Indian Journal of Agricultural Sciences **94** (12): 1381–1384, December 2024/Short Communication
https://doi.org/10.56093/ijas.v94i12.145145

Drone-based foliar nutrient spray improves physiology, nutrient uptake and yield of greengram (*Vigna radiata*)

T RAMESH[1]*, K DAYANA[1], S RATHIKA[1] and S PAZHANIVELAN[2]

Anbil Dharmalingam Agricultural College and Research Institute (Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu), Tiruchirappalli, Tamil Nadu 620 027, India

Received: 10 November 2023; Accepted: 30 August 2024

Keywords: Drone, Foliar spray, Greengram, Grain yield, Physiology, Spray fluid

Greengram [*Vigna radiata* (L.) Wilczek] is the third most important and significant short duration pulse crop in India (Ramesh *et al.* 2023). Increasing greengram production is essential to ensure food security and affordability of the Indian population. The average yield of greengram is low mainly due to cultivation under rainfed condition and low level of input use. Greengram produces large number of flowers but few of them are retained. Abscission of flowers, low partitioning efficiency and shedding of pods are the main reasons for low productivity of greengram (Kunjammal and Sukumar 2019). Foliar nutrients application at flowering stage of greengram certainly improves the crop physiological growth, reduces flower drop, improve pod and seed setting and finally boost productivity to meet the demand raised by the ever-increasing population of our country.

Pulse wonder is a foliar nutrition product developed by Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu mainly to boost the yield of pulses. It contains macro- and micro-nutrients that are water soluble and facilitate better complete absorption that increases crop growth and development. It is recommended to all pulses at 1% concentration in 500 litre of water/ha through manual spray. It increases yield by 10% by decreasing flower shedding in pulses and offers better moisture stress tolerance to the crop (Mandre *et al.* 2020). The existing practice of manual spray of nutrients requires more time, resources and skilled labour. Labour scarcity and increased labour wages are serious concerns for the farmers to adopt foliar spray of nutrients and pesticides. Many times, the cost of spraying is higher than cost of inputs. Under these circumstances, drones for foliar application offers cost-effective and timely operation. Drone is an unmanned aerial vehicle gaining popularity in agriculture, to help in crop production, protection and crop health monitoring. When drones are to be used for foliar spray, the spray volume and nutrient concentration need to be standardized to have better nutrient-use efficiency over existing manual spray. Since the operation time and speed of a drone is many times higher than manual spray, the spray volume has to be optimized. Further, when the spray volume is reduced in drone spray, the nutrient concentration has to be standardized to avoid less or excess use of nutrients. But, no studies on foliar spray of nutrients in greengram using drones are available. Hence, the present study was carried out to optimize the spray volume and nutrient concentration for drone application of nutrients to accelerate the physiological growth, nutrient uptake and productivity of greengram.

The present study was carried out during summer 2021 at Anbil Dharmalingam Agricultural College and Research Institute (Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu), Tiruchirappalli (10º45' N, 78º36' E and 85 m amsl). The experimental soil was sandy clay with a *p*H of 8.9. The soil contained 0.42% organic carbon, 189: 17.8: 246.1 kg/ha available NPK, respectively. The experiment was conducted in randomized block design (RBD) with 7 treatments, replicated thrice. The test area of each treatment was 200 m^2 (20 m × 10 m). Treatments consisted of 1% and 2% nutrient solution (TNAU pulse wonder), two levels of spray volume (30 and 50 litre/ha) for drone application, manual spray (500 litre/ha spray volume) and control. The drone model AD610D utilized for spraying. Flight height at 1.5 m and spraying swath at 3.5 m were maintained during spraying. Drone flying height, flight velocity and GPS were pre-determined for the experimental site and controlled by a well-trained operator. A flat fan type of nozzle was used for spraying.

Greengram variety VBN (4) was sown (30 cm × 10 cm spacing) on 21 April 2021. The recommended fertilizers dose @25:50:25 kg/ha NPK was applied as basal before sowing. The crop was irrigated immediately after sowing and

[1]Anbil Dharmalingam Agricultural College and Research Institute (Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu), Tiruchirappalli, Tamil Nadu; [2]Water Technology Centre, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. *Corresponding author email: ramesht@tnau.ac.in

life irrigation was given at 3 DAS. Subsequent irrigations were given to the crop on 7–10 days' interval based on crop demand and weather conditions. Totally 4 irrigations were given during the cropping period. Total rainfall of 320.2 mm was received in 9 rainy days during cropping period. Mean maximum and minimum temperature of 36.6ºC and 25.8ºC were recorded, respectively. Mean relative humidity of 81.2% at 07.16 h and 41.2% at 14.16 h was recorded. Mean sunshine hours and wind velocity were 7.2 h/day and 5.8 km/h, respectively. Mean pan evaporation per day was 6.4 mm/day. For weed management, pre-emergence herbicide pendimethalin 30% EC at 1.0 kg/ha was applied on 3 DAS followed by one hand weeding on 30 DAS. Pulse wonder was sprayed during peak flowering stage (45 DAS) and data were recorded at before spray, 15 days after spray and at harvest. The matured pods of greengram were harvested in plot wise at 65–73 days in staggered manner. The harvested pods were sun dried, threshed and winnowed. Finally, total grain yield was quantified.

Ten plant samples were uprooted randomly from each plot on 15 days after foliar spray. These collected samples were first air dried and then oven dried at a temperature of 65 ± 5ºC until a constant weight to obtain dry matter production (DMP), which was used for growth analysis.

The crop growth rate (CGR) (g/m^2/day) was calculated as (Watson 1952):

$$CGR = (w_2 - w_1)/ p\ (t_2 - t_1)$$

The relative growth rate (RGR) (g/g/day) and net assimilation rate (NAR) (mg/cm/day) were calculated as (Williams 1946):

$$RGR = \frac{\log_e w_2 - \log_e w_1}{t_2 - t_1}$$

where W_1, Whole plant dry weight at t_1; W_2, Whole plant dry weight at t_2 and t_1; and t_2, Time interval in days.

$$NAR = \frac{w_2 - w_1}{t_2 - t_1} \times \frac{\log_e l_2 - \log_e l_1}{l_2 - l_1}$$

where W_1 and W_2 are dry weight of the plant (mg) at times t_1 and t_2; t_2–t_1, Time interval; L_1 and L_2 are leaf area (cm^2) at t_1 and t_2, respectively.

The chlorophyll content was measured using a chlorophyll meter (SPAD 502 meter) on 10 randomly selected fully opened leaves (Peng *et al.* 1993). Chlorophyll a, chlorophyll b and total chlorophyll were estimated using the acetone method given by Arnon Daniel (1949). Soluble protein and nitrate reductase activity were estimated as the procedure given by Lowry *et al.* (1951) and Nicholas *et al.* (1976), respectively. Plant samples collected from individual plots at harvest stage were analysed for nitrogen uptake (Humphries 1956) and phosphorus and potassium uptake (Jackson 1973). From the net plot area, the grain yield was obtained at harvest stage. Experimental data collected was statistically analysed as outlined by Panse and Sukhatme (1967).

Physiological parameters: Application of pulse wonder 2% with spray volume of 50 litre/ha using drone exhibited significantly higher crop growth rate (CGR) (7.22 g/m^2/day), relative growth rate (RGR) (0.0407 g/g/day), NAR (0.1921 mg/cm^2/day), SPAD reading (43.1), chlorophyll a (0.856 mg/g), chlorophyll b (0.236 mg/g) and total chlorophyll (1.114 mg/g), soluble protein (44 mg/g) and nitrate reductase activity (102 µg NO_2/g/h) over manual spray and control (Table 1). However, this was statistically comparable with application of Pulse wonder 2% in spray volume of 30 litre/ha and pulse wonder 1% in 50 litre/ha spray volume. Pulse wonder at 2% in 30 litre/ha spray volume registered 8.4, 16.6 and 9.8% higher leaf chlorophyll (SPAD reading), soluble protein and nitrate reductase activity, respectively over manual spray. The combination of phytohormones, growth regulators and macro and micronutrients nutrients present in the Pulse wonder positively influenced the plant growth rates (Kunjammal and Sukumar 2019), chlorophyll content, auxin levels, enhanced photosynthetic enzyme synthesis and higher nitrate reductase activity. Pulse wonder contains a cofactor enzyme-magnesium that increases a catalytic role resulting in higher soluble protein (Sivakumar and Jaya Priya 2017). Pulse wonder was more effectively absorbed under drone application than manual spray might be due to

Table 1 Effect of foliar application of pulse wonder using drone on growth analysis, physiological parameters and yield of greengram

Treatment	CGR (g/m^2/day)	RGR (g/g/day)	NAR (mg/cm/day)	SPAD value	Chlorophyll a (mg/g)	Chlorophyll b (mg/g)	Total chlorophyll (mg/g)	Soluble protein (mg/g)	Grain yield (kg/ha)
DS Pulse wonder 1% in 30 litre/ha	5.64	0.0339	0.1659	39.5	0.678	0.178	0.866	37	668
DS Pulse wonder 1% in 50 litre/ha	6.64	0.0383	0.1835	41.6	0.799	0.219	1.029	41	700
DS Pulse wonder 2% in 30 litre/ha	6.96	0.0396	0.1880	42.5	0.831	0.227	1.059	42	723
DS Pulse wonder 2% in 50 litre/ha	7.22	0.0407	0.1921	43.1	0.856	0.236	1.114	44	747
MS Pulse wonder 1% in 500 litre/ha	5.40	0.0328	0.1621	39.2	0.667	0.171	0.852	36	666
MS Pulse wonder 2% in 500 litre/ha	5.89	0.0350	0.1687	40.0	0.749	0.189	0.927	39	677
Control	4.04	0.0260	0.1295	36.1	0.517	0.135	0.643	33	574
SEm ±	0.26	0.0016	0.0077	1.36	0.029	0.008	0.040	1.7	30
CD (*P*=0.05)	0.58	0.0035	0.0168	2.97	0.065	0.017	0.087	3.7	65

CGR, Crop growth rate; RGR, Relative growth rate; NAR, Net assimilation rate; DS, Drone spray; MS, Manual spray.

uniform distribution, a greater number of droplets, maximum penetration of nutrients on the active site of the leaf (abaxial surface) due to turbulence caused by drone resulted in higher chlorophyll a, chlorophyll b, total chlorophyll, soluble protein and nitrate reductase activity in greengram. The advantages of drone spray over manual spray were confirmed by Yang *et al.* (2018).

Grain yield: Significantly higher grain yield (30.1% more grain yield than control) was exhibited with drone application of pulse wonder 2% with spray volume of 50 litre/ha (Table 1). However, this was statistically comparable with pulse wonder 2% in 30 litre/ha spray volume and 1% pulse wonder + spray volume of 50 litre/ha. The increased grain yield was attributed to a balanced supply of nutrients from pulse wonder have improved the partitioning of assimilates and overall transport efficiency with the ability of biotic and abiotic tolerance, reduced flower shedding and increased seed setting percentage resulted in greater number of pods/plants, seeds/pod, pod length and pod weight (Marimuthu and Surendran 2015). Delayed senescence in continuous translocation of photosynthates, which was also an important reason for increased yield. Between spraying methods, application of Pulse wonders 2% with 30 as well as 50 litre/ha spray fluids registered 8.5 and 12.1% more grain yield respectively over manual spray. Enhanced absorption of nutrients from the Pulse wonder under drone application over manual spray was mainly because of the rotation of the propellers and the interaction of air generated a downwash air flow that fluttered and flipped the leaves over, thus facilitating maximum deposition of spray droplets from top to bottom of the crop canopy (Yang *et al.* 2018). Finer droplet size under low spray volume application facilitates maximum spray coverage and droplet penetration on the active site of leaves (Martin *et al.* 2020). The flight height operated at 1.5 m above the ground exhibited uniform distribution of nutrients with higher efficiency than manual spray (Qin *et al.* 2016). All the factors together resulted in higher absorption of nutrients by the crop, thus reflected in increased physiological parameters, better crop growth and yield. Between two nutrient concentrations, 2% performed better than 1% concentration, which might be due to increased dosage and absorption. Spray fluid used in the drone at 30 and 50 litre/ha was statistically comparable.

Nutrient uptake: Foliar application of Pulse wonder 2% using drone with spray volume of 50 litre/ha registered significantly more N uptake of 53.6 kg/ha, P uptake of 11.6 kg/ha and K uptake of 37.8 kg/ha over knapsack spray and control (Fig. 1). Pulse wonder as a foliar nutrient using drone supplied a readily available form of balanced nutrient for efficient absorption, which improved the photosynthetic rate, nutrient content and DMP of greengram and thus increased NPK uptake (Rajeshkumar *et al.* 2017). Further, increased nitrate reductase activity improved the N assimilation, in plant and consequently higher nitrogen uptake.

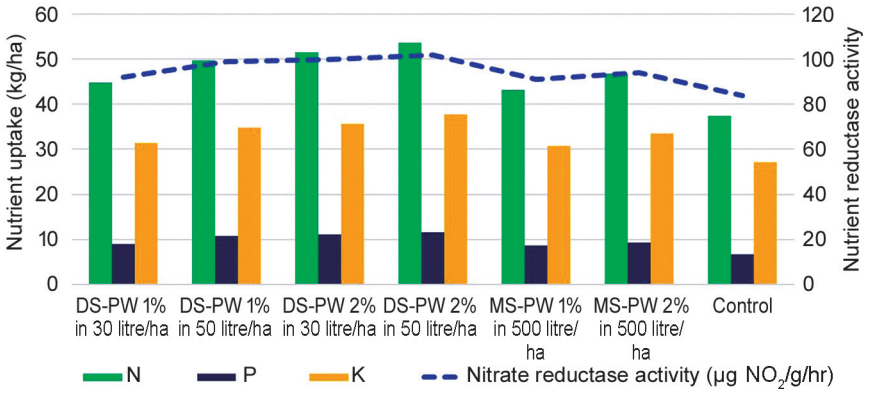

Fig. 1 Effect of foliar application of Pulse wonder using drone on NPK uptake and nitrate reductase activity of greengram.
DS-PW, Drone spray-Pulse wonder; MS-PW, Manual spray-Pulse wonder.

SUMMARY

The present study was carried out during summer 2021 to optimize the spray volume and nutrient concentration for drone application of nutrients to accelerate the physiological growth, nutrient uptake and productivity of greengram. The experiment was conducted in randomized block design (RBD) with 7 treatments, replicated thrice. Treatments consisted of 1% and 2% nutrient solution (TNAU Pulse wonder), two levels of spray volume (30 and 50 litre/ha) for drone application, manual spray (500 litre/ha spray volume) and control. The results showed that foliar application of nutrients through drones in greengram at flowering stage increased the physiological growth, nutrient uptake and yield over manual spray. Spray fluid used in the drone at 30 and 50 litre/ha was statistically comparable with each other, indicating that 30 litre/ha is sufficient for nutrient spray. When compared to 500 litre/ha spray fluid under manual spray, the drone used only 30 litre, with a reduction of 470 litre/ha (94%). However, the concentration has to be increased from 1–2% under drone application to have a significant effect. From the present study it may be concluded that drones could be effectively used for foliar application of Pulse wonder 2% with spray volume of 30 litre/ha at flowering stage, for better plant physiological activities, nutrient uptake and yield of greengram under the current scenario of labour scarcity in agriculture.

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