstone Bridge Bouycos water Bridge operated by dry cells.

While placing the gypsum block in soil, care should be taken that the blocks must have close contact with undisturbed soil. After placing, the blocks get wetted with soil moisture due to capillary movement. Pure gypsum block sets in about 30 minutes. The gypsum block is sensitive to soil to moisture from 1.0 atm tension to 20.0 atm. How ever, the gypsum blocks are not reliable in wet soils.

*modern gypsum
block soil moisture*



3) Granular Matrix Sensor:

A Granular matrix sensor for electronically measuring soil water has been patented (Larson, 1985; Hawkins, 1993) and is marketed as the Watermark soil moisture sensor (Irrometer Co., Riverside, CA). Granular matrix sensor technology reduces the problems inherent in gypsum blocks (i.e., loss of contact with the soil by dissolving, and inconsistent pore size distribution) by use of a granular matrix confined in a metal case. Granular matrix sensors operate on the same electrical resistance principle as gypsum blocks and contain a wafer of gypsum embedded in the granular matrix. The electrodes inside the GMS are embedded in the granular fill material above the gypsum wafer. The gypsum wafer slowly dissolves, to buffer the effect of salinity of the soil solution on electrical resistance between the electrodes. According to Larson (1985), particle size of the granular fill material and its compression determines the pore size distribution in GMS and their response characteristics.

As plants use water from the soil, the soil dries and water is drawn out of the sensor, sensor resistance increases. Upon irrigation or rainfall, the GMS takes up water and the resistance decreases.



*Granular matrix
sensor*

4) Neutron meter (neutron scattering method):

Soil moisture can be estimated quickly and continuously another with neutron moisture meter without disturbing the soil. Another advantage is that soil moisture can be estimated from large volume of soil. This meter scans the soil to about 15 cm. diameter around the neutron probe in wet soil and 50 cm in dry soil. it consists of a probe and a scalar or rate meter. The probe contains fast neutron source, which may be a mixture of radium and beryllium or Americium and beryllium. Access tubes are aluminum tubes of 50 to 100 cm length and are placed in the field where moisture to be estimated.

Neutron probe is lowered into access tube to the desired depth. Fast neutrons are released from the probes, which scatter into the soil. When neutrons encounter nuclei of hydrogen atom of water, their speed is reduced.

The scalar or the rate meter counts the number of slow neutrons, which are directly proportional to water molecules. Moisture content of soil can be known from the calibration curve with counts of slow neutrons.

Limitations:

The two drawbacks of the instruments are that it is expensive and moisture content from shallow top layers cannot be estimated. The fast neutrons are also slowed down by other source of hydrogen (present in the organic matter). Other atoms such as chlorine, boron and iron also slow down the fast neutrons, thus overestimating the soil moisture content.



9



5) Dielectric sensors

Dielectric sensors are of two types

- Time domain reflectometry (TDR)
- Frequency domain reflectometry (FDR)

Time domain reflectometry (TDR) sensors:

TDR soil moisture measurement devices require a device to generate the electronic pulse and need to be carefully calibrated in order to precisely measure the amount of time it takes for the pulse to propagate down the line and back again. They are also sensitive to the saline content of salt and relatively expensive compared to some measurement methods. However, TDR devices do respond quickly to varying soil moisture.

Advantages

- Calibration is relatively insensitive to textural difference
- Output wave provides electrical conductivity information
- Good accuracy
- Insensitive to salinity changes when EC is low to moderate.

Disadvantages

- Expensive
- Does not work at high EC (trace will flatten)
- Requires waveform analysis (comes with most packages)
- Sensitive to gaps in soil contact



10

Frequency Domain Reflectometry (FDR) Sensors:

There are many soil moisture probes on the market today that use the Frequency Domain Reflectometry method (FDR) of soil measurement. This method of measurement also uses an oscillator to propagate an electromagnetic signal through a metal tine or other wave guide, but with this method, the difference between the output wave and the return wave frequency is measured to determine soil moisture. Frequency Domain Reflectometry (FDR) probes are considered accurate but must be calibrated for the type of soil they will be buried in. They offer a faster response time compared to Time Domain Reflectometer (TDR) probes and can be connected to a standard data logger to collect readings. Electromagnetic (EM) field is produced between the positive and negative plates

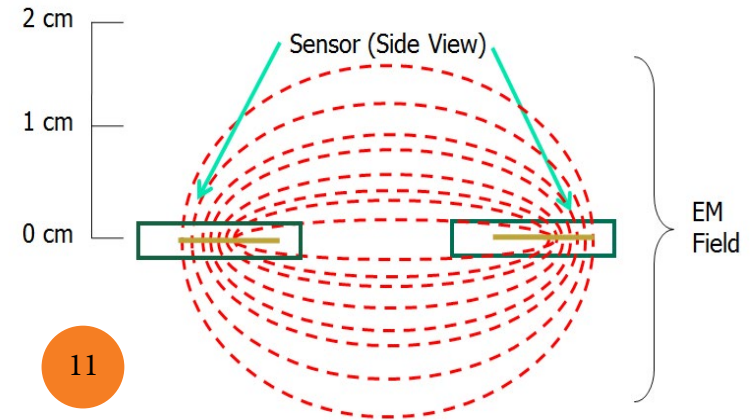
Charging of capacitor directly related to dielectric. Sensor circuitry converts capacitor charge to an output of voltage or current. Sensor output is calibrated to water content using the direct volumetric water content method discussed earlier

Advantages

- Lower cost
- Easy to install/use
- Best resolution to changes in water content of any method
- Resolve changes of 0.00001 m³ m⁻³
- Low Power

Disadvantages

- Some probes are sensitive to soil texture and temperature fluctuations
- Depends on probe measurement frequency
- Some require down-hole installation
- Sensitive to air gaps in soil contact



6) Dual-needle heat pulse

It works by reading changes in heat capacity of soil with respect to linear function of water content. Reading is taken by creating calibration that relates VWC to heat capacity.

Measurement is taken by using dual needle probe. One needle contains a heater, the other a temperature measuring device. Heat one needle and record temperature over time on the other. Uses maximum temperature rise (ΔT) to calculate heat capacity and convert to VWC

Advantages

- Small measurement volume
- Most location-specific method available
- Can measure water content around growing seed

Disadvantages

- Requires data logger with precise temperature measurement and analysis
- Can be susceptible to temperature gradients in soil (time and depth)
- Integrates small soil volume
- Fragile

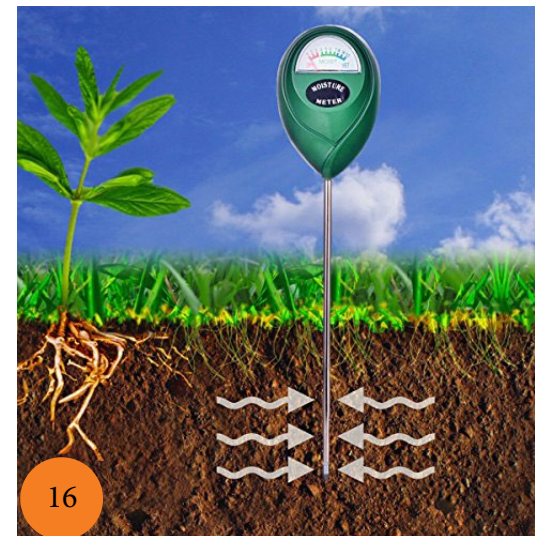
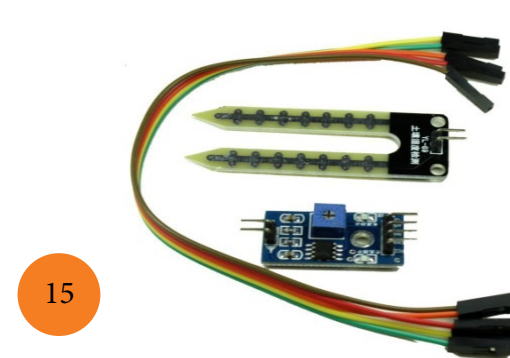


Scenario in India

Most Indian farmers determine soil moisture condition by Feel and Appearance method. A practical estimate of moisture content is obtained by the feel and appearance of soil samples taken from the desired depths. This is a skill based on previous experiences, knowledge and practices. The soil sample is squeezed in the hand and its feel and appearance are taken into consideration. In this method, actual moisture content is not determined.

It is of prime importance that the product has to be cheap and affordable to farmers. Only a few humidity sensors are available in Indian market and that too in low cost. Lack of information is another reason for less popularity of moisture sensors among farmers in India.

There are cheap Arduino based soil moisture sensors available Online. These are **Frequency Domain Reflectometry (FDR)** based and require proper knowledge to assemble and install.



Sensor requirements and soil characteristics

A soil moisture sensor measures the level of moisture present in the soil and helps farmers decide irrigate the crop with the right amount of water required for a specific crop.

Studies have shown that a properly configured soil moisture sensor can reduce outdoor water use by up to 62 percent or more over traditional irrigation methods. By watering your plants when needed, farmer can increase landscape health, promote deeper root growth, and make plants more disease resistant.

What does it take to make a great soil moisture sensor?

-Sensitivity

Sensitivity is the sensor's ability to monitor small changes in soil moisture content. Sensitivity is very important in light soil such as sand or engineered soils.

-Repeatability

Repeatability refers to how well the sensor can report the same value when measuring the same moisture content. You cannot have repeatability without sensitivity.

-Accuracy

Accuracy is sometimes used to describe sensitivity and repeatability; however, it can also describe the sensor's ability to report true volumetric moisture content (VMC).

-Durability

Durability or reliability is arguably the most important factor in a commercially used soil moisture sensor.

Understanding Soil Moisture Content Levels

Saturation: At the saturation level, nearly all of the spaces between soil particles are filled with water. After a soil has reached saturation, it does not become more saturated; although, in some situations where water is trapped, it can become flooded. However, at the saturation level, gravity pulls water downward through the soil more rapidly.

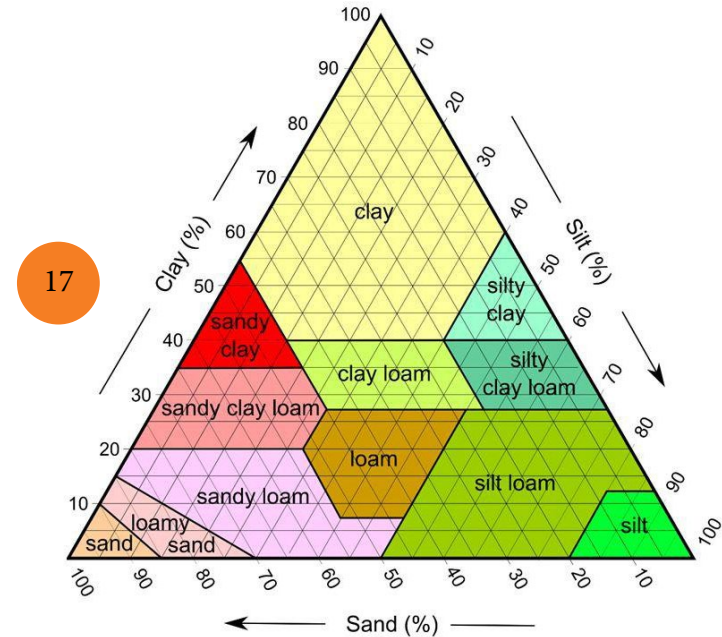
Field Capacity: When soil is at the field capacity level, it means that all excess moisture has drained freely from that soil. The amount of remaining moisture is the field capacity. Imagine dipping a sponge in a bucket and allowing it to soak up water (it becomes saturated). When you pull the sponge from the bucket, water drips freely. When the dripping stops, the sponge has reached field capacity. To irrigate properly, you would turn off the water when the soil in the root zone of the plants reaches field capacity.

Maximum Allowed Depletion (MAD): When the soil moisture content reaches this level, irrigation needs to start. In most cases, the maximum allowed depletion level is just before the plants begin to show visible signs of stress.

Permanent Wilting Point: At the permanent wilting point, the level of water in the soil is not sufficient to meet the plant's needs. This term is of little importance to most landscape irrigators unless you are considering a true high deficit irrigation strategy.

Oven Dry: When soil is dried in an oven, nearly all water is removed. This moisture content level is used to provide a reference for measuring and reporting volumetric soil moisture content (VMC). VMC is the most common way to communicate a soil moisture point. If you dig up a volume of soil, weigh it, then cook it until it's dry, and then weigh it again, the VMC is the percent of change in weight.

Table shows water holding capacity of various types of soil in soil pyramid.



Texture	Silt	Clay	$W_{1.5}$ (kg/kg)	W_{ad} (kg/kg)
Sand	0.05	0.03	0.008	0.003
Loamy sand	0.12	0.07	0.015	0.005
Sandy loam	0.25	0.10	0.045	0.015
Sandy clay loam	0.13	0.27	0.143	0.048
Loam	0.40	0.18	0.106	0.035
Sandy clay	0.07	0.40	0.204	0.068
Silt loam	0.65	0.15	0.098	0.033
Silt	0.87	0.07	0.075	0.025
Clay loam	0.34	0.34	0.174	0.058
Silty clay loam	0.58	0.33	0.166	0.055
Silty clay	0.45	0.45	0.204	0.068
Clay	0.20	0.60	0.234	0.078

Table 1 Representative silt and clay fractions, and – 1.5 MPa and air-dry water contents for the 12 soil texture classes.

Current Research -Sensor developed at IIT Bombay

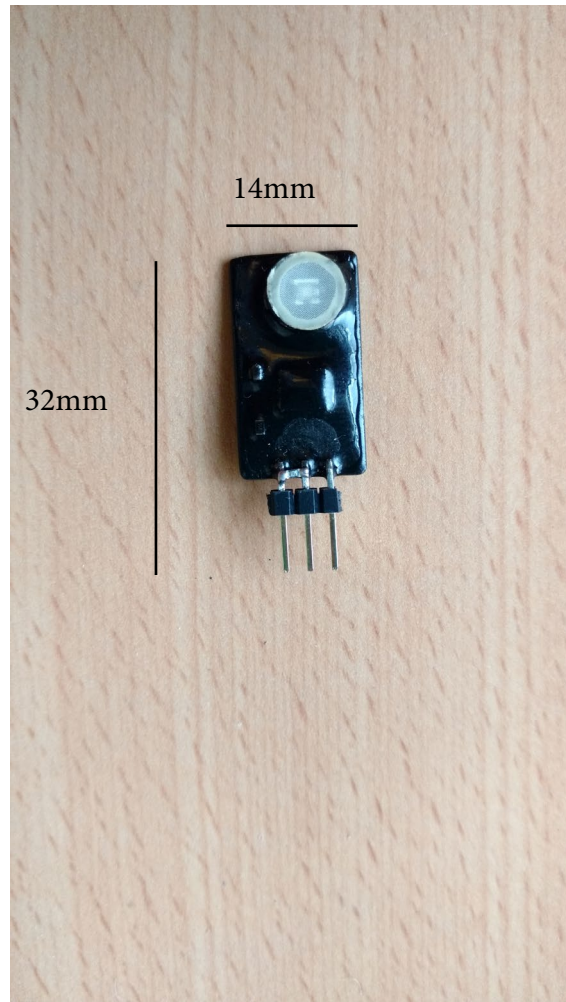
An advanced version of a compact moisture sensor was designed and developed at electrical department of IIT Bombay by Mrs. Rajul S Patkar under her Phd. Thesis “Low cost piezoresistive cantilever platforms for agricultural applications”. The technology is patent pending and this has put forward great opportunity to develop low cost moisture sensor for small and medium scale farmers across the country.

The sensor is waterproof and responds fast which helps in easy measurement of moisture/humidity.

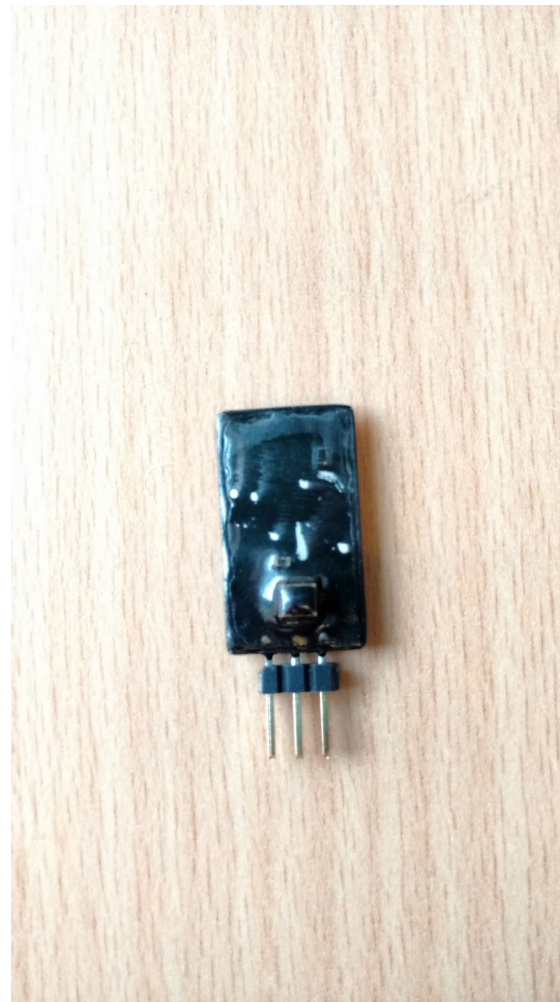
- (a) Soil moisture system prototype version(2),
- (b) humidity sensor
- (c) sensor module (soil moisture and soil temperature)



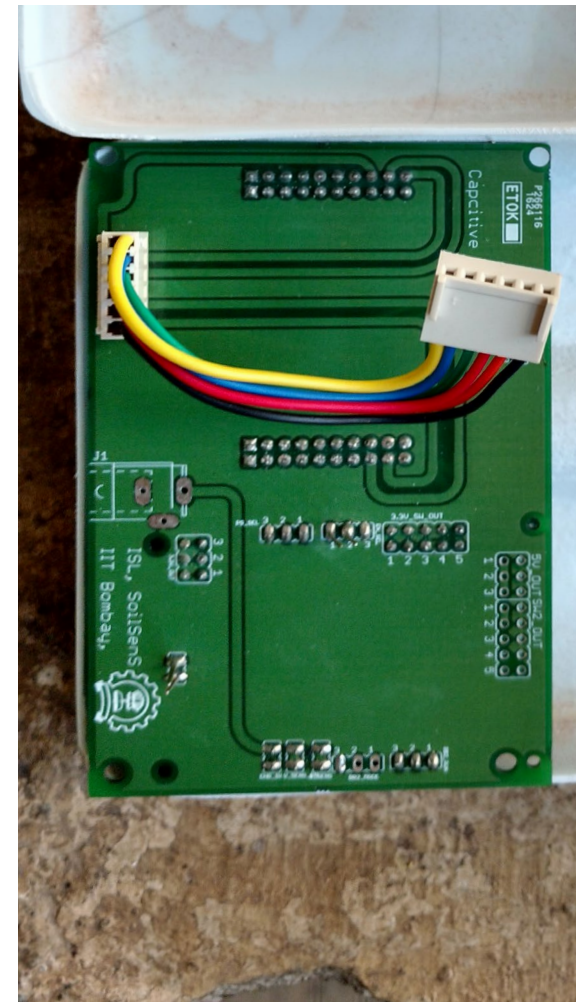
(d) Packaged soil moisture sensor



Final design of sensor-front
Sensor thickness-5mm



Final design of sensor-back



Internal PCB of control unit
Dimension-10.6*7*4cm



02 Objective and design brief

Objective

The objective of the project is to design a soil moisture measuring equipment based on the proposed sensor technology developed at electrical department of IIT Bombay. The project is aimed to benefit small scale farmers and will prevent excessive wastage of water as the equipment helps determine moisture content of soil and thereby suggests farmers to irrigate conservatively.

Design Brief

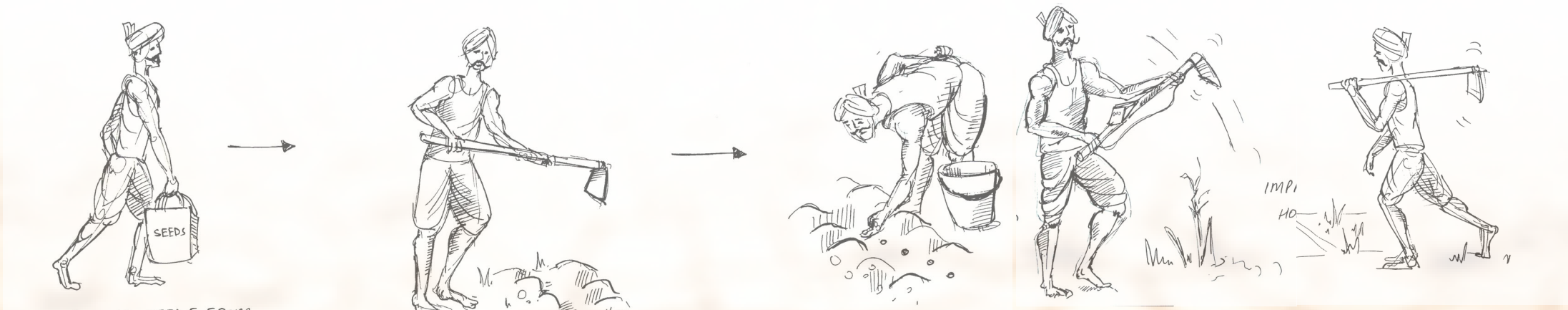
To design and develop an equipment which detects the moisture content in the soil. The product will typically benefit a small scale farmer such that it helps him/her determine the water requirement for various crops cultivated in different soil types. While keeping the following constraints in mind

-Cost : The estimated cost of product should not exceed 1000/Rs(selling price)

-Portable unit : The unit should be portable and easy to handle that indicates moisture levels at different locations in the field randomly

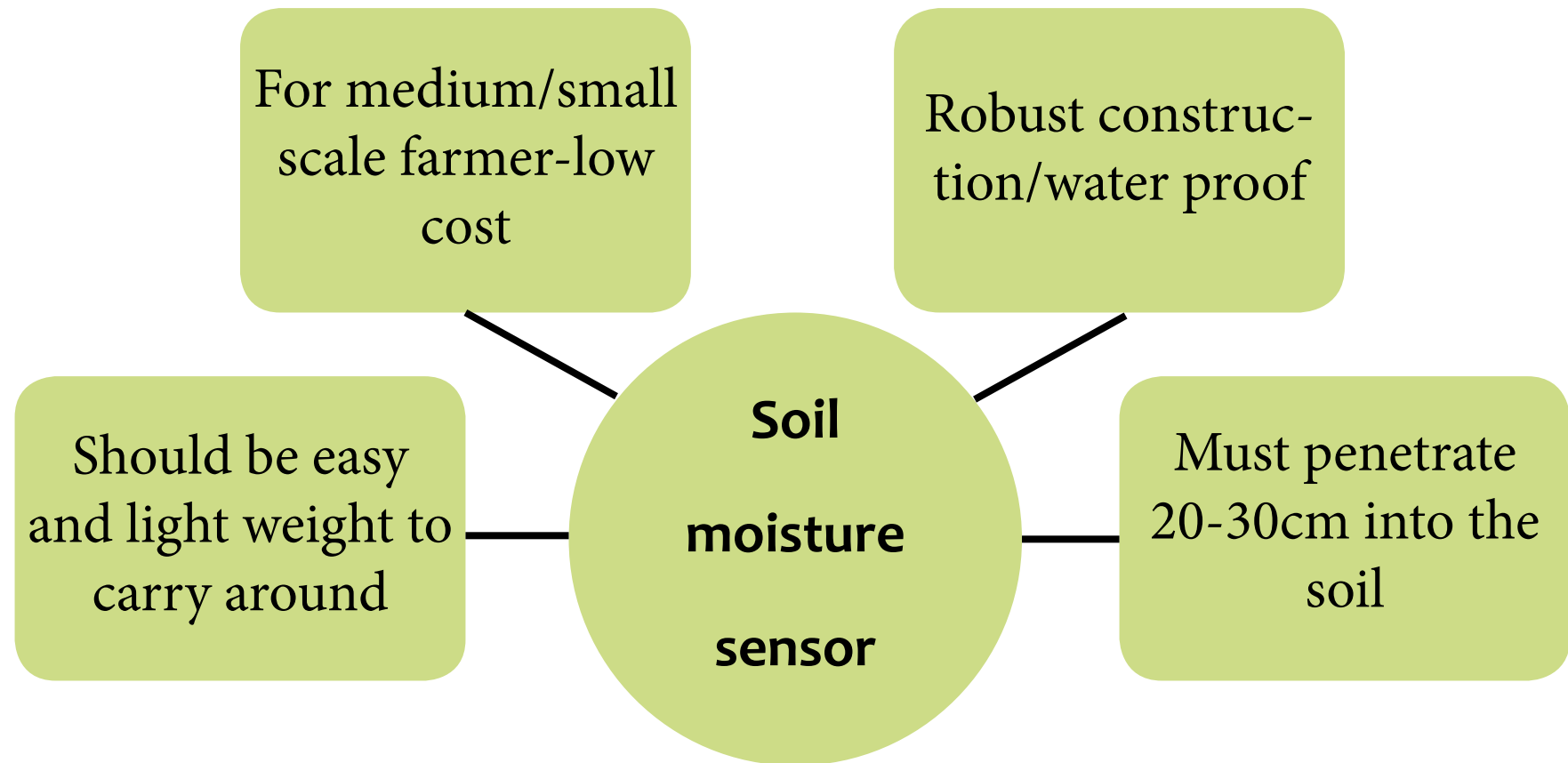
-Feedback : The unit indicates five levels of moisture content that can be customized depending on type of soil and crop

-Deployment : The deployment should be such that the sensor is well protected and does not come in direct contact with soil



03 Ideation and Brainstorming

Priorities in Consideration



Major considerations to be taken care while designing includes:

Light weight and easy use:

The device will need to be used multiple times at different areas in the field. Hence it is essential that the product should be easy to use and light weight while considering ergonomic possibilities.

Cost:

The cost of product is expected not to exceed Rs.500 as it is aimed to benefit small and medium scale farmers.

Robust construction/water proof:

The product will be exposed to outdoor conditions and might come in contact with water from sprinkles. Hence waterproofing is essential. IP 54 (ingress protection from dust and water proofing for water sprays from all direction) is taken into consideration.

Must penetrate 20-30cm into the soil:

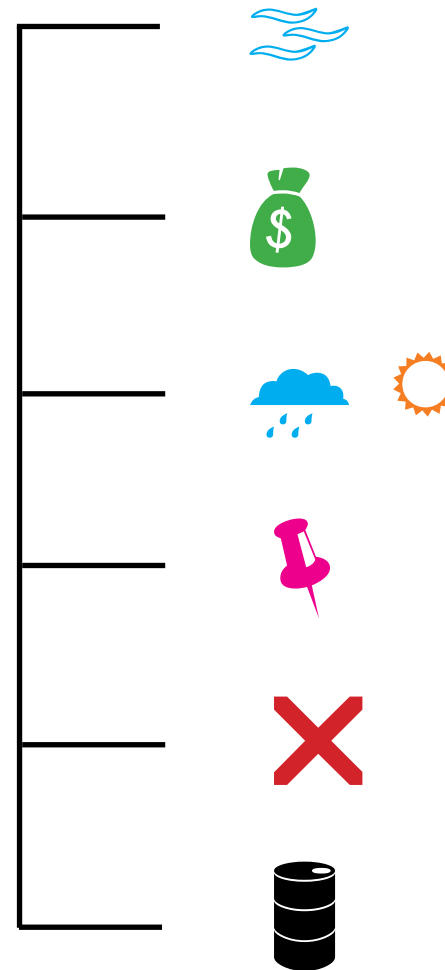
The sensor is attached to the tip and it should have a provision of taking soil moisture content up to 30cm depth.

Sensor should not come in direct contact with soil:

The sensor tip does not require to come in direct contact with the soil. That means the sensor is not directly exposed. This is crucial for longer life of sensor.

Modular construction:

Another important factor is modularity of parts which helps in easy replacement once sensor/body is damaged.



Activity analysis -Farming



BUYING SEEDS FROM
KRISHI KENDRAS
(STORED SEEDS)



PLOUGHING AND SETTING
OF SEEDS



SOWING OF SEEDS



Going to field



Ploughing with hoe

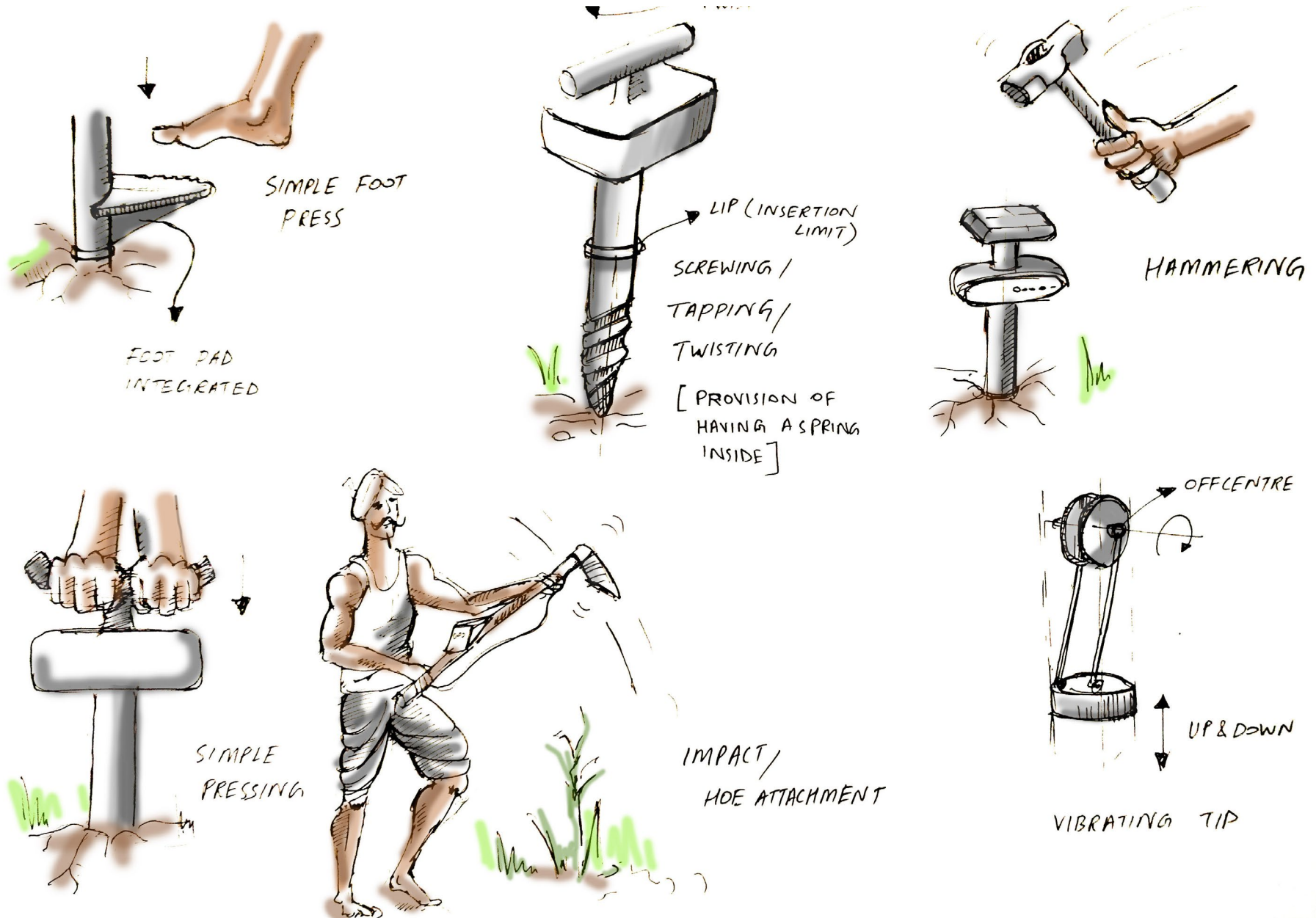


Removing weeds

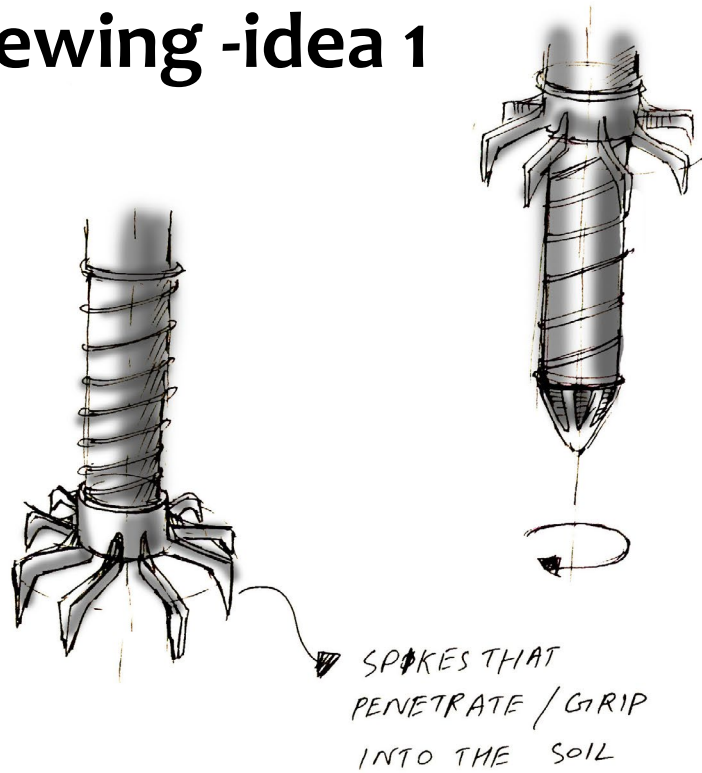


Watering

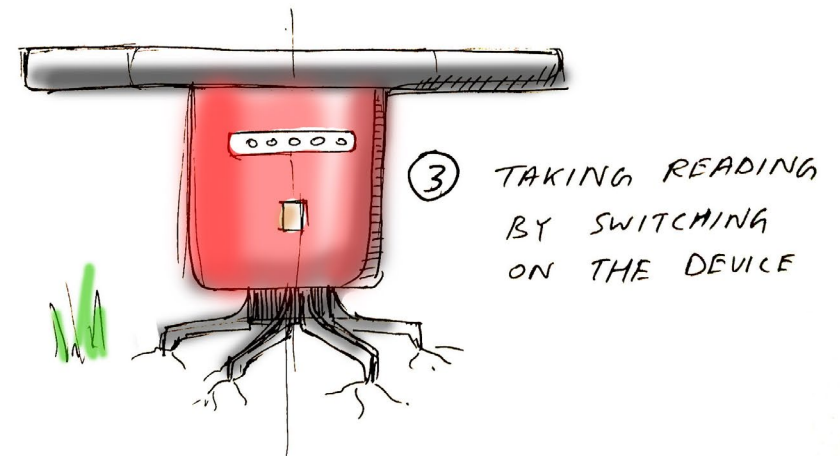
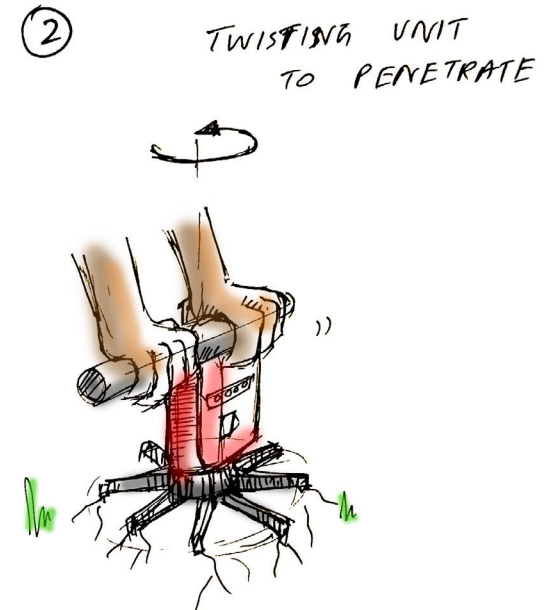
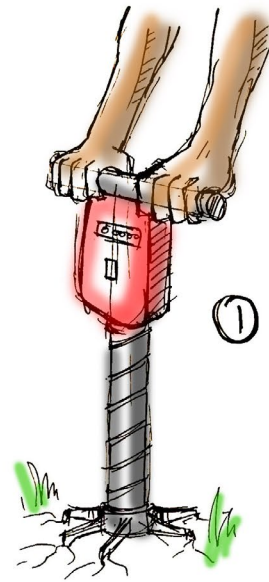
Methods of penetration into the soil



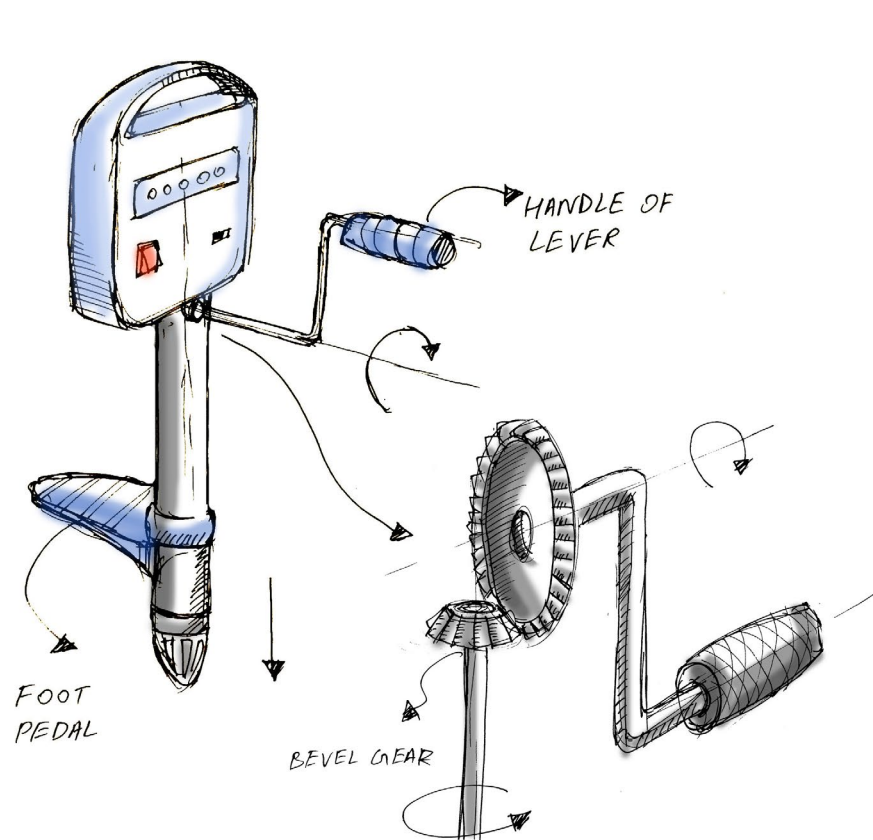
Screwing -idea 1



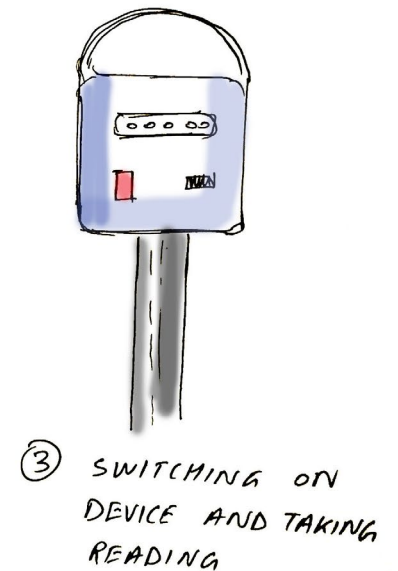
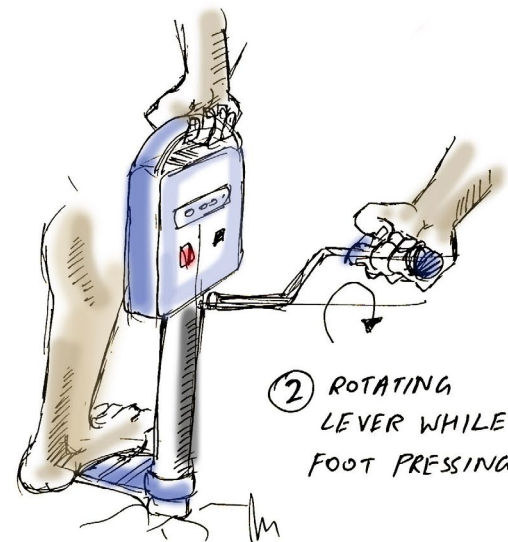
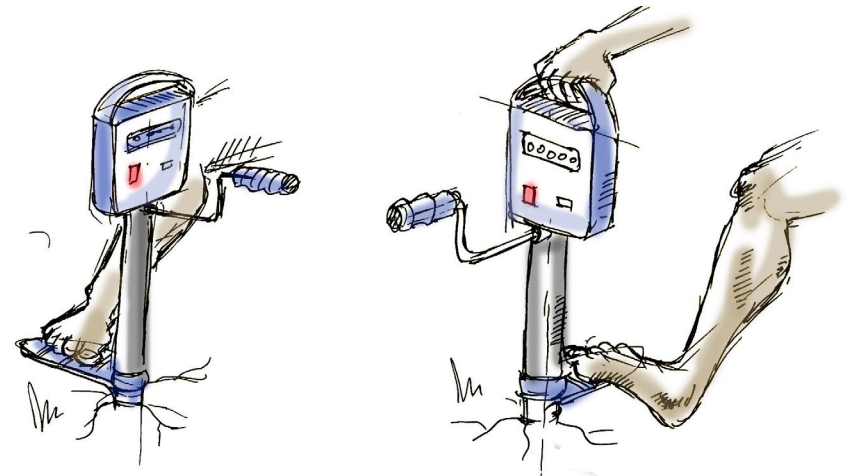
Claws resembling spider legs grip the unit which is then screwed down by twisting the handle in clockwise direction. The external screw thread keeps claws stationary as the unit screws itself down until the desired depth is achieved. The unit is switched on and reading is taken.



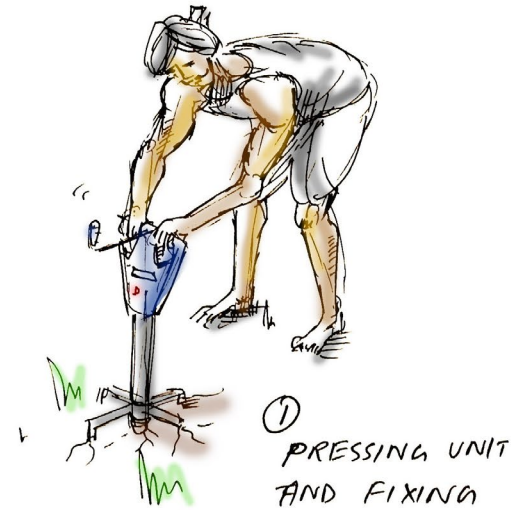
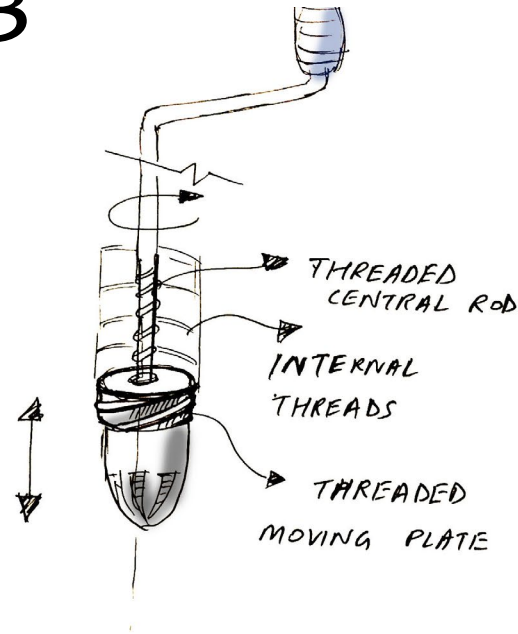
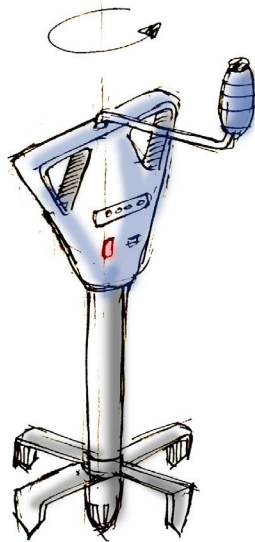
Screwing -idea 2



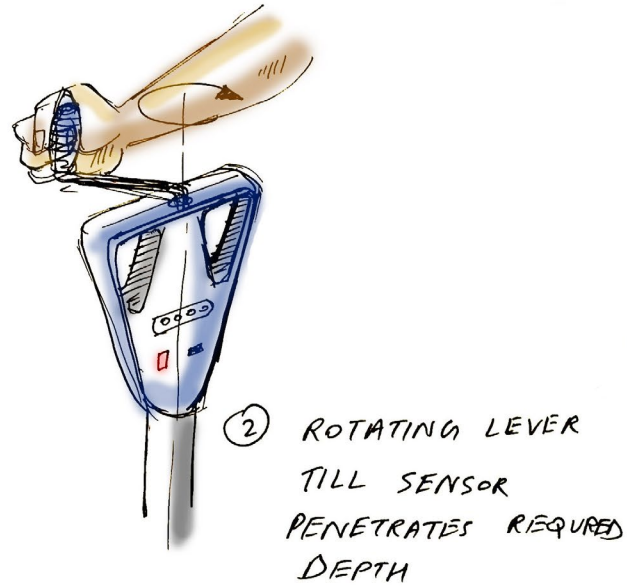
The bevel gear assembly helps in achieving twist motion of the pointed tip. Force is applied at the top handle as well as the foot pedal which makes it easy to achieve the desired depth. The sensor is fixed at the tip and is enclosed in a mesh to prevent soil from entering.



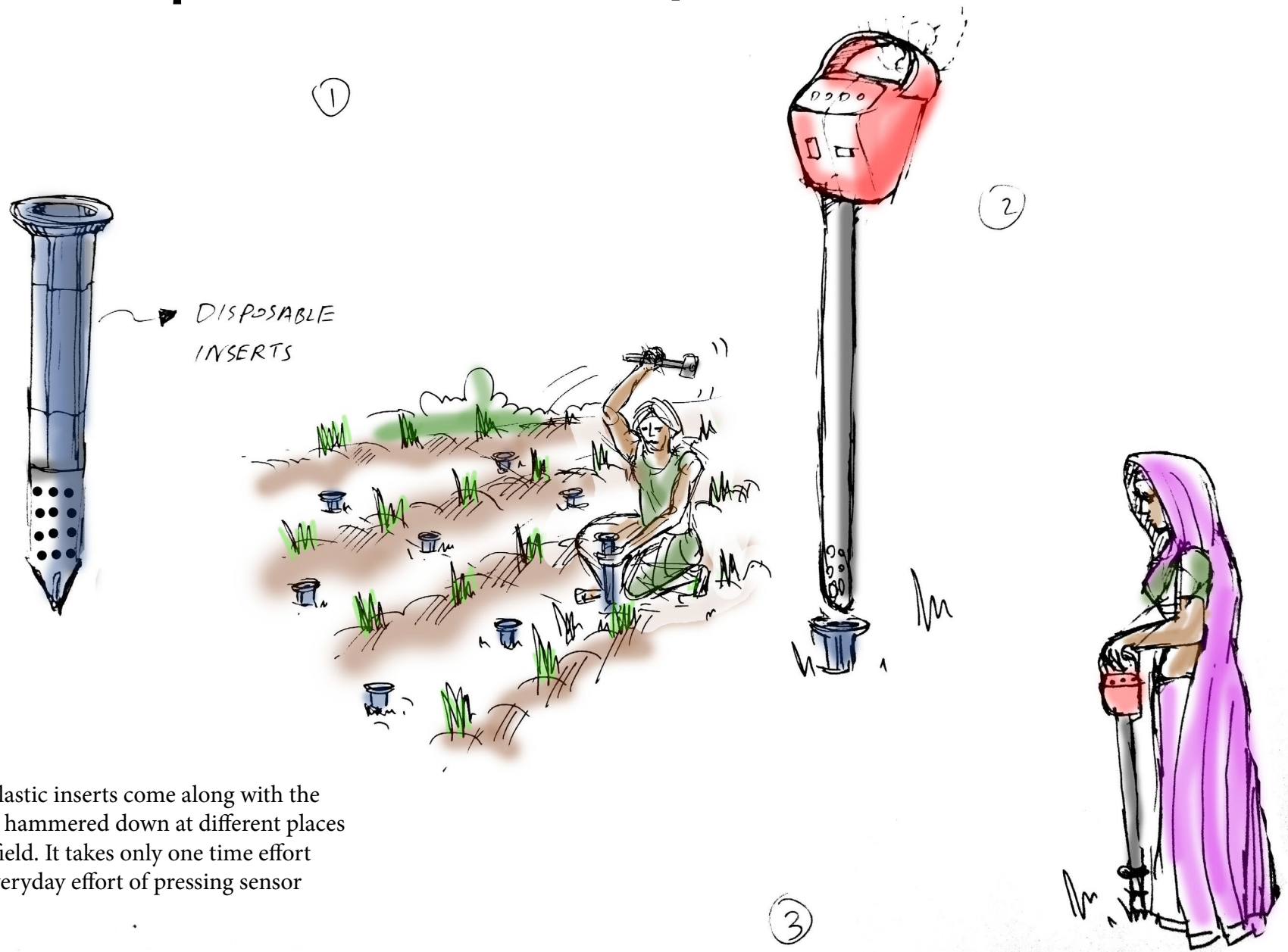
Screwing -idea 3



The unit has a fixed claw that grips the soil. Once fixed, the user steps over the claws and the lever is rotated. The plunger as well as the tube is threaded internally which allows the tip to extend while keeping the unit in place. Once the desired depth is achieved, the unit is switched on and reading is taken.

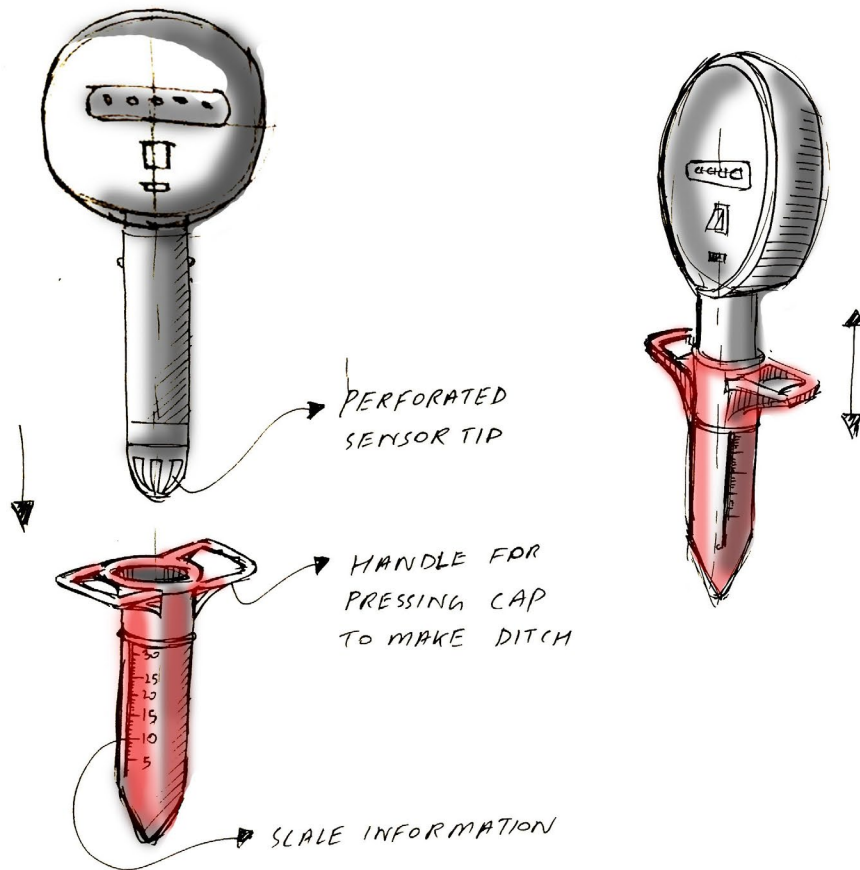


Disposable plastic insert -Idea 4

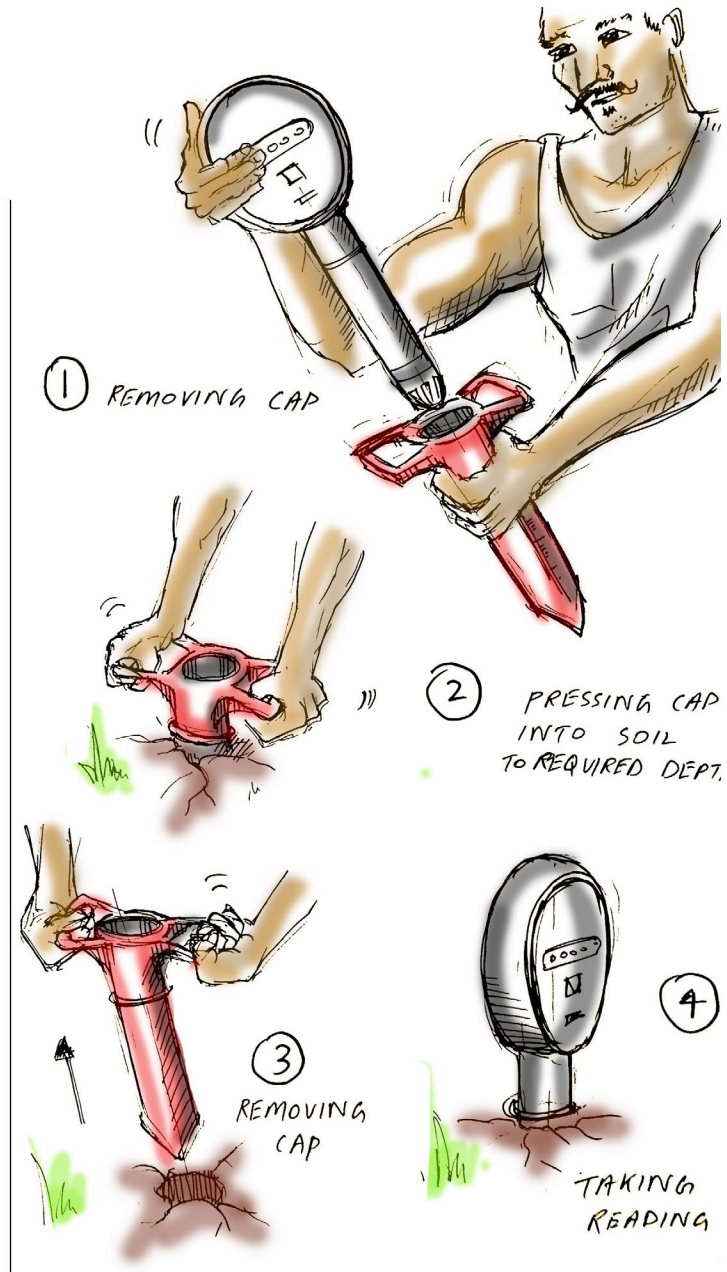


Disposable plastic inserts come along with the kit which are hammered down at different places (grid) in the field. It takes only one time effort instead of everyday effort of pressing sensor down

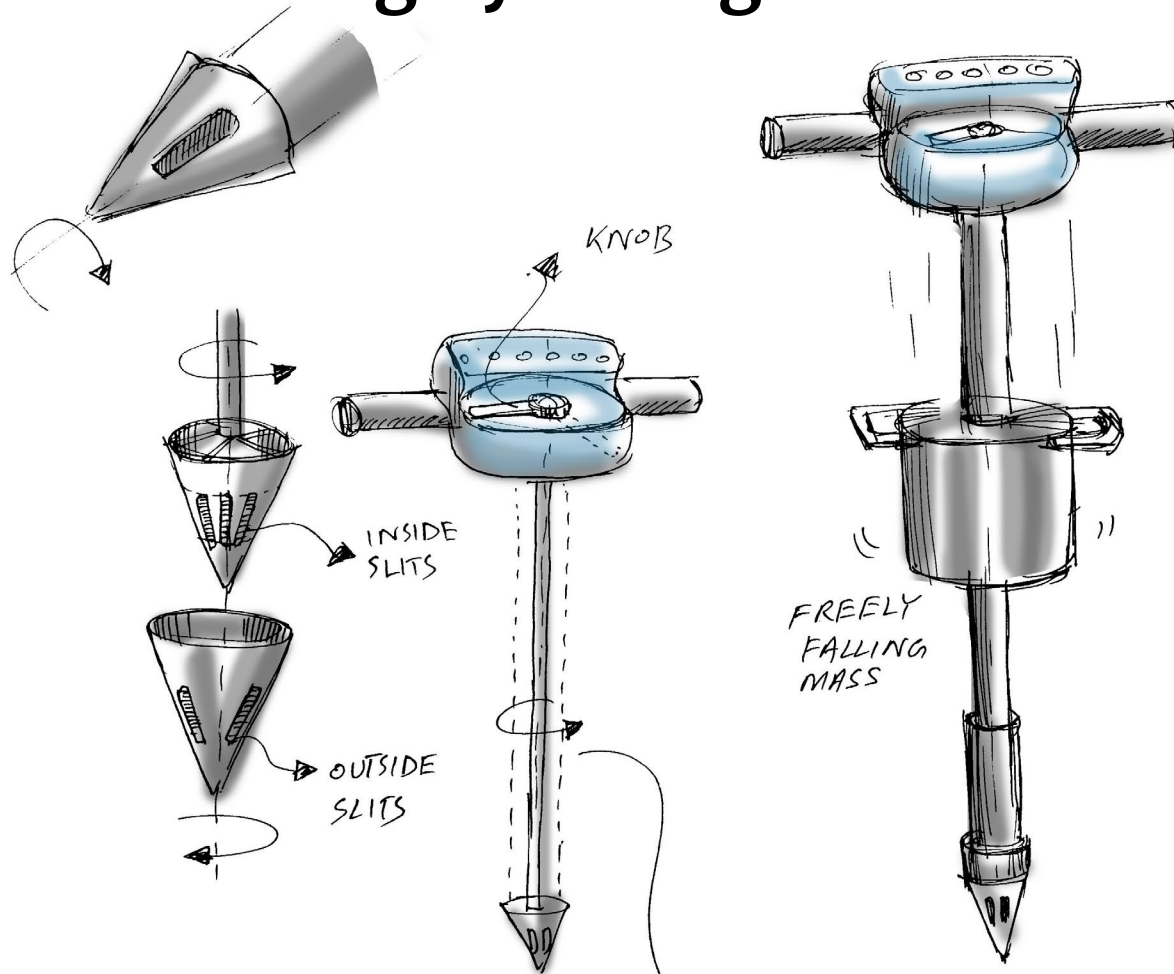
Pre-insert -idea 5



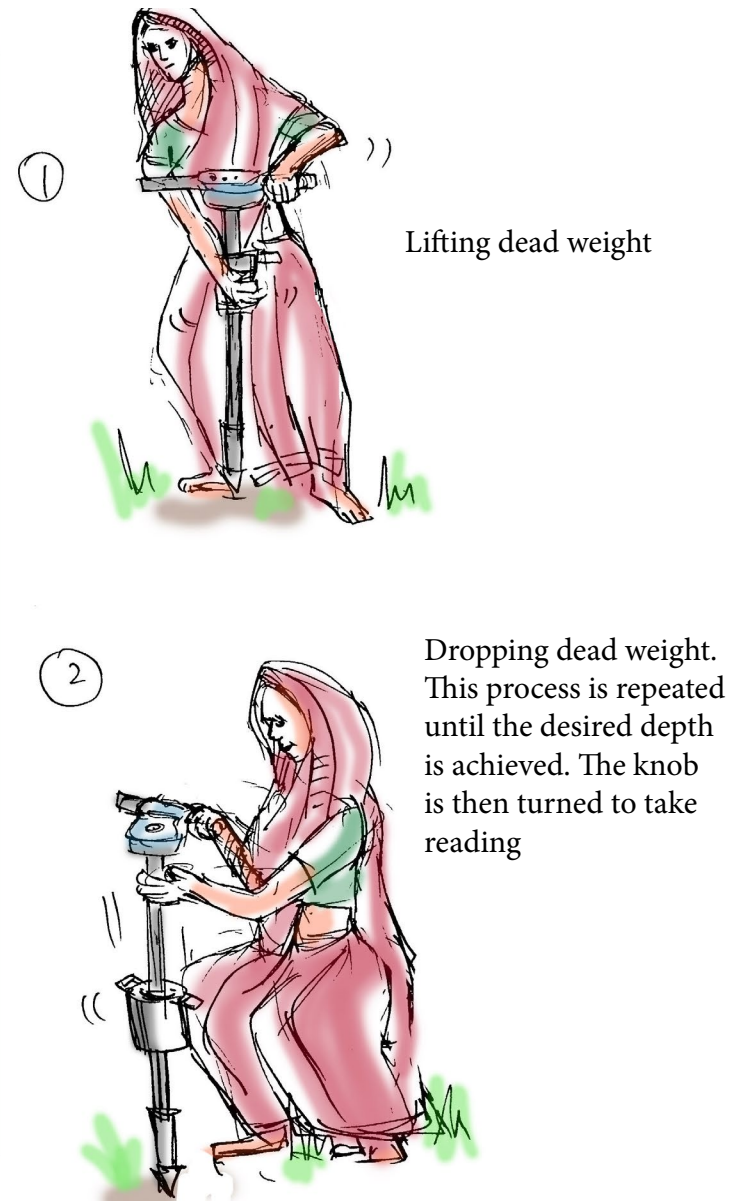
The unit comes with hollow metal cap that is removed and pressed down the soil to achieve the desired depth. The cap is then removed and the unit with sensor tip is inserted into the dug hole. The unit is then switched on to get the reading.



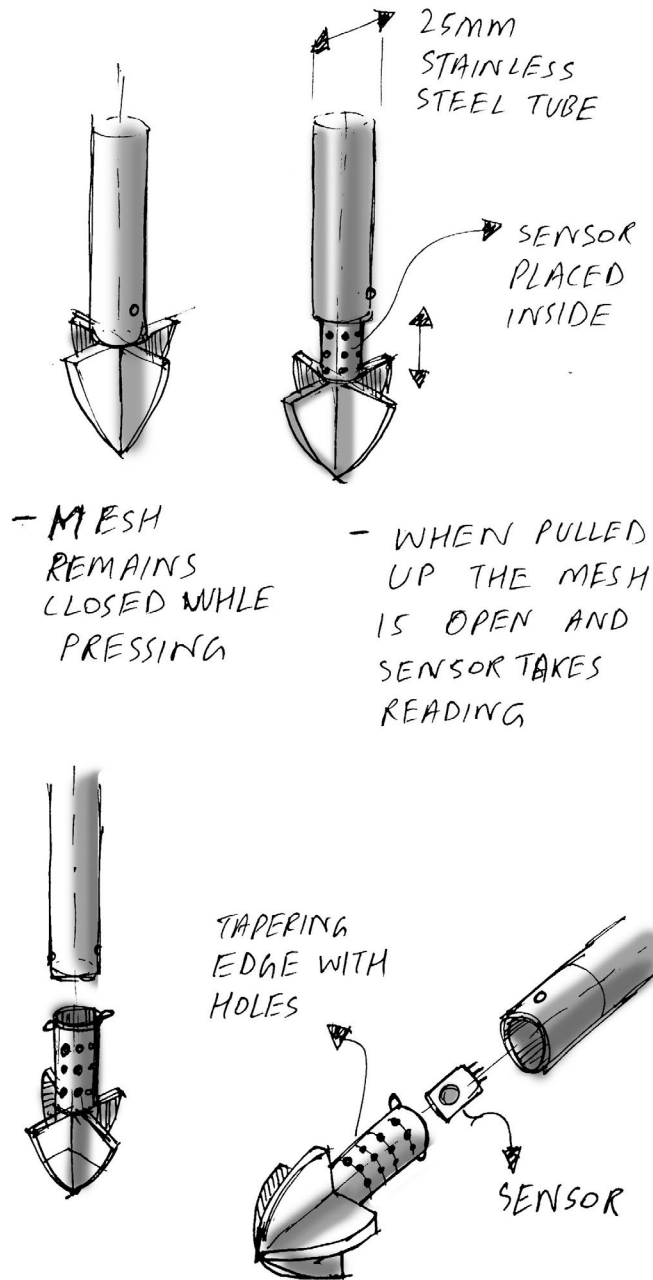
Hammering by sliding mass -idea 6



The sensor is kept at the tip and is enclosed by two overlapping tapering caps with slits on both. The slits are closed while the unit is hammered down by lifting and dropping free sliding mass. Once the desired depth is achieved, the knob at the top is twisted to align the slits. The sensor is thus exposed and reading is taken



Press and lift -idea 7



② PRESSING



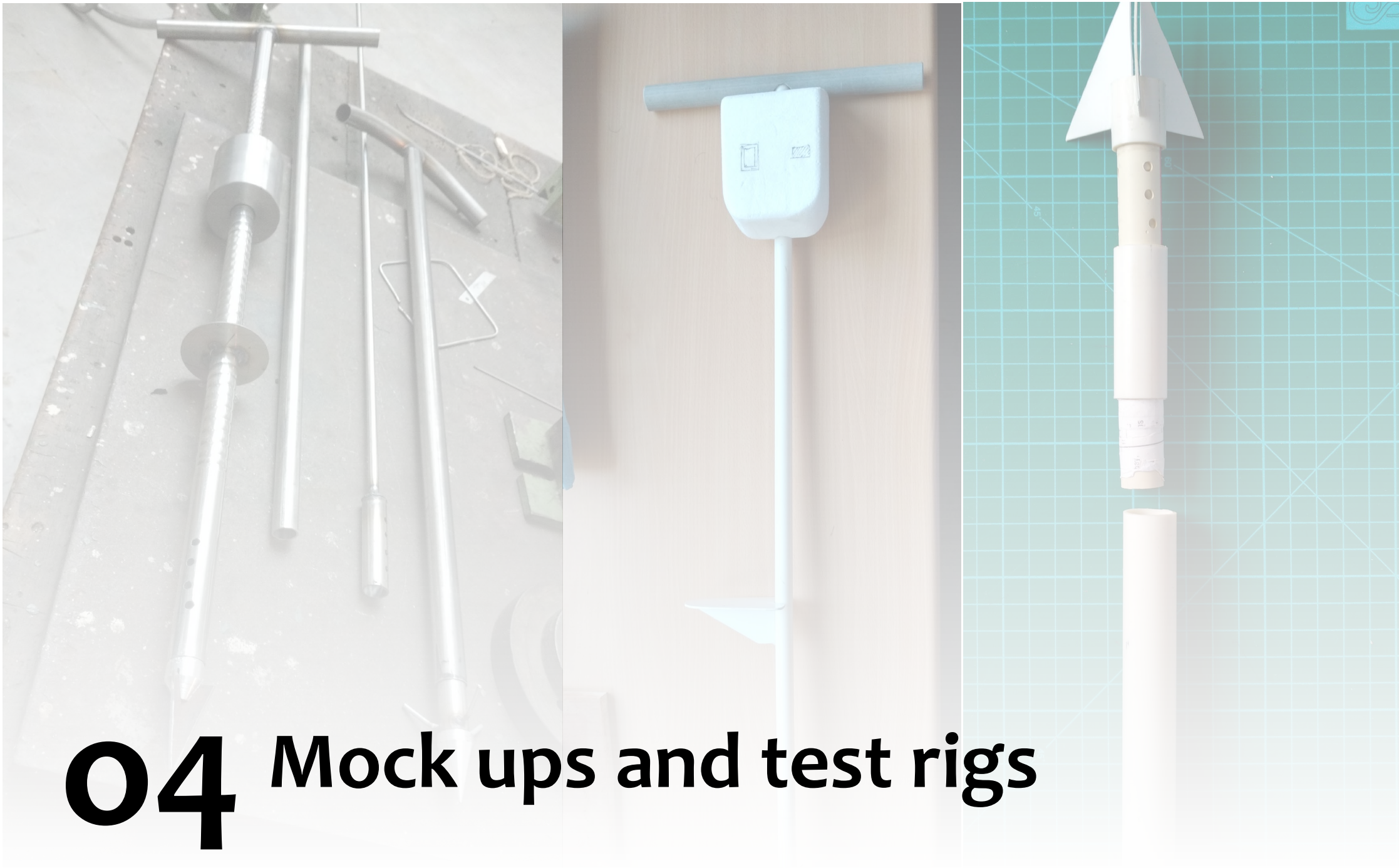
③ SWITCHING ON DEVICE AND TAKING READING



The unit consist of a foot pedal and a top handle. The unit pressed from the top handle while foot pressed at the same time to achieve the desired depth. Once the depth is achieved, the handle is lifted which slides open the sensor module by friction caused.

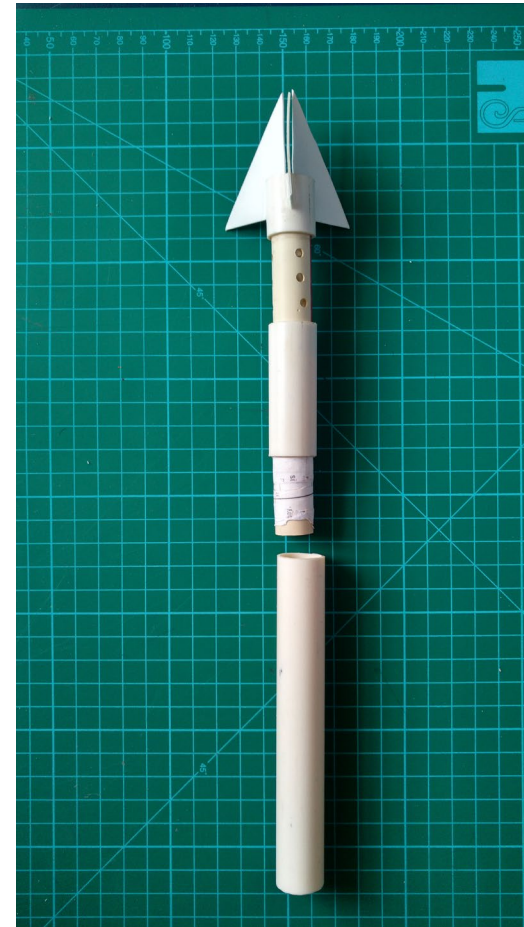
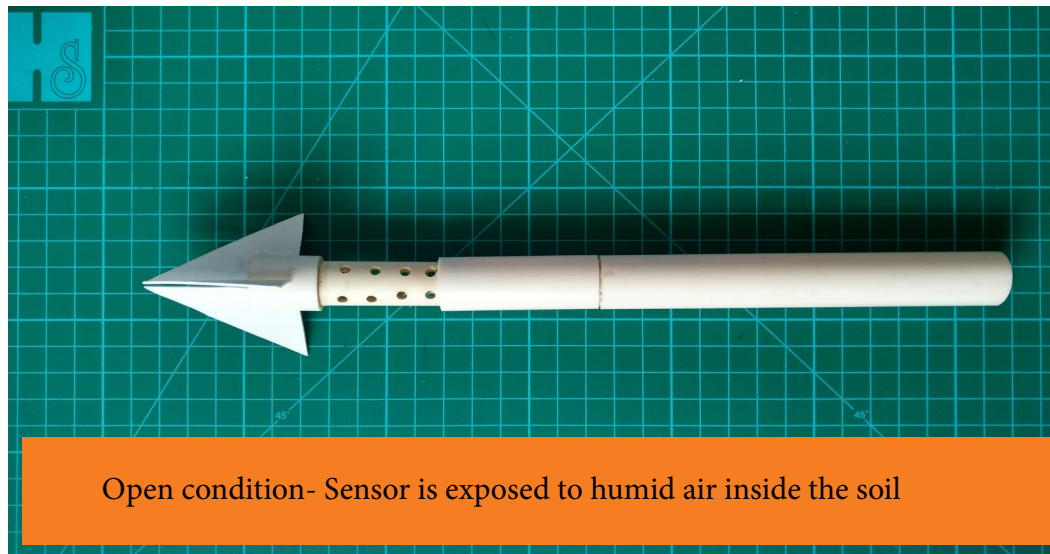
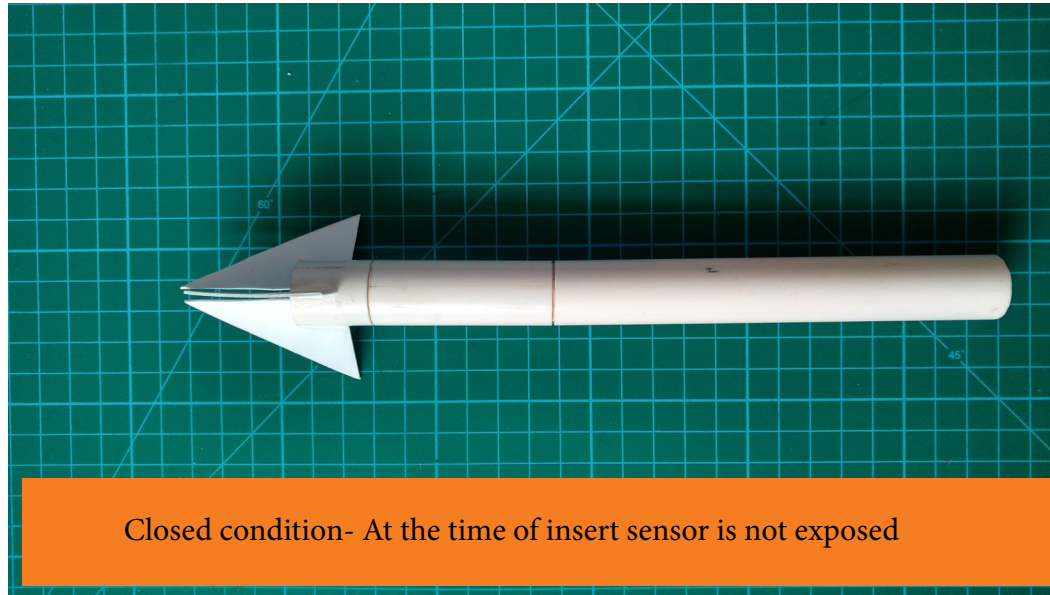
Idea evaluation- pros and cons

Concept	Merits	Demerits	Champion property
Idea 1	-Spikes offer better grip for twist -Easy to manufacture	-Multiple twisting required to reach desired depth	Easy penetration by screwing action
Idea 2	-Easy handling -Direct implication of usage	-Foot pedal need to be pressed continuously -Moving parts	Foot press
Idea 3	-Faster penetration because of screwing action at tip	-Moving parts -Needs more effective fixing mechanism as reaction force tends to lift the unit	Screwing Action at the sensor tip
Idea 4	-Requires only one time effort to dig and insert all the disposable inserts	-Cost of disposable insert will add -Limits flexibility -Requires maintenance as pores gets blocked and need washing	One time effort
Idea 5	-Compact unit (small) -Cap is inserted first and main module is placed in the hole made which result in longer life of sensor	-Multiple parts -User need to bend every time of usage	Cap makes the hole
Idea 6	-Desired depth is attained easily by 2-3 repeated lifting and releasing of sliding mass -Slits are closed while insert	-Sliding mass makes the unit heavy and significantly increase cost	Slits are kept closed while insert and opened only to take reading which keeps sensor safe
Idea 7	-No complex mechanisms or moving parts -Robust design	-Uses pure human effort to reach the required depth -Fin extensions cause more resistance to pull out	Robust design with no moving parts



04 Mock ups and test rigs

Mock ups



A mock up of the sensor tip of idea 7 was made using CPVC to understand the basic working and parts involved

Mock ups



Different types of heads made and studied to find the most effective one



Various conical heads were made in wood and tested in soil to find out which design has least resistance to penetrate. It was observed that conical sections with more taper created less resistance. Fins also help to guide easily.



Test rig in stainless steel tube-concept 1



A test rig was prepared using telescopic SS pipe. To make the pointed end, stainless steel sheet of 3mm was cut in triangular shapes with grooves to cross fit each other. This then welded and fitted. Hammering mass is made out of mild steel.

Test rig in stainless steel tube-concept 2



The sensor is kept in a slotted channel which opens once the unit is lifted after inserting into the field. The set up has foot pedal welded to main body and is easy to make and assemble.

Steps involved -concept 1



The unit kept over the point where reading is to be taken



The sliding mass is lifted up and is left to fall freely. As it hits the stopper, the whole unit is pressed downwards. This action may be repeated 2-3 times



Once the desired depth is achieved, the knob is twisted (switched on) to align the slits which allows sensor to take reading

Steps involved -concept 2



The unit kept over the point where reading is to be taken



Force is applied over the foot pedal to press down the unit to desired depth



Once the desired depth is achieved, the unit is lifted. The resistance caused results in opening of slotted channel and sensor is exposed

Task analysis-concept 1



The unit was tested on standard volume of dry soil filled tub



The sliding mass is lifted up and is left to fall freely.



Since the soil selected was too dry it took couple of repeated hammering to achieve desired depth.

Task analysis-concept 2



The unit kept over the point where reading is to be taken



Force is applied over the foot pedal to press down the unit to desired depth



Depending on how wet the soil is, force required is different in each case

Control unit design



Control unit vacuum formed in styrene

The mock for control box unit was made based on the original dimension of PCB board. It consists of two halves -the front half and the back half. The front half houses LED unit. The back half is connected to main steel frame by screws at the back . The PCB is also fixed to the back half. Both front and back halves are connected by screws.



Internal electronics placed inside

Takeaways

It is observed that concept 1 with hammering had penetrated easily even on very dry soil conditions with only drawback of multiple lifting and release of mass. The design even though was effective, considering the cost of manufacture(mild steel mass of 3 kg made by turning operation) and also the ease of maneuverability in the fields(heavy to handle) compromised both top priorities in consideration. However the concept of slits that is aligned by twist action ensured no soil enters into the sensor chamber while pushing into the soil.



It was observed the concept 2 with lift open mechanism retains more amount of soil while the unit is taken out making it necessary to clean the unit after use. It was also observed that more effort from the user was required to attain desired depth depending on moisture condition. Hence concept 2 with a provision of hammering from the top can be provided (using a wooden mallet) that will make digging easy.



Prototyping

A prototype to scale was made with precision. The control box was injection molded while several operations like threading, drilling slit holes in 90 degrees etc involved seeking industrial assistance.



Sensor enclosure with thread. Slit holes are drilled separately



Finished sensor enclosure with slit holes



Tapering tip with thread made in lathe



Tapered tip is screwed to main pipe and fixed with a grub screw



Foot pedal is welded to main pipe and rubber grip is fixed on flat plate



Control box is vacuum formed as two separate halves



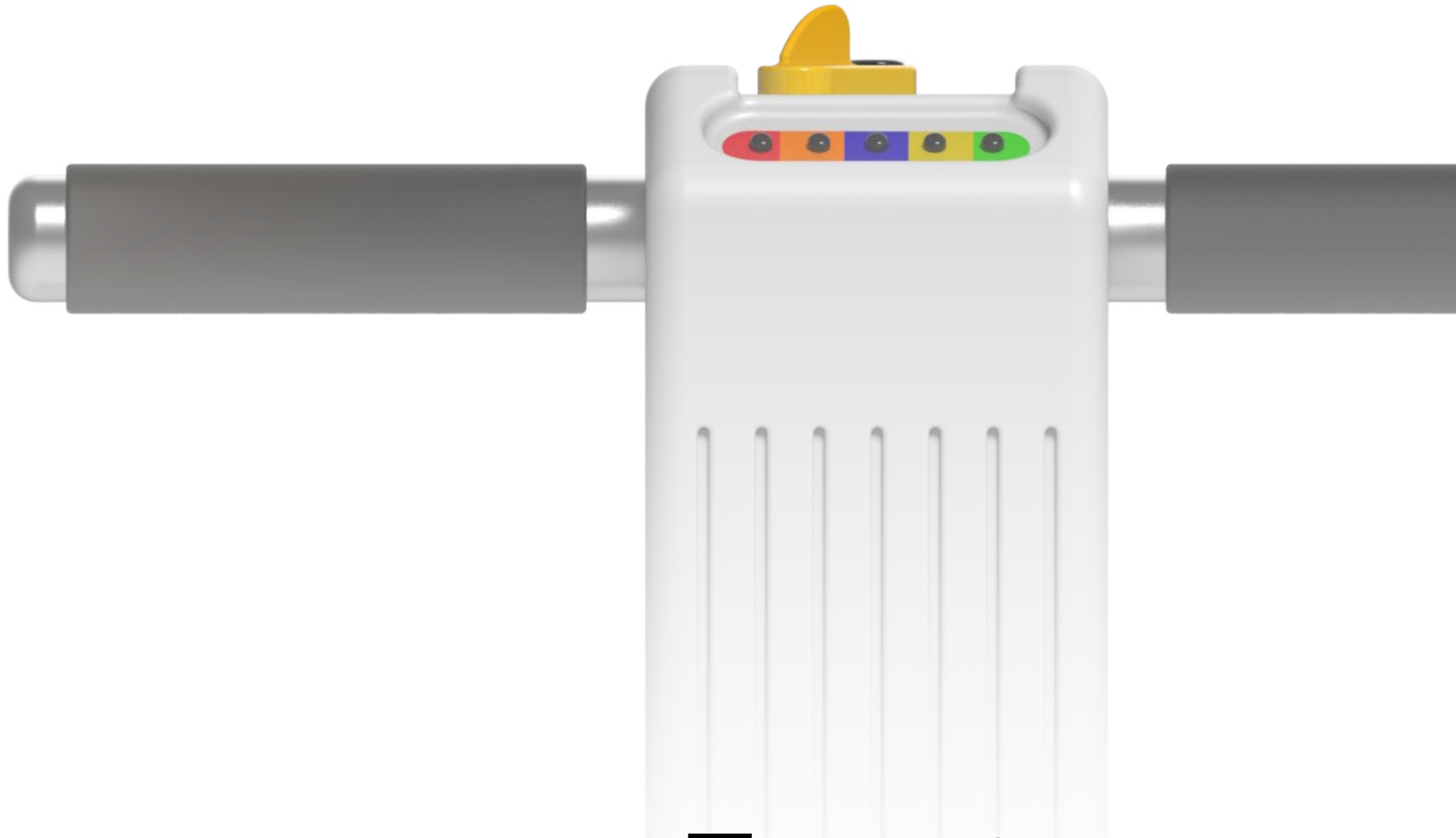
Auger tool and soil moisture sensor unit

The prototype is painted and finished. Knob to switch off/on is fitted at the top and handle grips are added for comfort grip





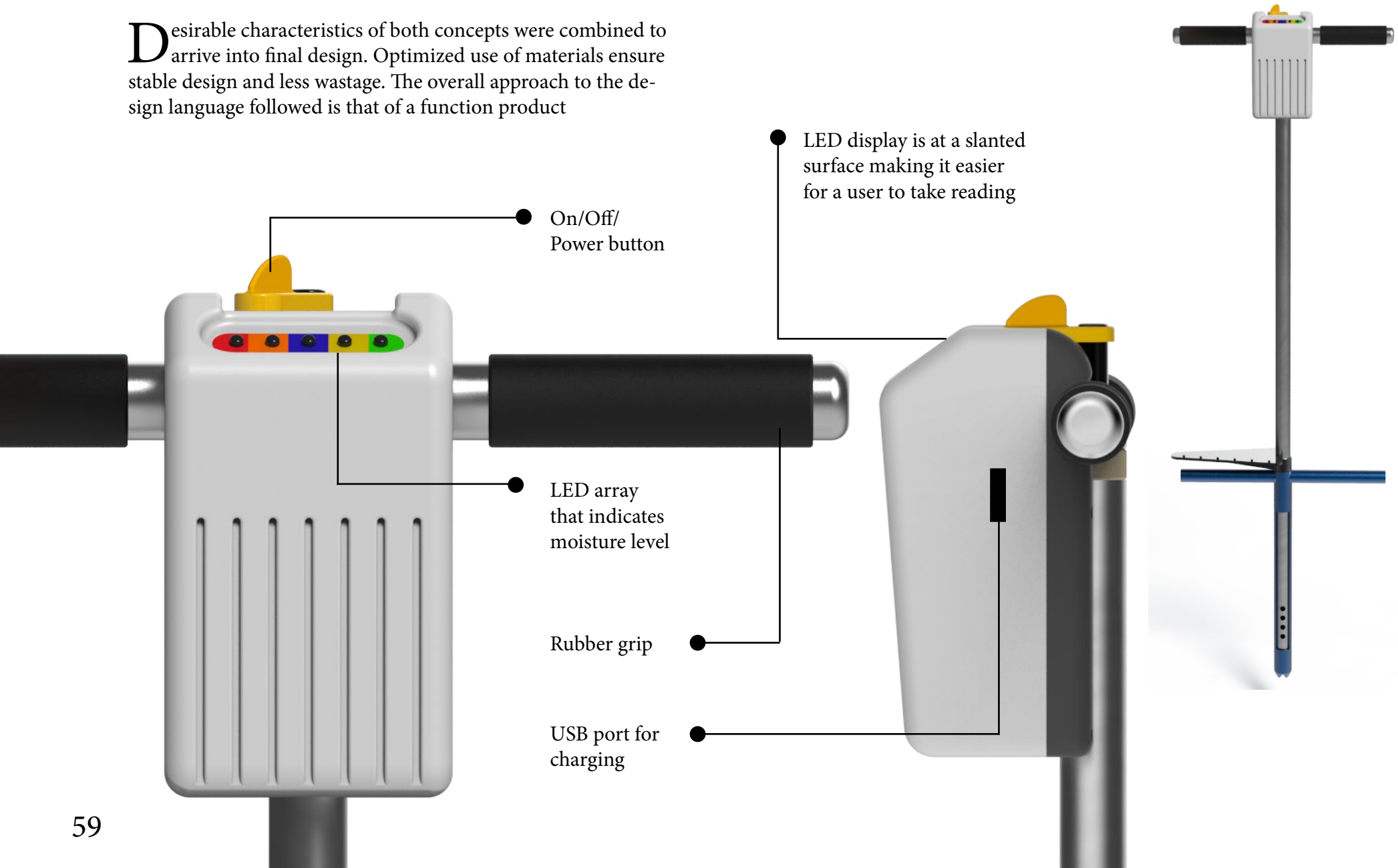
Labels and texts are reduced so as to make it easy for the user to interact even if they are illiterate. A catalogue will be provided and farmers will be trained on how to use the product at the time of purchase of product. Modular parts make it easy for service



05 Final Concept

Final Concept

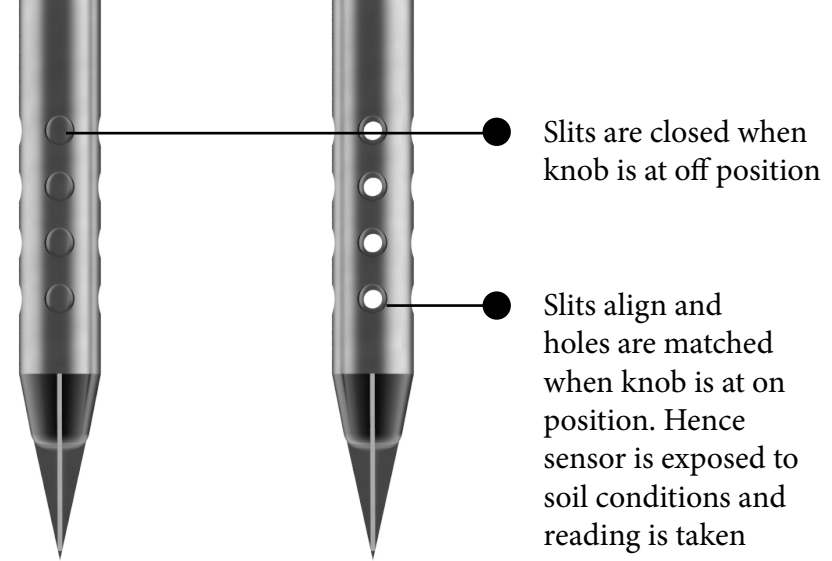
Desirable characteristics of both concepts were combined to arrive into final design. Optimized use of materials ensure stable design and less wastage. The overall approach to the design language followed is that of a function product



User interaction

The yellow knob is twisted after penetration into desired depth. The rotation of knob in other words is ON/OFF action. The device is OFF at the time of insert and is switched ON once marked depth is achieved. The reading is taken and is again switched off before removing device from soil to prevent any chance of soil going inside the sensor chamber

Knob to twist open sensor enclosure

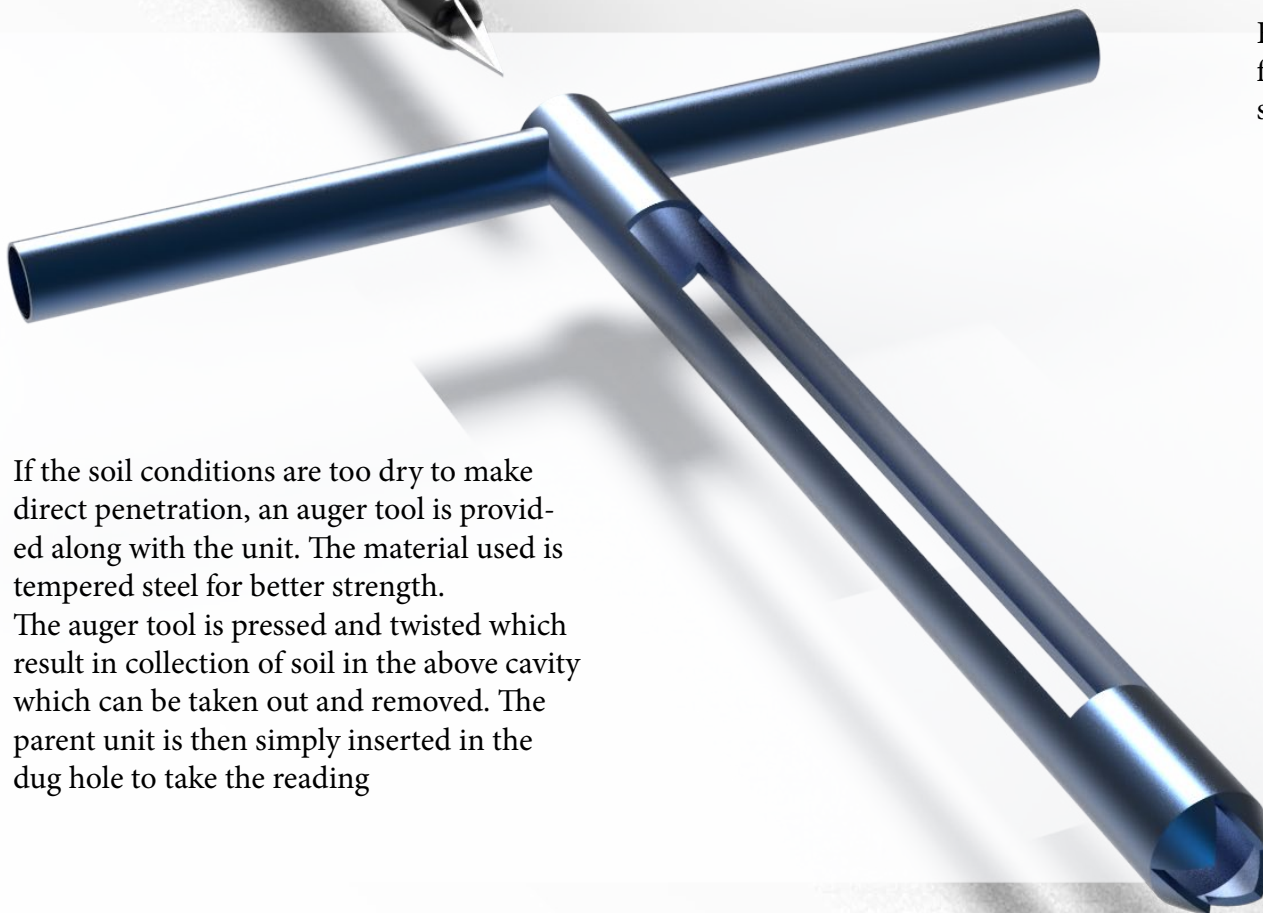


5 different LED's ranging from red to green indicate various levels of moisture in the soil. The interface of the device is made simple and was given consideration that target user find it less difficult to operate.

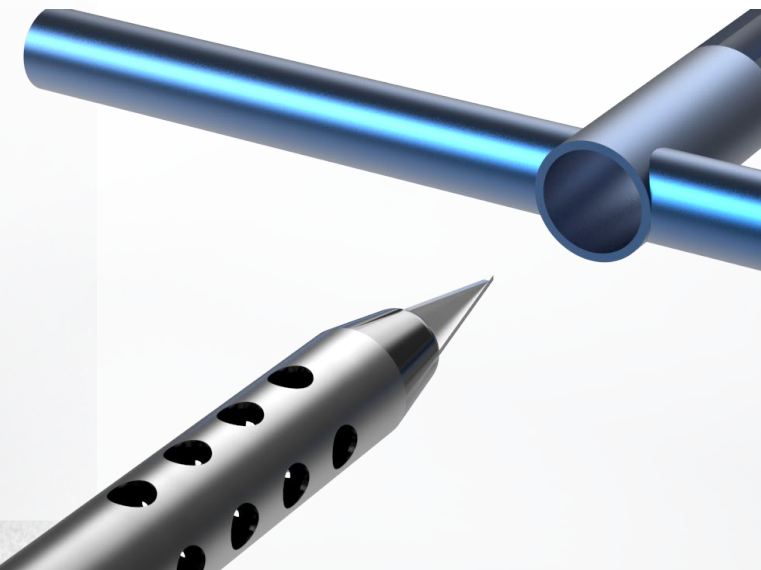




For easy packaging, the auger tool fits like a cap for the parent unit. This also helps protect/secure the sharp head of the soil moisture sensor



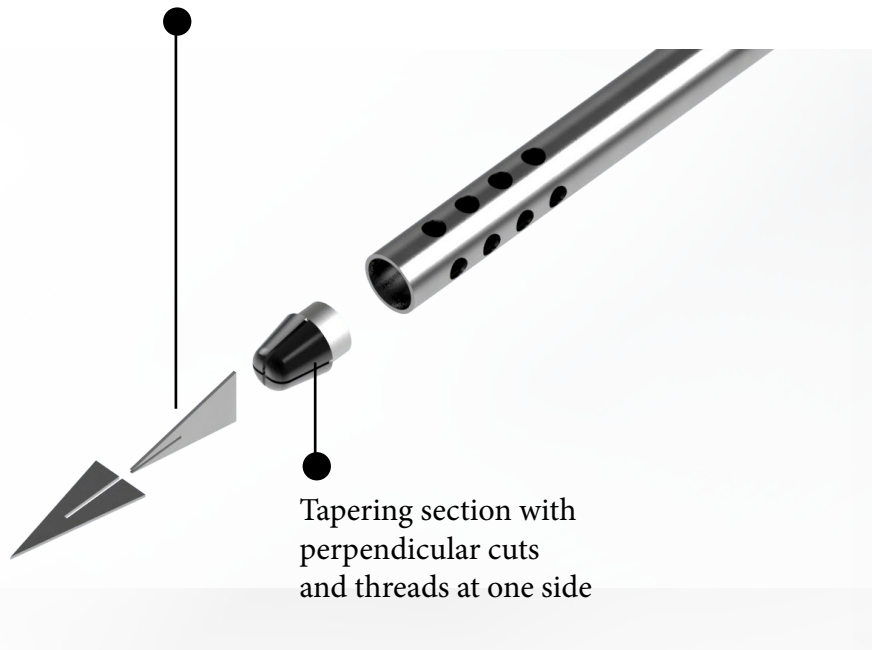
If the soil conditions are too dry to make direct penetration, an auger tool is provided along with the unit. The material used is tempered steel for better strength. The auger tool is pressed and twisted which result in collection of soil in the above cavity which can be taken out and removed. The parent unit is then simply inserted in the dug hole to take the reading



Tip assembly

The tapering tip consists of an assembly two triangular stainless steel sheets with grooves opposite to each other which are interlocked and then welded to a tapering section. This setup is screwed to the main pipe. A grub screw ensures locking of thread and prevents any chance of loosening. The tapering section creates lesser resistance while pushing against the soil that makes it easier to penetrate.

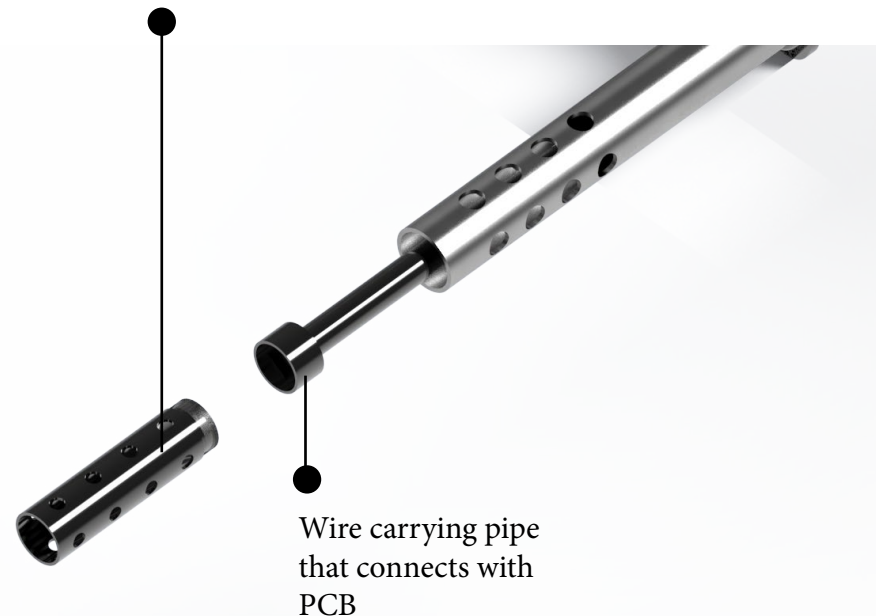
Stainless steel sheets



Sensor enclosure

The sensor is enclosed in another pipe that goes inside the main steel pipe. This also has slit holes drilled to match with outer slits. This part will have a rubber insert to tightly seat the sensor. This setup is screwed to a smaller pipe which carries wires and connections from PCB board

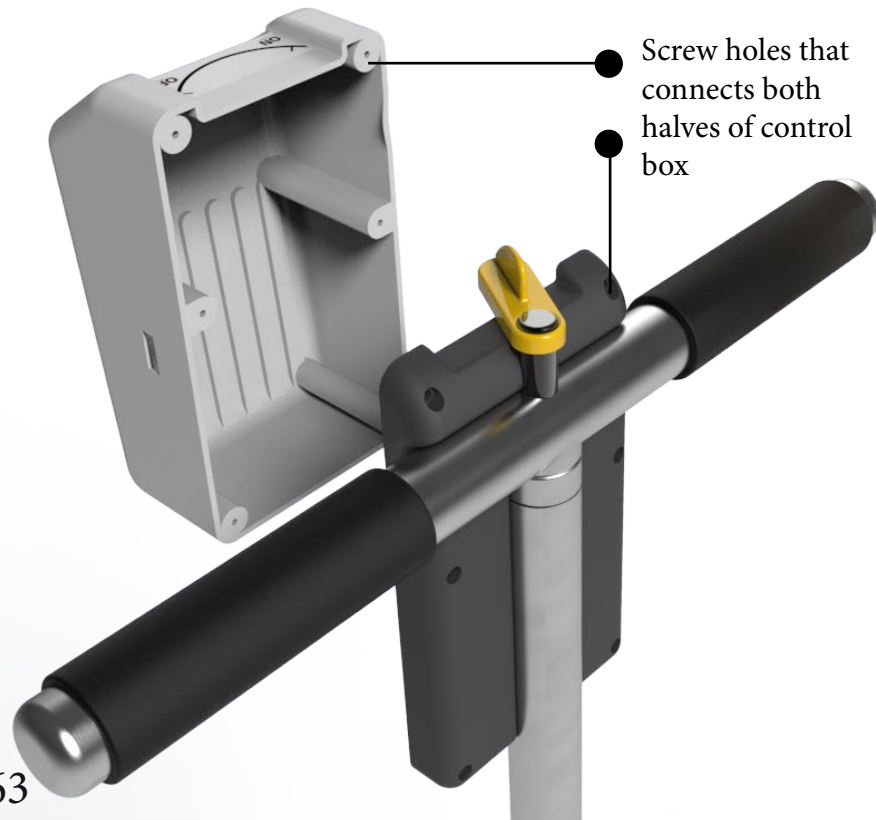
Sensor enclosure with rubber seat inside and thread at one side



The control unit is made of ABS plastic which is durable resistant. The two halves of the box are injection molded and is screwed from behind. The unit is water resistant with waterproof rating IP 54 (ingress protection from dust and water proofing for water sprays from all direction) is taken into consideration. Drill holes are made in the main pipe to take out wires as well as fixing control box to the main pipe.

A foot pedal is welded to the main pipe. The rubber padding ensures proper grip while using the pedal.

The top handle is connected to the main pipe by screwing



Technical drawing of a mechanical pencil in front view. The drawing shows a vertical pencil with a horizontal eraser at the top. The eraser is 300 units wide. The total height of the pencil is 911 units. The height of the body below the eraser is 302 units. The drawing is labeled "Front view" and "Scale: 1:6".

The image displays two orthographic views of a mechanical component, labeled 'Left view' and 'Front view', both at a scale of 1:2.

Left view: This view shows the side profile of the part. Key dimensions include a base width of 15, a vertical height of 140, and a slanted top edge with a length of 120.88 and an angle of 94.4°. A circular feature at the top left has a diameter of 35.05, and a smaller circular feature has a diameter of 20.

Front view: This view shows the front face of the part. It features a central vertical slot and four circular holes, one in each corner. The overall width is 21.74. The vertical dimensions are 72.7 for the lower section and 53.01 for the upper section.

Conclusion

The final product was tested for its mechanical strength and ease of sliding in soils with different moisture contents. It was found that the device went in with relative ease and the concentric mechanism functioned as expected. In cases where the soil was excessively dry, the auger tool was competent enough to make the initial hole after which the soil moisture sensor was inserted. The change in the control box meant that the reading were easily visible even in bright sunlight. Moreover it is designed to be injection molded without any undercuts making it efficient and economical to manufacture.

The product is ready to be tested with different electronic and sensors as required.

References

Fig 1 : http://travel.paintedstork.com/blog/wp-content/uploads/2009/07/paddy_field.jpg

Fig 2 : <http://luirig.altervista.org/cpm/albums/nrcs1/0115-Level-furrow-irrigation-on-lettuce--Yuma--Az-.jpg>

Fig 3 : https://egusssd.files.wordpress.com/2012/12/citrus_2.jpg

Fig 4 ; <https://tiffanychenggg.files.wordpress.com/2015/10/screen-shot-2015-10-02-at-10-16-01-pm.png>

Fig 5 : http://2.wlimg.com/product_images/bc-full/dir_75/2238493/image-01_p_1569013_316186.jpg

Fig 6 ; <https://wiki.metropolia.fi/download/thumbnails/132842172/Tensiometers.jpg?version=2&modificationDate=1431943380000&api=v2&effects=border-simple,blur-border>

Fig 7 : http://www.soilmoisture.com/images/D/5201F1L03_Soilmoisture_G-Block_6ft.jpg

Fig 8 ; http://aces.nmsu.edu/pubs/_h/H640/images/resistanceMeter_opt.jpeg

Fig 9 : <https://dl.sciencesocieties.org/images/publications/vzj/6/2/406fig2.jpeg>

Fig 10 : <http://www.ictinternational.com/content/uploads/2014/04/smm-display-01.jpg>

Fig 11 : https://www.researchgate.net/profile/Svetoslav_Atanasov2/publication/309390819/figure/fig2/AS:426077945372673@1478596306759/Figura-2-Princip-na-dejstvie-na-FDR-senzor-vlavo.png

Fig 12 : http://bcsydz.com/images/up_images/201654184053.jpg

Fig 13 : http://www.myhoskin.com/newsletters/images/GS1_soil_moisture_sensor.jpg

Fig 14 ; http://www.ums-muc.de/fileadmin/_processed_/csm_GS1_3bb-23c9ffc.jpg

Fig 15 : https://images-na.ssl-images-amazon.com/images/I/61ryD-0BHl9L._SL1001_.jpg

Fig 16 ; https://images-na.ssl-images-amazon.com/images/I/81BpRYYGg-cL._SL1417_.jpg

Fig 17 : https://s3.amazonaws.com/classconnection/755/flash-cards/5653755/jpg/soil_pyramid-14BB315B7EC207EBA6F.jpg

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