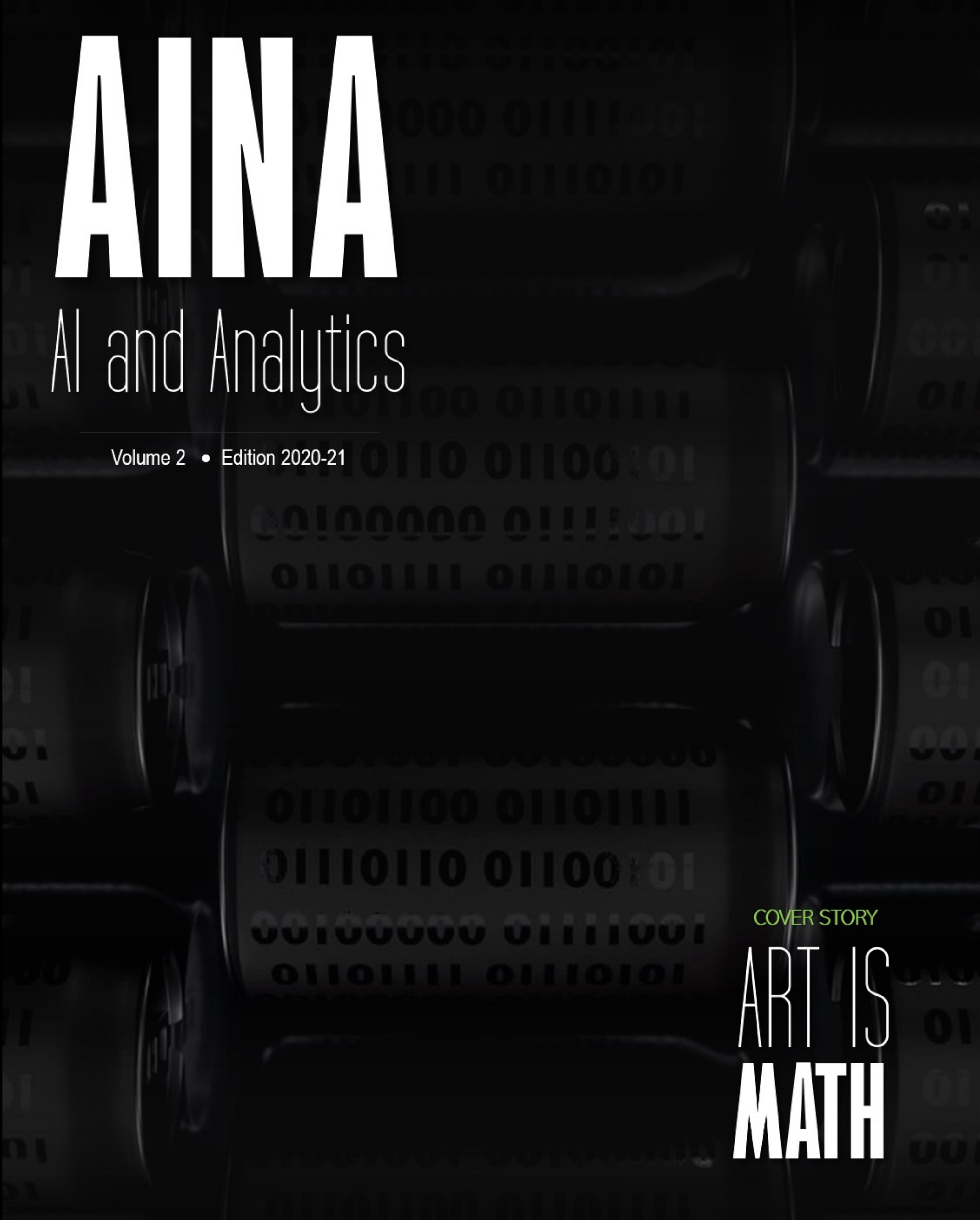

# AINA

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COVER STORY

# ART IS MATH

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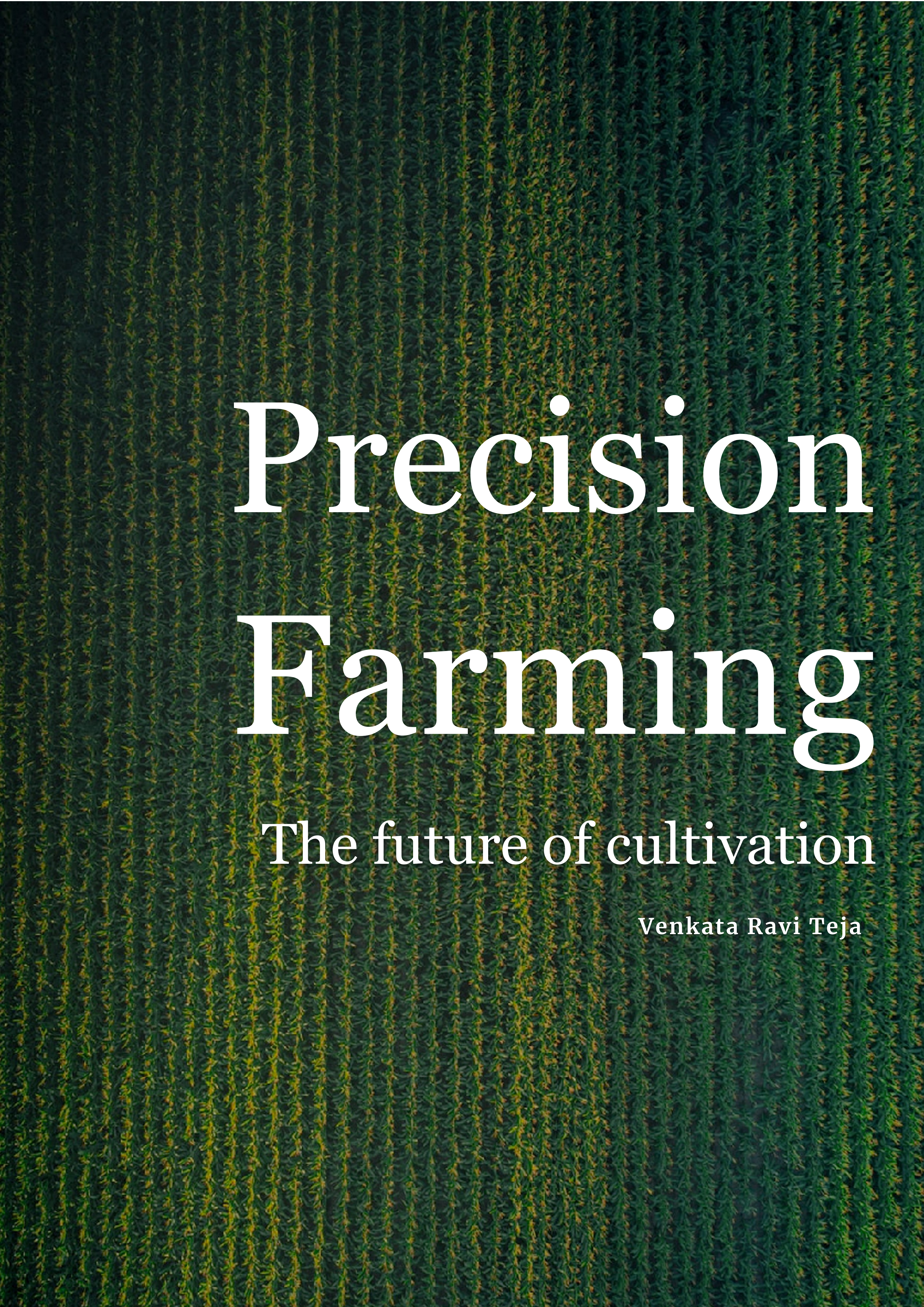


# Precision Farming

## The future of cultivation

Venkata Ravi Teja

According to Food and Agriculture Organization (FAO), the arable land per person has reduced from 0.38 hectares to 0.23 hectares from 1970 to 2000. It is expected to decline to 0.15 hectares by the year 2050. Excess use of chemical fertilizers and pesticides has a detrimental effect on the environment, reducing soil fertility and polluting the air and water. Extreme weather conditions like cyclones and droughts are increasing in the past years due to climate change. Water scarcity is posing a great challenge, and it is going to worsen in the coming years. United Nations have estimated that by 2050, the farmers have to ramp up the food production by 70 percent. The present challenge is to produce more food with fewer resources & extreme conditions.

| GCP = PCP x N | PCP = η x ANR x SAR |
| --- | --- |

For increasing the Gross crop production (GCP), we have to either increase number of crop cycles (N) or Per crop production (PCP). We can't increase 'N' in a year beyond a certain number as the vital nutrients in the soil are limited and takes time to rejuvenate through the decomposition of organic matter. 'PCP' is constrained by the available natural resources (ANR) in the field, and neither can we increase the amount of Supplied Artificial resources (SAR) like chemical fertilizers as it severely damages soil fertility in the future. So, all we can do is maximizing 'η' the farming process efficiency.

## Concept of Precision farming

The farming process efficiency can be maximized through precision farming. Precision farming manages nonuniform farm fields following correct practices in the right place and time. It increases profitability and sustainability by optimizing available natural resources and protecting the environment. Precision farming through information enables farmers to monitor crop and soil conditions in a heterogeneous farm field and provide crops with the required resources specific to the site. It also helps farmers in planning the activities from the time of seed plantation to harvesting. This approach requires access to real-time data about the crop, soil, and other pertinent information.

In Precision farming, Satellites, aerial vehicles, and sensors mounted on ground vehicles or handheld collect the required data from the entire field. GPS (Global Positioning System) receivers integrated with field data gathering equipment collect the location and time data. The GPS enables the farmer to navigate to a specific location accurately in the farmland for soil sampling and inspect the stressed crops.

A geographic information system (GIS) represents the field data collected by remote sensing methods through maps that are created using GPS information. GIS is a powerful visualization tool. It creates multiple maps for yield, crop and soil health, weed density, plantation planning, etc., with their respective geographic coordinates.

## Advantages of remote sensing over ground-based methods

Precision Farming includes ground-based methods using sensors planted at various regions in the field and remote sensing methods through which farm fields will be monitored in a no-contact mode. The limitation of ground-based methods is that they will give point-wise information specific to where the sensor is placed. Point-wise sensors are not economical in the case of large and heterogeneous fields. Remote sensing, on the other hand, provides continuous information across wide regions. The satellite data can also be obtained at affordable costs.

## Remote Sensing in precision farming

Remote sensing methods are used in crop and soil monitoring. It detects the abnormalities in the crop much before the human eyes can recognize it. The early warnings on crop and soil health help the farmers in avoiding the loss in crop yield. Optical remote sensing with spectral imaging is the most commonly used technique. It collects the information from the earth's surface through visible, near-infrared, and short-wave infrared sensors. It depends on the reflected light from the target object for identifying them through their spectral signatures, which are unique to that material. The Spectral signature is the ratio of reflected to incident radiant energy of the material. Regular RGB cameras can capture light across the three visible wavelength bands of red, green, and blue, whereas spectral imaging captures the light in the visible spectrum and beyond it. The bands beyond visible are represented as False color composites of Red, Blue, and Green.

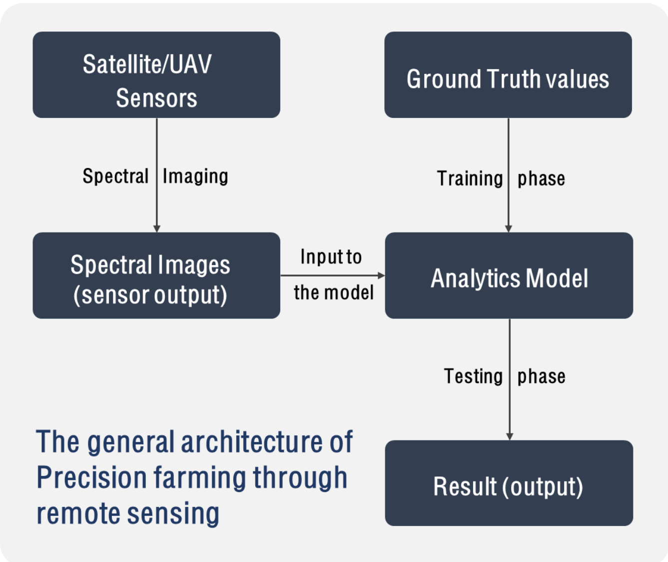
Spectral imaging is broadly divided into Multispectral and Hyperspectral Imaging. Multispectral imaging captures the spectral information from the specified wavelength range of the electromagnetic spectrum in discrete spectral bands. Hyper Spectral imaging collects spectral data in the form of several continuous narrow wavelength bands. The choice between these two techniques depends on the task.

## Concept of Band Ratios

The reflectance values are obtained through spectral imaging for various wavelengths over all the pixels. The limitation with Reflectance values is they change with the angle of sun rays, time of the day, and year. Due to this variation, we can't rely on pure reflectance values for our analysis. Band ratioing is used as a solution to the variability of reflectance with local factors. Different materials exhibit different levels of reflectance at various bands. Band ratios enhance these spectral differences between the bands and curtail the influence of topography and other factors on reflectance. Let's say there are two types of plants, among which Type1 has high reflectance compared to Type2 at particular wavelength bands A and B. In this case, we can't distinguish between the two types of plants based on absolute reflectance values, As the reflectance of Type 2 plants on the sunlit side will be more than that of Type1 in the shadow. Here we will instead take the ratio of bands A and B to distinguish between the two varieties of plants.

## Spectral imaging methods vs. deep learning methods

All the spectral imaging use cases in precision farming can also be done using deep learning. But, the deep learning model on regular RGB images has disadvantages in terms of its requirement of high processing power, time, and high amount of data to fit the model. A neural network is a black-box model, thus limiting its explainability. Through the band ratio techniques, we can build explainable models which are computationally less intensive, making them economically viable for farmers.



The general architecture of Precision farming through remote sensing

# Soil Monitoring

## Soil organic carbon determination

Soil organic carbon (SOC) is a key indicator in assessing soil health. SOC helps in nutrient and moisture retention and stabilizes the soil structure. SOC controls the C:N(carbon to nitrogen) ratio. An optimal C:N ratio enables the microbes to release the nutrients into the soil by decomposing organic matter. SOC levels are dynamic and require constant monitoring. Spectral imaging can be used for soil mapping over varying levels of SOC. Soils with high SOC content are darker and have low reflectance in the visible range. So, Regression models can be developed using the spectral band ratios as independent variables and actual measurement of SOC from Soil samples as dependent variables in the training phase. This developed model is used on new data to obtain SOC.

## Crop Health Monitoring using Vegetation indices

Band ratioing is a simple ratio that indicates crop and soil health, but it has a couple of problems. The first is the issue with division by zero when red reflectance becomes zero. The second being its wide range of values, which makes it difficult to compare. Hence Spectral indices are derived from band ratios to address these problems. These indices are combinations of reflectance properties from two or more wavelength bands. Spectral indices used for assessing crop health are called Vegetation indices.

Normalized Difference Vegetation Index-NDVI also referred to as the measure of the greenness of the area, is the most commonly used among all vegetation indices. A healthy plant reflects more in the near-infrared band and absorbs more in the red band, whereas stressed vegetation reflects red light and absorbs near-infrared light.

$$\text{NDVI} = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})}$$

**NIR** - Reflectance in the Near-Infrared

**Red** – Reflectance in the range of red

| NDVI value | Indication |
|---|---|
| -1 to 0 | Inanimate object |
| 0 to 0.33 | Stressed or unhealthy vegetation and appears in orangish-red |
| 0.33 to 0.66 | Moderate health and appears in tint green |
| 0.66 to 1 | Healthy crop and appears green |

The crops are classified into one of the above classes depending on the NDVI value.

The above thresholds could have been obtained using the general architecture where the analytics model used is a Decision tree on a single variable. But, agronomists defined these thresholds empirically .

## Crop calendar derivation using NDVI time series

The temporal profile of NDVI gives information on various growth stages of the crop and the overall performance of the crop in a particular season or period. Different physiological stages of the crop in its growth cycle would sequentially occur, maintaining the exact chronology over time. The smoothed NDVI time series would provide information on the dates of green-up (beginning of cycle) & harvesting, maximum NDVI date, & length of crop growth.

Crop calendars can be developed based on this, which provide information on the optimal time window for seeding date, duration of the crop Life cycle, and optimum date for harvesting. This would help the farmer plan to purchase inputs, finances, and labor requirements.

## Crop yield estimation

Accurate crop yield estimation is of much interest to policymakers for the country's food security. They plan the food imports and exports depending on the yield estimates. Monteith method is a popular model which uses biomass for crop yield estimation. The net primary productivity (NPP) is the biomass accumulation in the plant.

$$NPP = fAPAR \times PAR \times RUE \times Wstress \times Tstress$$

fAPAR, which is the fraction of absorbed photosynthetically active radiation (PAR), can be estimated by developing a regression model using NDVI values as the independent variable. The model should be trained with existing ground truth values, and the trained model can be used to estimate fAPAR values for different NDVI values

$$fAPAR = A \times NDVI + B$$

**A** and **B** are regression coefficients

**HI** – Harvest Index

$$\text{Estimated Grain Yield} = \sum_{\text{Sowing}}^{\text{Harvest}} (NPP \times HI)$$

RUE (Radiation use efficiency) is relatively constant for a specific crop when calculated over a complete growth cycle. Water stress can be calculated through Land Surface Water Index (LSWI). Temperature stress can be computed through weather data. It depends mainly on the difference of mean daily temperature from the minimum, maximum, and optimum temperature of photosynthesis.

$$Wstress = \frac{(1-LSWI)}{(1-LSWImax)} \qquad LSWI = \frac{NIR - SWIR}{NIR + SWIR}$$

**SWIR** - Reflectance in the range of Short Wave Near Infrared.

## Drought Monitoring in the field

Drought in agriculture is referred to as a soil moisture deficiency. It badly affects the production and growth rate of the plants. Meteorological drought indicators were developed in the past for drought monitoring. A new methodology using spectral indices was developed, addressing the issues of the past methods. Standardized Vegetation Index (SVI), Standardized Water Index (SWI), and Evaporative Stress Index (ESI) are the remote sensing-based indices used in drought monitoring.

SVI, SWI, and ESI are calculated from the anomaly or respective Z scores for their time series, i.e., the deviation of their values in the time series from their individual mean values per standard deviation of their values.

$$Z\ score = \frac{Value - Value\ mean}{Value\ std} \qquad f = \frac{ET}{PET}$$

Individual values in the above time series, for Vegetation Index (VI), is usually NDVI or EVI (Enhanced Vegetation Index), and for Water index, it is NDWI, which is equivalent to LSWI.

Evapotranspiration is the combined evaporation and transpiration to the atmosphere from the surface. ESI can be calculated from the z score of the ratio of evapotranspiration (ET) to the Potential evapotranspiration (PET).

For all three indices, a value less than -1 represents a dry condition. Conversely, high negative values of these indices indicate a severe drought. Recent studies show that a synthetic index combining these three indices includes the information from vegetation growth from SVI, vegetation water content from SWI, and evapotranspiration from EVI, giving more accurate predictions.

$$SVDI = w1 \times SVI + w2 \times SWI + w3 \times ESI$$

**SVDI** - Synthetic Vegetation Drought Index

**w1**, **w2,** and **w3** are weights of three indices.

## Thermal Remote Sensing

Another Precision farming technique that gained popularity off late is Thermal imaging which utilizes the long-wave infrared portion of the spectrum. Thermal remote sensing has its advantage when it comes to its ability to operate at night. Similar to optical remote sensing, it can also monitor crops and soil. It captures the radiant (emitted) temperature from the crops, which can be used to detect crop stress and plan irrigation cycles. Thermal Images are either displayed as greyscale images or color composites. In greyscale images, brighter areas indicate warmer regions and darker areas indicate cooler regions. In fact, Thermal and optical remote sensing techniques are not competing; instead, they complement each other.

## Conclusion

Precision farming is the perfect solution to avoid the upcoming food crisis by increasing the efficiency(η) of farming practices. But, the bottleneck for its implementation is the lack of expertise and technical knowledge in processing the available raw data for real-world applications. This can be addressed when the number of educated farmers increases. Also, the big companies which are competent to implement precision farming techniques need to support the farmers and make this practice widespread.

Today we are witnessing more and more companies and startups providing state-of-the-art farming technologies and solutions. It is quite evident that precision farming is the next big thing, especially when a big player like Microsoft are aggressively investing in Precision farming.