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Design and Development of Site Specific Grape Vineyard Fertilizer Applicator Prototype

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The current fertiliser application methods for grape vines are labour intensive and lead to overuse of fertiliser. Frequent rain and vineyard orchard wash over often pollute water sources. Therefore, the right amount and placement of fertiliser can not only improve crop growth but also reduce the risk of chemicals to human health and the environment. To overcome the above problems a site specific fertiliser applicator for grape vineyard with mechanical sensing system was developed. The sensing system was designed to apply fertiliser to the root zone of the plant canopy. An experimental unit was developed to optimise design and operation parameters for fertiliser production per plant. The urea's physical and engineering qualities were determined for metering mechanism design. The average value of bulk density, angle of repose, urea grain diameter, grain weight in single flute measured were 0.759 ± 0.011 gcm^{-3}, 26.22 ± 1.18°, 3.38 ± 0.23 mm, 1.46 ± 0.04 g, respectively. The coefficient of static friction with plywood, galvanised iron and mild steel with painted surface were observed 0.3177 ± 0.0092, 0.2868 ± 0.0077, and 0.3177 ± 0.0092, respectively. For fertiliser given per plant, the effect of exposure length was $p < 0.001$. The sensor device opens the delivery tube for fertiliser in 0.9–0.95s.

Keywords: Angle of repose, Bulk density, Green revolution, Mechanical sensing system, *Vitaceae*

Introduction

India is an agrarian economy employing more than 50% of the Indian work force and contributes 17–18% to the country's GDP during 2018.[(1)] The production of food grains and horticultural crops is 296.65 and 319.6 MT respectively, during 2019–2020.[(2)] The present elevation in Indian agriculture is attributed to use improved high-yielding varieties, fertilizer, manure, chemicals etc., and some of the important policy decisions taken during green revolution in 1960s. Moreover, with burgeoning population, the country faces the challenge to meet the food demand. In addition, segregation of net cultivatable land (140.82 million hectare), limited natural resources and climate change are major threat for cultivars. Thus, sustainable utilization of limited agricultural inputs is required to meet the food and nutritional need of the population. To achieve the nutritional demand of the country, production of horticultural produce along with agricultural practices need to be modernized.[3] Moreover, apart from meeting the nutritional demand, horticultural produce further adds commercial value with high export potential. Therefore, precise use of agricultural inputs at right time and proper place is necessary to enhance the quality and quantity of horticultural crops.

Grape (*Vitis* sp.) which belongs to family *Vitaceae* is one of the most popular and commercially important crops among the horticultural cultivars. The crop is grown under versatile agro-climatic conditions namely hot tropical, mild tropical and sub-tropical climatic environment in India. The agronomical requirement of crop differs with variety and soil conditions. It is generally grown in spacing of 6 m × 3 m (or 4 m × 3 m) and 3 m × 3 m (or 3 m × 2 m) for vigorous varieties and less vigorous varieties respectively.[4,5] These varieties require proper nutrition for their growth and production. Application of fertilizer is needed to enhance yield, growth and physiological properties of grapes.[6] The correct placements often improve efficiency by which vines take up nutrients and consequently encourage acceptable yields and the production of marketable fruit. Fertilizers and manure at the affected part supply nutrients to soils and help to correct nutrient deficiencies of soil.

Vineyards are generally grown in sandy loam or heavy clay soil. The agronomical requirement of N, P_2O_5 and K_2O per hectare is 500:500:1000 and

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660:880:660 kg for light sandy and heavy clay soils respectively. The petiole analysis is carried out annually after 45 days spur pruning to fix the fertilizer dosage. The annual dosage is given 60 percent through inorganic fertilizer and 40 percent through organic sources.[5] Many placement techniques are available for fertilizer application among growers.

The most commonly used methods for delivering the solid fertilizers are broadcasting, band placement, and pellet application.[7] In broadcasting the applied fertilizer are not fully utilized and it also aids the weed growth near the root zone. Also, it is slow, non-uniform application and having erosion risk. Pellet handling is not uniform, and pellets may adhere to forceps during handling. Band application is costly, slow and may cause salt burn to plant.[7] Fertilizers are applied to the soil in millions of tonnes to promote crop development. However, over and low use of fertilizer results in wastage of chemicals and adversely affects public health and contaminates the ecosystem**.**

Compared to broadcasting and pellet application, placing the fertilizer in well prepared soil near the plant root zone ensures better crop management, uniform growth, less production cost and high crop yield. All these conventional methods discussed above are labour intensive, lower efficiency, time consuming, non-uniform application of fertilizer and manure in field.[8,9] Therefore, a suitable management technique is required for placement of fertilizers near to the root zone of the crop instead of a uniform distribution over the whole area to promote more growth and more effective use of plant nutrients due to limited movement of fertilizers in the soil.[10]

Presently, fluted roller metering mechanism is used to meter the fertilizer and is powered by the ground wheel. The rotating fluted roller directly meters the fertilizer and transfers it to the fertilizer tube. Development of cut-off mechanism for dispensing the fertilizer close to the plant root zone necessitates the identification of design and operational parameters for the metering unit. In this study an attempt has been made to develop site specific fertilizer applicator for grape vineyard. The investigation is intended to identify best suitable combination of design parameters of the metering mechanism and operational parameters affecting the distribution and placement of the fertilizer.

Material and Methods

The site specific fertilizer applicator was developed and fabricated in research workshop of ICAR-Central Institute of Agricultural Engineering, Bhopal. The evaluation was carried out in seeding and planting laboratory.

Measurement of Physical and Engineering Properties of Urea

The bulk density, angle of repose, coefficient of static friction, weight of urea grains in a single flute and average grain diameter was measured for urea and used for design of hopper and fertilizer metering mechanism. The bulk density (ρ_b, gcm^{-3}) is expressed as the mass of the fertilizer bulk sample to the volume of measuring cylinder.[11] The weighing balance and 400 ml measuring cylinder was used for measurement of weight and volume for estimation of bulk density at given moisture content.

Angle of repose affects the movement of fertilizer from the fertilizer box to the metering mechanism. It was determined by using an angle of repose apparatus. The apparatus is of inverted conical shape with a sliding gate at the bottom and circular base of 450 mm diameter for material deposition. The apparatus was filled with neem coated urea, and the sliding gate at the bottom was slowly removed until it formed a cone on the circular base. The diameter and height of the cone formed was recorded. Using the following equation, the angle of repose (θ) was obtained.[12]

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right) \quad \ldots (1)$$

where, H = height of the cone formed on the circular base, cm and

D = diameter of the cone, cm

Three surfaces namely galvanized iron, plywood and mild steel with painted surface was used for measurement of coefficient of static friction. Urea filled into the wooden box was used to slide on an adjustable tilting table without its direct contact the table surface. The angle of the surface was recorded from a scale and the static coefficient of friction was taken as the tangent of this angle. Same method has been used by the other researchers for measurement of static coefficient of friction of grains and seeds.[11–13]

The amount of urea delivered per revolution of fluted roller estimated by measuring weight of urea in a single flute for given no of flutes on the roller. Digital Vernier Calliper was used to measure average grain diameter by taking sufficient number of replications.

Experimental Set Up for Laboratory Test

The optimal operating parameters for precise metered application of urea were tested over sticky

Fig. 3 — Effect of Exposure length on amount of urea delivered (at different forward speed, kmh^{-1})

Fig. 4 — Effect of operational parameters (i.e. Forward speed) on urea amount delivered (at different exposure length, mm)

Table 4 — ANOVA for amount of urea delivered per plant

Source	DF	Type III SS	Mean Square	F Value
Exposure length	3	25211.24	8403.74	511.69
Forward speed	4	227.55	56.88	3.46
Exposure length * Forward speed	12	676.53	56.37	12.71

Table 5 — Comparison between the parameters by using DMRT

Means with the same letter are not significantly different (Amount of urea, g)

Forward Speed, kmh^{-1}	Mean	Exposure Length	Mean
2	51.23^{a}	8	24.10^{a}
2.5	50.68^{a}	16	35.64^{b}
3	47.42^{b}	24	57.01^{c}
3.5	46.89^{b}	32	77.62^{d}
4	46.76^{b}	—	—

fertilizer dropped increased with increase in the exposure length. Increase in volume of fluted metering roller with increase in exposure length is attributed for this trend.

The Coefficient of Variation (CV) of amount of fertilizer delivered to per plant was found to be in the range of 15 to 22% for all forward speeds of 2, 2.5, 3, 3.5 and 4 kmh^{-1}, which is within acceptable range for fertilizer application. As the forward speed increased from 2 to 4 kmh^{-1}, CV values increased from 13.5 to 22 per cent which was in acceptable ranged as reported.[14] It shows that this mechanical dispensing system could maintain uniform fertilizer delivery per plant basis in the range of tested forward speeds. This analysis indicates that the increase in forward speed (Fig. 4) decreases the amount of urea delivery between forward speed 2 to 4 kmh^{-1}. This may be due to increase in forward speed which increases rpm of fluted roller from 30 to 59 rpm, resulted in reduction in filling percentage of fluted roller.

The ANOVA results (Table 4) revealed that exposure length had a significant effect on the amount of fertilizer provided per plant, with a $p < 0.001$ significance level. Further, DMRT performed for exposure lengths, which indicated all the levels affected significantly different in terms of fertilizer amount delivery. Similarly, forward speed has shown significant effect on amount of fertilizer delivery at $p < 0.001$. Even this found significant, seeing at size of metering mechanism and fertilizer application in grapes crop, this difference in fertilizer amount can be considered variation caused due to several other operational parameters and has least practical implication. Further DMRT analysis (Table 5), reveals that the effect of the forward speed at 2 and 2.5 kmh^{-1} was significantly different from other levels of forward speed, results are in confirmation with researcher.[15] This indicates there is no limitation from mechanical sensing system from point of view of its triggering as grape tree spacing is offering more time than required for single triggering of actuation of mechanical dispensing system. The interaction effect of exposure length and forward speed was also found to be highly significant at $p < 0.0001$. Furthermore, from the laboratory experiments it was established that there was significant change in fertilizer delivery rate per plant at varying exposure length of the fluted roller. This result is in confirmation with the method used by various researchers to change the rate of fertilizer by manipulating the exposure length of the fluted roller.[15] Indeed; adjustment of exposure length of the fluted roller was used instead of change in speed ratio of the transmission system for adjusting the fertilizer delivery rate.

The regression model was fitted between response variable (amount of fertilizer delivered per plant) and independent variables using linear and quadratic regression model (Table 6). It was observed that the linear model can be fitted to response and independent variables at $p < 0.0001$. Likewise, the quadratic model was significant at $p = 0.0004$. In addition, the interaction effect of exposure length and

Table 6 — Regression model of performance parameter (amount of fertilizer delivered per plant) against the independent variables

Regression	DF	Type I Sum of Squares	R-Square	F Value	Pr > F
Linear	2	24823	0.9441	629.27	<0.0001
Quadratic	2	354.163072	0.0135	8.98	0.0004
Cross product	1	50.384628	0.0019	2.55	0.1158
Total Model	5	25228	0.9595	255.81	<0.0001

forward speed was non-significant at $p < 0.005$. The reason for non-significant model for the interaction is attributed to the contribution of forward speed in the regression model. It was confirmed that increase in forward speed has nominal effect of fertilizer delivery rate.

Conclusions

A simple, robust and low cost mechanical plant sensing and precise fertilizer dispensing mechanism evolved as an alternative to sensor and electronics based sophisticated precision fertilizer application system. Precise site specific fertilizer delivery affected significantly by exposure length of fluted roller and forward speed of the machine. Exposure length of fluted roller contributed proportionally in increasing amount of urea delivered, which is easiest way for modifying application rate in certain range without any alteration in the speed ratio of designed system. Although, forward speed found significant effect on fertilizer delivery, it shows decreasing trend with amount of fertilizer delivery. However, practically it is of least consideration as mostly tractor is operated in the range of 1 to 3 kmh^{-1} during fertilizer application depending on field conditions, soil type, row to row spacing of orchard crop and size of power unit to pull application fertilizer application machinery through field. Also, wider plant to plant spacing gives enough time for completion of entire cycle of plant sensing, triggering and dispensing of precise quantity of fertilizer and final placement of its target root zone near to plant. The CV values of amount of fertilizer delivered per plant basis was found in the acceptable range (13.5 to 22%) for all levels of exposure length of fluted roller and forward speed which suggest reasonable uniformity for fertilizer application in the orchard field. This developed system is suitable to all widely spaced orchards having row to row spacing of 2.5 to 3 m presently, but can be modified to suit for more wider row to row spacing's.

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