



CONSTANT HEAD GRAVITY FEED PUMPING SYSTEM FOR METERING AQUEOUS FERTILIZER

Kamal Kant, Indra Mani, Pushpa Devi and Ram Pyare

Chandra Shekhar Azad University of Agriculture and Technology, Kanpur- 208002 (U.P.)

Email: kamal_iari@rediffmail.com, Mobile 9412502884

ABSTRACT

Uncertainty of soil moisture at the time of sowing is the main bottleneck in crop production in the rain fed areas as it creates problem in proper germination of seed and good establishment of crop in the initial stage. A tractor drawn aqua-ferti seed drill based on peristaltic pumping system for enhancing water productivity in rain fed areas has been reported. Keeping the limitations of peristaltic pump in view, a tractor drawn aqua ferti seed drill based on gravity feed system using rotary gear pump was developed. The heart of the machine is aqueous fertilizer metering system using constant head gravity feed mechanism with variable nozzle sizes. The constant head in the aqueous fertilizer tank was maintained by supplying required amount of aqueous fertilizer using rotary gear pump. To determine optimum design values of machine parameters an experimental set up was developed to vary head and nozzle sizes to optimize discharge from different nozzles. The metering system consisted of a rotary gear pump having maximum discharge of 50 l/min. at an rpm of 1450, two symmetrically mounted water tanks for supplying aqueous fertilizer to another centrally mounted water tank where a constant aqueous fertilizer level was maintained. The constant head levels were 47.5, 42.5, 37.5, 32.5 and 27.5 cm. The pumping system also consisted of nine nozzles having 10, 8, 6 and 4 mm opening connected to a 96 mm dia tube nine in number carrying aqueous fertilizer directly to the nine respective furrows of the machine. The system was test evaluated and for a liquid head of 47.5 cm and 10 mm nozzle opening the pumping unit gave a maximum discharge of 9650 l/ha which meets the requirement of wheat crop in dryland areas.

Keywords : Gravity, feed pumping, aqueous fertilizer

Dry land agriculture constitutes about 67 % of total cultivated area (118 Mha) in India and contributes 42% to food production with average productivity of 0.7 to 0.8 t/ha. Timeliness is more important in rain fed farming to utilize the available moisture for crop establishment. Uncertainty of soil moisture during sowing time is the main bottleneck in crop production in the rain fed areas as it creates problem in proper germination of seed and good establishment of crop in the initial stage. Also, in absence of moisture the applied fertilizer remains unavailable to the plant due to

inadequate soil water to dissolve, dilute and convey it to the root depth level.

The solution of the problem lies in making nutrient rich moisture at seeding depth during sowing time helps in successful germination and initial root and shoots development as in aqueous form fertilizer is readily available to the plants when applied in the liquid form Tiedjens (1944). Once this happened, the root moves beyond seeding depth to draw stored moisture from lower soil depth for further growth and development of plants. Minhas (1982) and Anonymous (1996) recommended that

application of aqueous fertilizer has a potential for increasing grain yield for dry land crops. But adoption of liquid fertilizer is limited due to absence of any proven techniques for its application (Singh and Singh, 1982). Smith *et al.* (1975) developed a micro nutrient applicator for orchards.

The applicator consisted mainly a tank, a recirculation pump which was driven by tractor PTO. Scotfort *et al.* (2001) developed a prototype slurry spreading system, using a commercially available pump and discharge tank. The system featured a positive displacement slurry pump, an electrically operated flow control valve and a novel spreading boom with fluidic diode. Salyani (1999) studied the relationship between pressure setting and nozzle flow rate for sprayers using positive and non-positive displacement pump system. Dey *et al.* (2006) developed a tractor drawn aqua seed drill using peristaltic pumping system for metering aqueous fertilizer.

The main problem faced in this system is cumbersome metering mechanism on rotating reel with potential wear of water carrying tubes. An easy to operate design of aqueous fertilizer metering system for uniform application of aqueous fertilizer in the field needs to be attempted. Keeping above in view, a study on design parameters of constant head gravity feed metering system for aqueous fertilizer was undertaken.

Materials And Methods

Aqueous fertilizer metering is the key task in design of aqua ferti seed drill. Based on the functional principle of the constant head gravity pump, the pump variables were identified as head in the central tank, different nozzle size opening and desired tube size. To study the pattern of their influence over discharge rate, an experimental setup was designed and fabricated having provision to vary the design variables, Fig 1.

The main component of the experimental set up was a constant head gravity tank mounted on a frame



Figure 1 Experimental setup for influence of nozzle size and head over discharge

having provision to vary aqueous fertilizer head for desired discharge with the help of different nozzle opening. To maintain a constant head in the tank, a rotary gear pump was mounted. A 45 hp tractor was used to power the rotary gear pump by the help of PTO power transmission system to get desired levels of discharge. To obtain the desired discharge according to requirement of the crop the provision was made to adjust nozzle opening, a lever was provided for this purpose. To store the aqueous fertilizer, two cylindrical tanks with horizontal opening having same size and connected by a PVC pipe for maintaining the same water level in both the tanks were used for storage. These tanks were attached on both sides of the machine for proper load distribution, Fig 2. Tubes of desired size made of plastic material were used for carrying discharge from nozzle output to furrow opener. One end of the tubes was connected to the nozzles; the discharge was collected at the other end using a measuring flask.

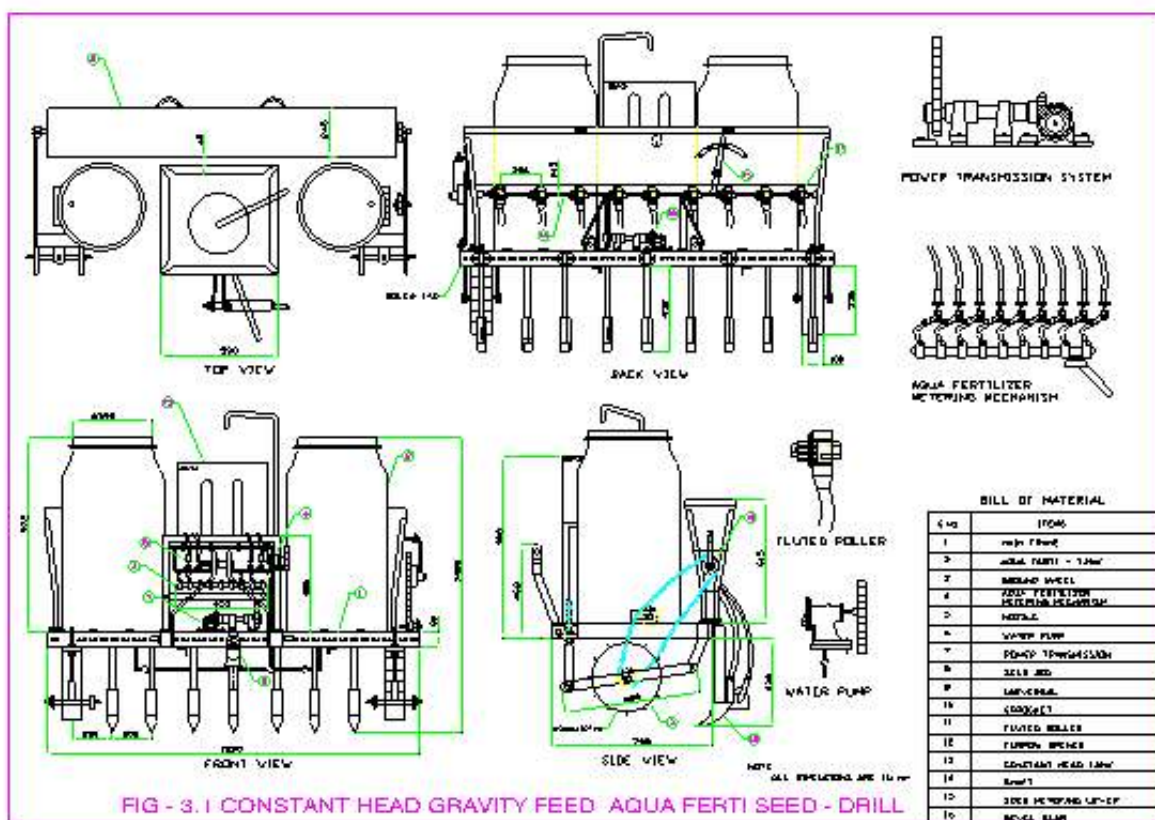


FIG - 3.1 CONSTANT HEAD GRAVITY FEED AQUA FERTI SEED - DRILL

The experiments on the set up were planned using randomized block design and discharge was measured at five levels of water head (47.5, 42.5, 37.5, 32.5 and 27.5 cm) and four nozzle opening sizes (10, 8, 6 and 4 mm). Three replicates of all the experiments, following the proposed experiment design, were done. The discharges for all the experimental levels were measured. Statistical analysis was performed to test the effect of individual design parameters as well as their interactions on discharge rate and to test the uniformity of discharge from all the tubes of a particular nozzle size and at different levels of head variables.

Results And Discussion

Performance evaluation of aqueous fertilizer metering system

Discharge rate and uniformity of applicator of aqueous fertilizer were two main performance parameters of aqueous fertilizer metering system. As

nozzle opening and head were two important operational variables, it was thought prudent to present the results for different nozzle openings to better understand their influences on performance vis-à-vis the influence of their interactions on discharge and uniformity.

Aqueous fertilizer head versus discharge for different nozzle openings

The influence of aqueous fertilizer head on discharge from different nozzle was studied. Five different levels of head i.e. 27.5, 32.5, 37.5, 42.5 and 47.5 cm were selected for experimentation. The discharge from nine different nozzles for nozzle opening of 10, 8, 6 and 4 mm was measured. The discharge increased constantly with increase in head from 27.5 to 47.5 cm. The discharges observed at 27.5, 32.5, 37.5, 42.5 and 47.5 cm head for an opening of 10 mm were 4.84, 5.59, 6.30, 7.31 and 9.65 l/min, respectively. Normally, the discharge from nine different nozzles was expected to be uniform because nozzle points were uniformly

spaced in the bottom of the central tank. However, minor variation was observed among the tubes at different heads. The overall variation in discharge caused by 72.72% increase in head (from 27.5 to 47.5 cm) through nine tubes, ranged between 93.25 to 105 %, Table 1. The same variation for 8 mm nozzle increase in head from among the nine tubes ranged between 93% to 101.2 %, Table 2. Variation in head level caused variation in discharge from 140.41% to 145.68 % for 6 mm nozzle opening, Table 3. Variation in discharge caused by increase in head among the nine tubes ranged between 78.89 to 85.04 %, for 4 mm nozzle opening, Table 4. Variation in discharge, from nine different tubes increased with increase in head levels for example at 27.5 cm head the observed variation was 3.37% which increased to 5.65, 5.69 and 8.92% at 32.5 cm, 37.5 cm and 47.5 cm for 10 mm nozzle size. An increasing variation in discharge from nine different tubes was observed with increase in head levels e.g. at 27.5 cm head the observed variation was 4.96% which increased to 11.39 and 12.5% at 42.5 cm and 47.5 cm. An aberration from this trend was noticed at 32.5 cm and 37.5 cm.

A minor variation, in the range of 0.03 to 0.23 l/min was observed from different nozzles at different heads at 6 mm nozzle opening. The largest variation in discharge from nine different nozzles of 9.62% was noticed at head levels of 32.5 cm, whereas the smallest variation in discharge of 1.55% was observed at head level of 27.5 cm. Similarly, an aberration of 3.9%, 3.78% and 4.31% in discharge were noticed at 37.5 cm, 42.5 cm and 47.5 cm head. An increase of 0.16 l/min in discharge was observed when head was increased from 27.5 to 32.5 cm, whereas for same amount of increment in head from 42.5 to 47.5 cm, the increase in discharge was 0.37 l/min, which was 23.42% higher. This shows that influence of head level on discharge was more pronounced at higher head level in comparison to lower head levels. In absolute terms, the lowest discharge of 1.06 l/min was observed at 27.5 cm

head from the 6th nozzle, whereas the higher discharge of 1.98 l/min was observed from 2nd nozzle at 47.5 cm head. It would be worth mentioning that the variation in discharge among nine tubes was minor and the statistical analysis was necessary to validate the significance of the variation.

The increase in discharge with increase in head was obvious due to increased pressure of the aqueous fertilizer column over the nozzles. With the uniform increment in head, it was expected that discharge would increase uniformly. However, experiment showed that at higher head level as between 37.5 to 42.5 and to 47.5 cm, the average increment in discharge was relatively higher. An increase of 0.75 l/min in discharge was observed when head was increased from 27.5 to 32.5 cm, whereas for same amount of increment in head e.g. from 42.5 to 47.5 cm, the increase in discharge was 2.34 l/min, which was 32% higher. This shows that influence of head level on discharge was more pronounced at higher head level in comparison to lower head levels. In absolute term the lowest discharge of 4.75 l/min was observed at 27.5 cm head for the 4th nozzle, whereas the higher discharge of 10.01 l/min was observed for 7th nozzle at 47.5 cm head. It could be concluded that sufficiently higher head level was helpful in getting reasonable discharge at the same time maintaining very low head would be detrimental in performance of the aqua ferti seed drill even at larger opening size.

Statistical analysis was done to know the relative performance of the aqua ferti metering system at different heads. The influence of head level over discharge was analyzed statistically for 4 different nozzle openings. The discharge obtained at 5 different heads i.e. 27.5, 32.5, 37.5, 42.5 and 47.5 cm for 10 mm nozzle opening was significantly different as the probability for treatment was observed as <.0001, however, influence of replication was non significant, Table 5. The influence of head level over discharge was analyzed

statistically for 8 mm opening size, Table 6. The discharge obtained at 5 different heads i.e. 27.5, 32.5, 37.5, 42.5 and 47.5 cm was significantly different as the probability for treatment was observed as $<.0001$, however, influence of replication was non significant. The influence of head level on discharge was determined statistically for 6 mm opening size, Table 7. The discharge obtained at 5 different heads i.e. 27.5, 32.5, 37.5, 42.5 and 47.5 cm was significantly different as the probability for treatment was observed as $<.0001$, however, influence of replication was non significant. The influence of head level over discharge was evaluated statistically for 4 mm opening size also, Table 8. The discharge obtained at 5 different heads i.e. 27.5, 32.5, 37.5, 42.5 and 47.5 cm were significantly different as the probability for treatment was observed as $<.001$.

However, the influence of replication was non significant. Statistical analysis reconfirmed the positive influence pattern of head level on discharge

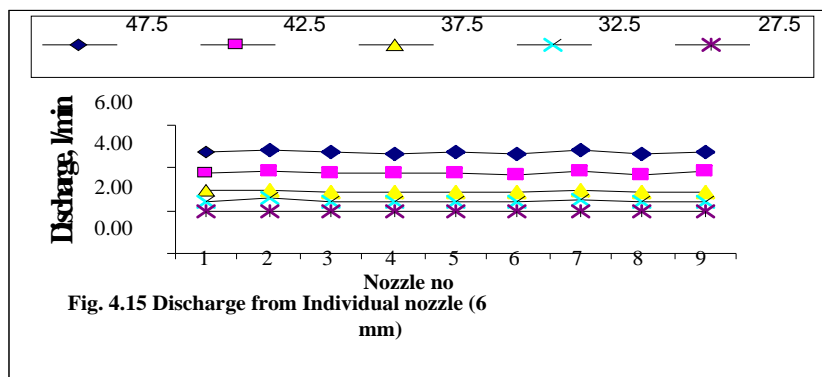
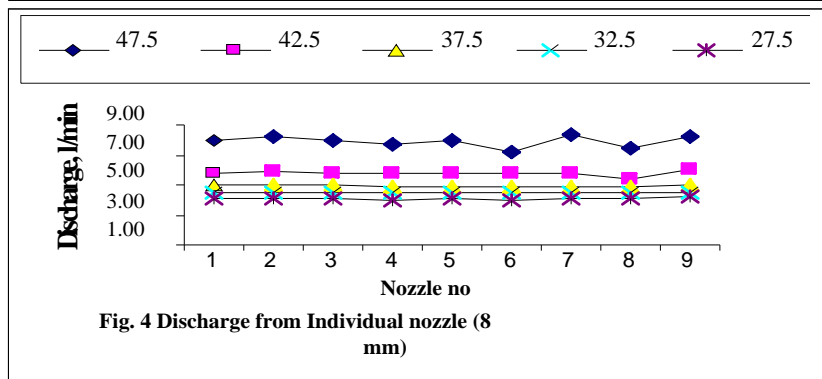
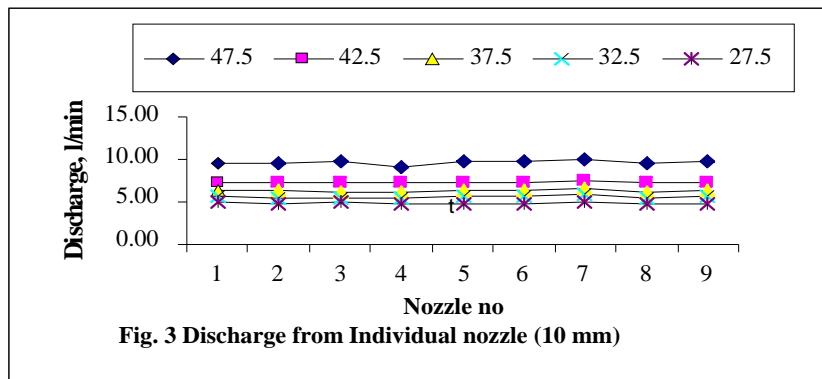
from different nozzles for all four nozzle openings. This reconfirmed the influence of head level over discharge at 10 mm nozzle opening. The correlation between head level and discharge was also determined statistically. A high value of R^2 of $>.994$ with coefficient of variation 1.973 was observed which showed the strong relationship between head and discharge as presented earlier. For 8 mm nozzle the value of $R^2 >.98$ with coefficient of variation 3.65 was observed which showed the strong relationship between head and discharge. For 6 mm nozzle the correlation between head level and discharge was also determined statistically. A high value of $R^2 >.996$ with coefficient of variation 2.017 was observed which showed the strong relationship between head and discharge. A high value of R^2 of $>.994$ with coefficient of variation 1.659 was observed which showed the strong relationship between head and discharge for 4 mm nozzle opening.

Table- 1: Pattern of discharge rate from the individual outlet at different heads and 10 mm nozzle opening

Nozzle no	Discharge l/min at different heads				
	47.5 cm	42.5 cm	37.5 cm	32.5 cm	27.5 cm
1	9.45	7.27	6.47	5.62	4.89
2	9.60	7.28	6.26	5.55	4.88
3	9.80	7.29	6.22	5.53	4.90
4	9.19	7.28	6.18	5.49	4.75
5	9.80	7.37	6.29	5.63	4.86
6	9.67	7.34	6.29	5.59	4.82
7	10.01	7.44	6.50	5.80	4.91
8	9.56	7.25	6.15	5.52	4.78
9	9.76	7.26	6.36	5.59	4.75
Average	9.65	7.31	6.30	5.59	4.84

Table- 2: Pattern of discharge rate from the individual outlet at different heads and 8 mm nozzle opening

Nozzle no	Discharge l/min at different heads				
	47.5 cm	42.5 cm	37.5 cm	32.5 cm	27.5 cm
1	7.99	5.76	4.94	4.50	4.14
2	8.16	5.92	4.95	4.53	4.16
3	8.00	5.81	4.94	4.50	4.13
4	7.75	5.73	4.85	4.45	3.98
5	8.00	5.79	4.93	4.53	4.11
6	7.25	5.75	4.83	4.43	4.03
7	8.37	5.81	4.92	4.53	4.16
8	7.44	5.44	4.82	4.43	4.07
9	8.23	6.06	4.94	4.53	4.18
Average	7.91	5.79	4.90	4.49	4.11



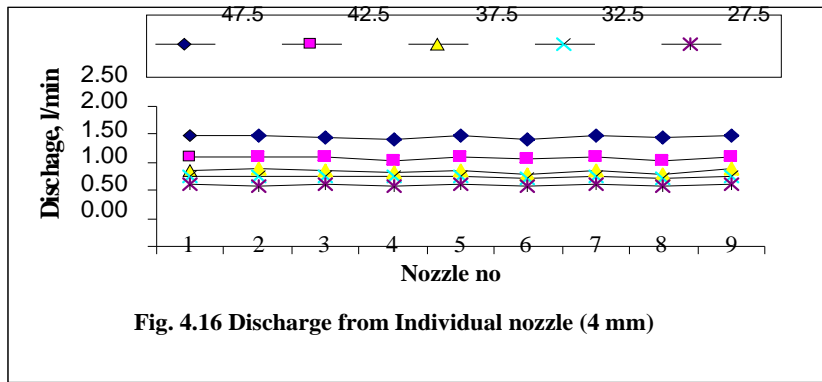


Table- 3: Pattern of discharge rate from the individual outlet at different heads and 6 mm nozzle opening

Nozzle no	Discharge l/min at different heads				
	47.5 cm	42.5 cm	37.5 cm	32.5 cm	27.5 cm
1	4.78	3.78	2.91	2.43	1.97
2	4.82	3.84	2.92	2.62	1.97
3	4.78	3.79	2.91	2.45	1.97
4	4.66	3.76	2.84	2.40	1.95
5	4.79	3.79	2.84	2.44	1.96
6	4.64	3.70	2.82	2.39	1.93
7	4.84	3.83	2.93	2.46	1.97
8	4.67	3.71	2.86	2.39	1.94
9	4.77	3.81	2.89	2.43	1.96
Average	4.75	3.78	2.88	2.45	1.96

Table- 4: Pattern of discharge rate from the individual outlet at different heads and 4 mm nozzle opening

Nozzle no	Discharge l/min at different heads				
	47.5 cm	42.5 cm	37.5 cm	32.5 cm	27.5 cm
1	1.97	1.58	1.35	1.26	1.10
2	1.98	1.60	1.37	1.26	1.07
3	1.96	1.58	1.34	1.26	1.10
4	1.92	1.54	1.32	1.24	1.07
5	1.97	1.59	1.37	1.26	1.10
6	1.92	1.56	1.29	1.23	1.06
7	1.97	1.61	1.35	1.25	1.10
8	1.93	1.54	1.30	1.23	1.07
9	1.97	1.58	1.38	1.26	1.10
Average	1.95	1.58	1.34	1.25	1.09

Table- 5: ANOVA for discharge at different head for 10 mm opening

Source	DF	S.S.	Mean Square	F value	Pr > F
Replication	2	0.0001126	0.0000563	0.00	0.9968
Treatment	4	375.7901630	93.9475407	5312.19	<.0001
R²	C.V.		Root MSE	Observed Mean	
0.994012	1.973846		0.132986	6.737407	

Table- 6: ANOVA for discharge at different head for 8 mm opening

Source	DF	S.S.	Mean Square	F value	Pr > F
Replication	2	0.0332059	0.0166029	0.42	0.6574
Treatment	4	248.2676056	62.0669014	1573.51	<.0001
R²	C.V.		Root MSE	Observed Mean	
0.980071	3.651044		0.198607	5.439737	

Table- 7: ANOVA for discharge at different head for 6 mm opening

Source	DF	S.S.	Mean Square	F value	Pr > F
Replication	2	0.0020659	0.0010330	0.25	0.7763
Treatment	4	133.5316804	33.3829201	8201.11	<.0001
R²	C.V.		Root MSE	Observed Mean	
0.996113	2.017160		0.063801	3.162901	

Table- 8: ANOVA for discharge at different head for 4 mm opening

Source	DF	S.S.	Mean Square	F value	Pr > F
Replication	2	0.00067145	0.00033573	0.59	0.5576
Treatment	4	12.26205001	3.06551250	5358.10	<.0001
R²	C.V.		Root MSE	Observed Mean	
0.994064	1.659342		0.023919	1.441484	

Effect of nozzle size on discharge from different head

In gravity flow system of discharge control from different nozzles, the nozzle opening size was the most important variable. The aqueous fertilizer application may require different rates of discharge in the field based on the existing conditions and field requirements. The varying rate of discharge requirements may be warranted keeping in view, the requirements of aqueous fertilizer or in other words

additional soil moisture. This variation may depend upon types of crop, available or residual soil moisture in the field or scant availability of water in the area. In case of very scant availability of water only critical moisture supply could be done. In fact, in this study nozzle size was the main control mechanism for regulating or metering the aqueous fertilizer.

The lowest nozzle opening gave lowest discharge of 1.09 l/min at 27.5 cm head, whereas the

highest discharge of 9.65 l/min was observed for 10 mm opening at 47.5 cm head. A uniform increment of 2 mm in nozzle size from 4 mm to 10 mm was expected to cause uniform variation in discharge. However, the variation in discharge with nozzle size for different heads was not in proportion and aberrations in some cases were observed. Consistently, increase in nozzle opening from 6 to 8 mm caused higher variation in discharge of 2.15, 2.04, 2.04 and 2.01 l/min. the relatively low variation was observed for both the nozzle sizes of 6 and 8 mm, Table-9.

The influence pattern of nozzle sizes was analyzed statistically for different head levels of 27.5, 32.5, 37.5, 42.5 and 47.5 cm. For 27.5 cm head level all the four nozzle openings e.g. 10, 8, 6 and 4 mm influenced the discharge significantly. The statistical value indicated that probability was much less than .01, a high R^2 of .999 was observed for 27.5 cm head which shows high level of correlation coefficient. Coefficient of variation 1.613 was observed. Results of t-grouping of four different nozzle sizes further explains that in addition to overall significant influence of head over discharge, the head level of 27.5 cm influenced the discharge in significantly different manner. Similarly, for 32.5 cm head level all the four nozzle opening of 10, 8, 6 and 4 mm influenced the discharge significantly. The statistical analysis presents that the probability was much less than .0001. A high R^2 of .998 was observed for 32.5 cm head which shows high level of correlation coefficient. The coefficient of variation of 2.12 was observed which further confirms that high level of correlation existed between discharge and head. Results of t-grouping of four different nozzle sizes further explain that in addition to overall significant influence of head over discharge; the both of 27.5 and 32.5 cm head level influenced the discharge in a significantly different manner. Similarly, for 37.5 cm head level all the four nozzle opening 10, 8, 6 and 4 mm influenced the discharge

significantly. The statistical analysis present that probability was much less than .0001. A high R^2 of .998 was observed for 37.5 cm head which shows high level of correlation coefficient. Here also, a coefficient of variation of 1.89 was observed. Results of t-grouping of four different nozzle sizes further explains that in addition to overall significant influence of head over discharge; the different head levels influenced the discharge in significantly different manner. In other words four levels of head influenced discharge differently.

For 42.5 cm head level, all the four nozzle opening of 10, 8, 6 and 4 mm influenced the discharge significantly. The statistical values show that probability was much less than .0001, a high R^2 of 0.998 was observed which shows high level of correlation coefficient. Coefficient of variation of 2.09 was observed in this case. Results of t-grouping of four different nozzle sizes further explains that in addition to overall significant influence of head over discharge, the four different head level influenced the discharge in significantly different manner. Similarly, for 47.5 cm head level all the four nozzle opening influenced the discharge significantly. The statistical analysis presents that probability was much less than .0001 and a high value of R^2 of 0.994 was also observed for this head which shows high level of correlation coefficient. In this case, coefficient of variation of 3.86 was observed. The four different head level influenced the discharge in significantly different manner. In other words all four levels of head influenced discharge in different manner.

Table- 9: Effect of nozzle size over discharge for different head

Nozzle sizes, mm	Discharge, l/min				
	Head levels, cm				
	27.5	32.5	37.5	42.5	47.5
4	1.09	1.25	1.34	1.58	1.95
6	1.96	2.45	2.88	3.78	4.75
8	4.11	4.49	4.90	5.79	7.91
10	4.84	5.59	6.30	7.31	9.65

Uniformity test

One of the requirements of aqueous fertilizer metering system was to apply same volume of aqueous fertilizer per unit length or per unit time from different nozzles. It was expected that discharge from different nozzles will be the same for different head and different nozzle sizes. However, a minor variation in discharge could not be ruled out as the nozzles manufacturing was done in the workshop using tools on lathe machines and available skill and expertise of the technicians. Any manual mistake may lead to variation of some amount as has been noticed in case of discharge of nozzle of different sizes, Fig 3-6. To reconfirm the above assertion statistical analysis was done to test the uniformity of discharge at different head for varying nozzle sizes. The result of t-grouping indicates that the head and nozzle sizes interacted significantly to influence the discharge from

different nine nozzles. However, the pair grouping of different nozzles showed that the discharge from individual nozzle was not significantly different as has been explained earlier.

Recommended design values of aqua ferti metering system

The aqua fertilizer metering system was test evaluated for different head and varying nozzle openings and matched with the capacity of rotary gear pump. The pump fitted with aqua ferti seed drill had capacity of maximum 60 l/min; the calibration for this pumping system is given in Table 10. Based on calibration chart a head level of 42.5-47.5 and 8 mm nozzle opening was selected for development of prototype gravity feed aqua ferti seed drill. However, this discharge level could be varied by change nozzle size during operation.

Table- 10: Calibration of aqua ferti metering system

Nozzle size, mm	Head level, cm	Discharge, l/min
10	47.5	87
	42.5	66
	37.5	57
	32.5	50
	27.5	44
8	47.5	71
	42.5	52
	37.5	44
	32.5	40
	27.5	37
6	47.5	43
	42.5	34
	37.5	26
	32.5	22
	27.5	18
4	47.5	18
	42.5	14
	37.5	12
	32.5	11
	27.5	10

Conclusions

Based on the results the following conclusion could be drawn.

1. The design variables of the constant head gravity feed pumping system were identified as constant head in the central tank and nozzle opening.
2. These design variables interacted individually and jointly to affect discharge rate.

3. The optimized design values of the pumping system for aqueous fertilizer seed drill may be taken as head level of 42.5-47.5 and 8 mm nozzle opening for development of prototype gravity feed aqua ferti seed drill. However, this discharge level could be varied by change nozzle size during operation.

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