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Design of a Tractor Drawn DGPS Integrated Variable Rate Fertilizer Applicator

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Abstract

Farm Mechanization 2.0 is a concept that has shed its shell and has risen to prominence over the years. Conversations around the need for mechanization in India have seen a rise. There is a requirement for increased technology intervention, ensuring the versatility of use and affordability in cost and profitability. India has the second-largest agricultural land globally, with 394.6 million acres. Mechanization is a reliable solution to enable farmers to increase the productivity of their land and make it cost-effective as well. The unstable soil nutrient conditions make it even more compelling for the farmers to optimize their farming processes to maximize yields. Recent developments in farm machinery have led to a renewed interest in intelligent agriculture. Data-driven technologies have attracted much attention for handling powerful data processing capabilities. This data-driven farm equipment technology creates a wide range of design and manufacturing practices. The acceleration of digital adoption and cutting-edge mechanization technology combines precision farm management tools (GPS/GNSS), end-user applications (machines), and data solutions (IoT). The variable rate fertilizer applicator has two types: sensor-based and map-based. In map based VRA, the aerial photographs are taken using UAVs to create prescription maps using image processing software and vegetation indices. The maps are inputted into the tractor with georeferencing of sites before the system goes about its activities. The VRA system consists of a tractor, implement, DGPS module, microcontroller, DC motor, actuator, metering mechanism and a conveyor. The grid sampling prevents the over-application of fertilizer in areas where nutrient levels are high. First, the map data gets synchronized with the real-time DGPS on the tractor, and it contains the deficiency level of each particular location in terms of latitude and longitude grids. Then, it starts to actuate the prescribed fertilizer via a metering mechanism to distribute and neutralize the nutrient level as it reaches each specified location. The benefits of variable-rate fertilizer application are saving the amount of fertilizer and the potential increase in yields.

Key words : *agriculture, fertilizer, map, tractor, UAVs, variable rate.*

Introduction

Variable rate fertilizer applicators enable more precise and targeted nutrient application, taking into account the spatial and temporal variability of soil properties and crop nutrient requirements. By using VRT, farmers can tailor the fertilizer application rates to specific areas within a field based on soil fertility, crop nutrient demands, and other factors. This approach allows for more efficient use of nutrients, minimizing both over-application and under-application, and ensures that crops receive the optimal amount of nutrients for their growth and development. Improved nutrient management leads to enhanced crop productivity, better yield quality, and reduced nutrient losses. Variable-rate fertilizer application (VRFA) applies various rates of crop nutrients by synchronizing existing machinery with mechatronics according to the variability within any agricultural field (1, 2, 3). One such effort is to be made to develop VRFA systems to meet the soil and plant needs. The meaning of precision agriculture is to finely and accurately adjust various soil and crop management according to the specific conditions of each operating unit in the field and maximize the use of various agricultural inputs to obtain maximum production and maximum economic benefits (4). Therefore, variable-rate technology (VRA) has become a common practice implemented by precision agriculture (PA) practitioners. It is the primary way by measuring the nutrient information of soil in advance. The fertilizer prescription map is provided based on soil nutrient information by decision analysis, and variable rate fertilizer applicator machinery can obtain operation geographic position coordinates by the GPS navigation in real-time in under the control of the control system, the system can guide fertigation according to fertilizer prescription map (4, 5). However, there are some limitations in VRA equipment that can create application errors where the actual application rate might differ from the desired rate, causing inaccuracy. In addition, the design parameters limitations of the spreader and the actuators affected the dosing accuracy (6). It is important to note that the outcomes of variable rate fertilizer applicators can vary depending on factors such as crop type, soil characteristics, climate, and the precision of data used for prescription mapping.

Limitations of Variable Rate Fertilzier Applicator : VRA relies on accurate and up-to-date data, including soil

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fertility maps, crop nutrient requirements, and spatial variability within fields. However, obtaining high-quality data can be a challenge. Soil sampling and analysis can be time-consuming and expensive, and data collection may not always capture the full extent of soil variability. Additionally, acquiring reliable and precise crop nutrient requirement data across different growth stages and environmental conditions can be complex. Adopting VRA technology involves upfront costs, including the purchase of specialized equipment such as variable rate applicators, sensors, and controllers. The initial investment can be significant, and the cost-effectiveness of VRA depends on the size of the farm, crop type, and local economic factors. Additionally, maintenance and calibration of VRA equipment are essential to ensure accurate nutrient application, which adds to the overall cost. Implementing VRA requires technical expertise and knowledge of precision agriculture practices. Farmers need to be familiar with the operation and calibration of VRA equipment, as well as data interpretation and integration. Challenges may arise in terms of equipment compatibility, connectivity, and software integration, particularly when utilizing multiple technologies and data sources. Training and technical support are crucial for successful VRA implementation.

Materials and Methods

VRA systems are of two types: map-based and sensor-based. This design map-based method was implemented with a fertilizer prescription map adopted in VRA systems because of its easy application. It uses a GPRS network supported VRA system that stores the fertilizer prescription map in a remote server. The GPRS network transmission delay can be disastrous for the system. The workflow of the VRA system relies on the support of a remote server which makes the cost of hardware very expensive. As the applicator moves across the field, the VRA controller constantly updated with the applicator location information provided by the GPS receiver and desired application rate at the location and then adjusts the flow rate of the liquid fertilizer to match the desired rate by controlling the servo valve opening based on the inputs from the speed sensor and flow meter and the swath width of the applicator (6, 7). The spreading uniformity is an important indicator to measure the variable-rate applicator performance. Because the size parameters of different fertilizers on the market (such as the average particle mass, particle diameter, surface roughness, etc.) are not the same, the size of different fertilizer particles will affect the uniformity of spreading. The fluted roller mechanism was selected to perform well when applying granular fertilizer with the mentioned factors. The amount of fertilizer is metered by its flutes. With the advantages of simple structure and uniformly applying fertilizer, the fluted roller has been widely adopted within the mechanical design of modern fertilizer spreaders (8). The parameters such as fertilizer metering mechanism (fluted roller, cup feed, and star wheel type), furrow opener (shovel type, shoe type and disc type) and tank shape (rectangular, cylindrical and polygonal) were selected for the laboratory studies. Based on the laboratory experiments and the literature reviews, the components such as fluted roller, polygonal fertilizer tank and double point shovel furrow opener were taken consideration for the design of variable rate applicator. The operational parameters such as forward speed of the tractor and flow rate of the fertilizer which depends on the prescription map data.

Creation of prescription maps : Using a drone the images are captured in a standard RGB or in a multispectral camera and stored. Then the images are cleaned and prepared to study the nutrient stress levels in the field. Geospatial software and statistical tools are commonly used for data analysis. This step involves

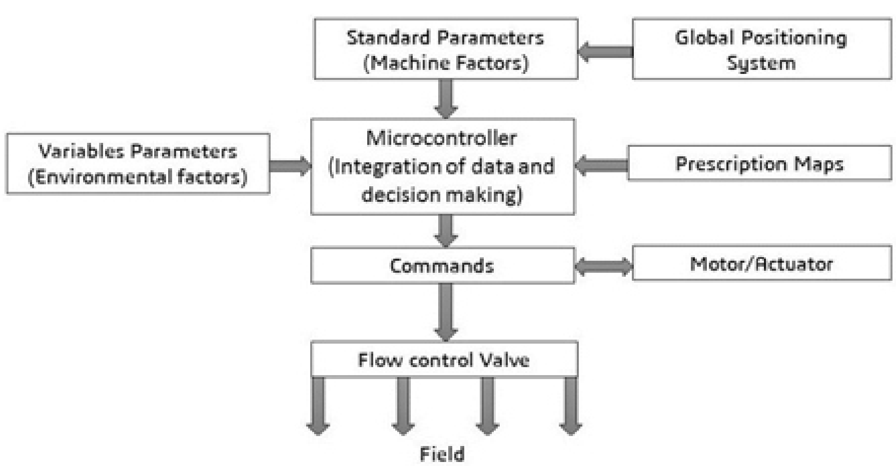

Figure-1 : Workflow of a VRA System.

identifying relationships between soil fertility, yield potential, and other relevant factors to determine the appropriate fertilizer rates for different zones within the field. Based on the calibrated data available from the image processing software, it analyses and compares different layers of information for a full insight of files and generates prescription maps. NDVI maps, most commonly used for agricultural applications, are made from specialized Normalized Difference Vegetation Index (NDVI) images, which are taken with cameras that can see in both the visual and the near-infrared spectrum. NDVI imagery is used to assess whether a certain area has green vegetation or not, based on the amount of infrared light reflected. The map divide the field into distinct management zones with similar soil fertility and yield potential characteristics. Each zone is assigned a specific fertilizer application rate tailored to its nutrient requirements. The prescription map can be represented using different formats, such as a digital file compatible with the variable rate fertilizer applicator or a physical map for manual application. The map-based VRA method in a particular field include the systematic soil sampling, site-specific maps of the soil nutrient, algorithm to develop a nutrient prescription map, controller for variable-rate fertilizer applicator.

The NDVI is based on re?ectance by the plant in infra-red (IR) and near infra-red (NIR) wavebands as follows:

NDVI = (NIR Red)/(NIR + Red)

The NDRE index is calculated by using the reflectances of near-infrared and RedEdge light to the sensor and plugging it into the Normalized Difference Red Edge index (NDRE) equation.

NDRE = (NIR – Red Edge)/(NIR + Red Edge)

Similiarly for different vegetation indices and the formulae are used for creation of the prescription maps as given in Table-1.

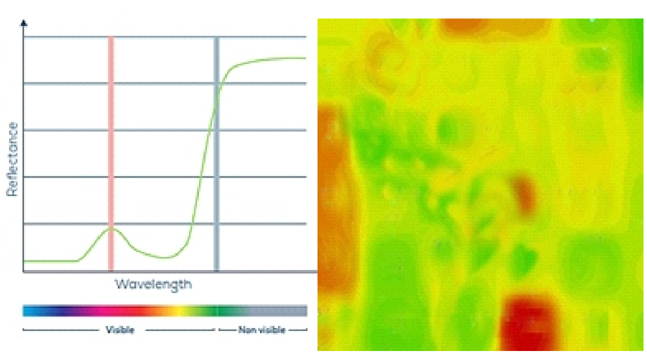

Figure-2 : Electromagnetic Spectrum and Resulted prescription map.

Table-1 : Calculation Formulae of different indices.

S. No.	Indices	Formulae
1.	GNDVI (Green Normalized Difference Vegetation Index)	(NIR - G) / (NIR + G)
2.	SAVI (Soil Adjusted Vegetation Index)	((NIR - R) / ((NIR + R) + 0.5)) * (1 + 0.5)
3.	OSAVI (Optimized Soil Adjusted Vegetation Index)	(NIR - R) / (NIR + R + 0.16)
4.	NDWI (Normalized Difference Water Index)	(R - NIR) / (R + NIR)
5.	MNDWI (Normalized Difference Water Index)	(G - SWR1) / (G + SWR1)
6.	IR/G (Ratio NIR and Green band (simple ratio))	NIR / G
7.	EVI (Enhanced Vegetation Index)	(NIR - R) / (NIR + 6 * R - 7.5 * B) + 1
8.	CVI (Chlorophyll Vegetation Index)	NIR * (R / G ** 2)
9.	GLI (Green Leaf Index)	(2 * G - R - B) / (2 * G + R + B)
10.	RECI (Red-Edge Chlorophyll Vegetation Index)	(NIR / R) - 1
11.	ARVI (Atmospherically Resistant Vegetation Index)	(NIR - (2 * R) + B) / (NIR + (2 * R) + B)
12.	VARI (Visible atmospherically Resistant Index)	(G - R) / (R + G - B)
13.	GCI (Green Chlorophyll Vegetation Index)	NIR / (G - 1)
14.	SIPI (Structure Insensitive Pigment Vegetation Index)	((NIR - B) / (NIR - R)
15.	NDBI (Normalized Difference Built-up Index)	(SWIR1 - NIR) / (SWIR1 + NIR)

Main frame : The main frame was having rectangular section of dimension 1450 x 470 mm. The square channel of 40 x 40 mm mild steel was used to fabricated the mainframe. It was designed basically to accompany the required components.

Fertilizer hopper : The cross section of the fertilizer hopper is polygonal. It has a capacity of 200 kg. It was designed in a 3 mm stainless steel sheet to avoid corrosion and chemical actions. The angle of repose or, more precisely, the critical angle of repose, is the steepest angle of descent or dip of the slope relative to the horizontal plane when material on the slope face is on the verge of sliding. The angle of repose is studied for the flutted roller metering mechanism and found that 25° - 35° inclination at the site of metered wheel helps better flow and prevents clogging.

The developed machine has of three main units, viz. control unit, hydraulic unit, mechanical unit. The major components are cultivator in which the fertilizer tank is mounted, agitator, metering mechanism, microcontroller, GPS module, magnetometer sensor, accelerometer sensor, servo motors, flow sensors, flow rate controller, conveyor tubes and power cords. The complete CAD design is shown in the Figure-3 and 4.

Mechanism of a VRA

The mechanism of a VRA typically involves several key

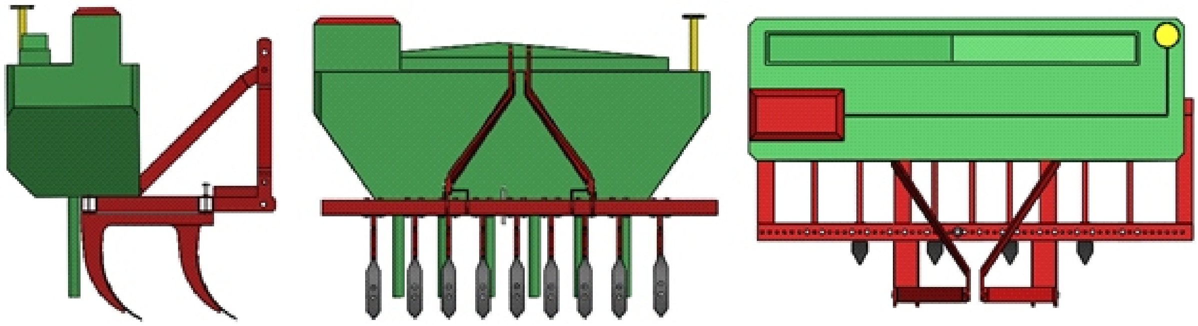

Figure-3 : Side View, Front View and Top View of VRA.

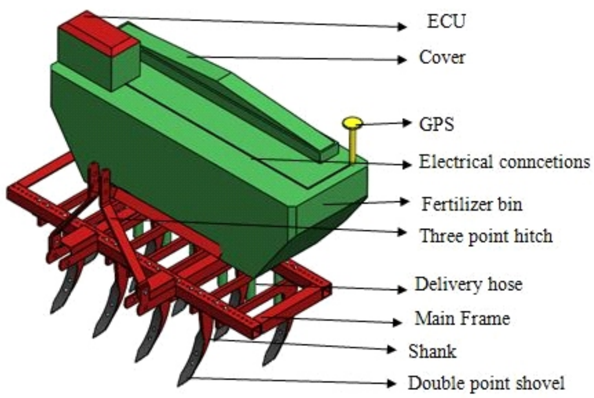

Figure-4 : Isometric View of a Variable Rate Applicator.

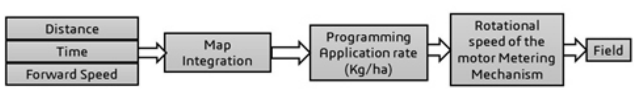

Figure-5 : Sequence of operation.

components that work together to achieve precise and adjustable actuation. The control system is responsible for monitoring and regulating the operation of the VRA. It typically includes sensors that provide feedback on the position, velocity, and other relevant parameters of the actuator. This feedback is used to adjust the actuation parameters and achieve the desired performance. The transmission system transmits the energy from the power source to the actuation mechanism. The actuation mechanism may employ mechanisms like gears, levers, linkages, or direct drive systems to achieve the required motion. The control algorithm may utilize proportional-integral-derivative (PID) control, model-based control, or other advanced control techniques to achieve precise and responsive actuation. The feedback loop is an essential part if any discrepancies between the desired and actual values are fed into the control algorithm, which adjusts the actuation parameters to minimize the error and maintain accurate control.

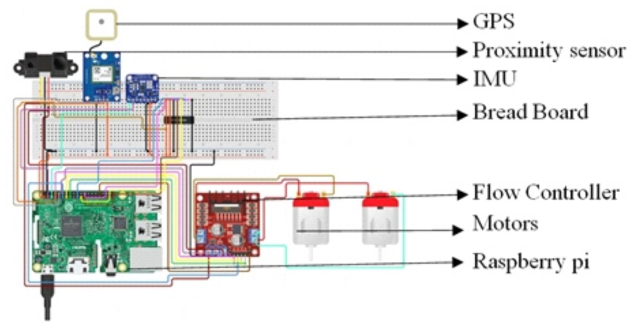

Figure-6 : Circuit design for VRA.

The DGPS module device connects to GPS satellites to retrive its location. Also provides the current time and date. The infrared proximity sensor shines a beam of IR light from an LED, and measures the intensity of light that is bounced pack using a phototransistor. The IR sensor is more economical than sonar rangefinders, yet it provides much better performance than other IR alternatives. Interfacing to most microcontrollers is straightforward: the single analog output can be connected to an analog-to-digital converter for taking distance measurements. The Triple-axis Accelerometer and Magnetometer (Compass) Board combines a accelerometer with a magnetometer (compass) module to create a navigation system and IMU (Inertial Measurement Unit). A DC motor driver with DC motors enables the speed and flow control for fluted rollers. The 2.4G Wireless Transceiver Module was provided to transfer the data easily. The circuit design is shown in the Figure-6.

Metering Mechanism : The mechanism which picks up fertiliser from the fertiliser bin and delivers it into the delivery hose is called a fertiliser metering mechanism.

Among various metering mechanisms, the fluted roller metering mechanism was selected for the development of the variable rate fertiliser applicator. The heart of the metering mechanism is the fluted roller. It consists of a cylindrical drum with flutes or grooves running along its surface. The number and size of the flutes can vary depending on the desired flow rate and the characteristics of the fertilizer being used. The fluted roller rotates as the applicator moves forward. The fluted wheel also known as fluted roller is driven by a square shaft. The rotation can be driven by a ground-driven wheel or through a mechanical or hydraulic system powered by the applicator's engine or power take-off (PTO). The fluted roller mechanism is shown in the Figure-7. As the fluted roller rotates, the flutes pick up fertilizer from the hopper. The flutes create voids that capture the fertilizer, and as they continue rotating, the fertilizer is carried along the surface of the roller. There are horizontal grooves provided along the outer periphery of the wheel and the wheel can be shifted sideways depending upon the variable feed rate. These rollers are mounted at the bottom of the fertiliser box. Variable dose is performed by controlling the rotation of metering device rotor by meant of controlling the rotation of a DC motor. The speed of the roller was programmed for a desirable application rate to dispense the fertilizer as shown in Figure 8. They receive the fertiliser granules in the longitudinal groves and pass on to the delivery tube.

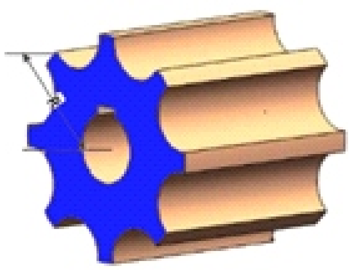

Figure-7 : Fluted roller metering mechanism.

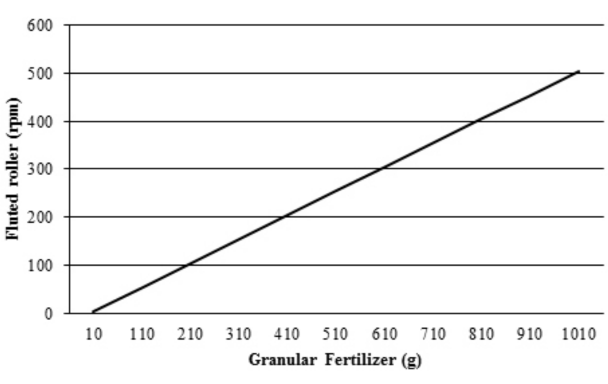

Figure-8 : Quantity of Fertilizer Spread (g).

Furrow openers : The choice of furrow opener depends on factors such as the type of crop, soil conditions, and specific equipment used. Among the different varieties of furrow openers the shovel type furrow openers are double point shovels were selected. There are nine shovels which are bolted to the shanks at their bottoms of the VRA. Shoe openers are designed to create a narrow slot or furrow in the soil for fertilizer placement. They feature a curved or V-shaped shoe that pushes the soil aside, creating a furrow without turning the soil. Shoe openers are often used in precision planting systems, as they minimize soil disturbance while providing accurate fertilizer placement. The granules travel through the tube and reach the furrow. It was found that shovel type openers are best suited for stony and root infested fields

Conclusions

VRA contributes to environmental sustainability by minimizing nutrient losses from agricultural fields, particularly nitrogen and phosphorus, which can negatively impact water bodies and ecosystems. By applying fertilizers precisely where they are needed, VRA reduces the risk of nutrient runoff into nearby water sources, which can cause eutrophication and harm aquatic life. Additionally, VRA helps prevent over-application of fertilizers, reducing the potential for nutrient leaching into groundwater. By improving nutrient use efficiency and minimizing environmental impacts, VRA supports sustainable agriculture practices and helps protect water quality and ecosystem health. By applying fertilizers at rates tailored to the nutrient requirements of different zones within a field, farmers can reduce over-application in areas with high soil fertility and ensure adequate nutrient supply in areas with lower fertility. This targeted approach helps to optimize nutrient utilization, minimize nutrient losses, and reduce environmental impacts. In this paper, the selection and design of various components to development of variable rate applicator were explained. The creation of appropriate farm machinery that works safely, reliably and well under actual field conditions on the farm, concerns with the mechanisms required to convert the output of machines to the desired form. This design may lead to entirely a new way of fertilizer applicator improvement over the existing high cost machines.

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