Design, Development and Evaluation of Tractor Drawn Seed cum Pressurized Aqua Fertilizer Drill

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2018

CERTIFICATE – I

*This is to certify that the thesis entitled "**Design Development and Evaluation of Tractor Drawn Seed cum Pressurized Aqua Fertilizer Drill**" submitted in partial fulfillment of the requirement for the degree of **DOCTOR OF PHILOSOPHY** in **AGRICULTURAL ENGINEERING (Farm Machinery and Power Engineering)** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of the bonafide research work carried out by **Mr. Avinash Kumar Gautam** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instruction.*

All the assistance and help received during the course of the investigation have been duly acknowledged by him.

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The matter embodied in the thesis has not been submitted for the award of any other degree/diploma. Due credit has been made to all the assistance and help.

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List of Abbreviations

Abbreviations		Description
AICRP	:	All India Coordinated Research Project
AGM	:	Assumed germination moisture
ANOVA	:	Analysis of variance
ASAE	:	American Society of Agricultural Engineers
ASM	:	Available soil moisture
BARI	:	Bangladesh Agricultural Research Institute
BBFP	:	Broad bed furrow planter
B:C	:	Benefit cost ratio
BD	:	Bulk density
BSP	:	Breeding seed processing
Bu/ac	:	Bundles per acre
C	:	Energy coefficient
CAE	:	College of Agricultural Engineering
cc	:	Cubic centimeter
CD	:	Critical difference
CH	:	Chemical
CI	:	Cone index
cm	:	Centimeter
cm^2	:	Square centimeter
CT	:	Conservation tillage
CSCFD	:	Conventional seed cum fertilizer drill
CT	:	Conventional tillage
CV	:	Coefficient of variance
^0C	:	Degree centigrade
DAP	:	Die ammonium phosphate

DAS	:	Days after sowing
db	:	Dry basis
DD	:	Direct drilling
DE	:	Direct energy
DH	:	Disc harrow
Dia.	:	Diameter
e.g.	:	Exempli Gratia (for example)
EC	:	Electricity consumption
et al.	:	And others
FC	:	Fuel consumption
Fig	:	Figure
FYM	:	Farm yard manure
g	:	Gram
GJ	:	Giga Joules
GMR	:	Gross momentary return
ha	:	Hectare
hp	:	Horse power
h	:	Hour
ICAR	:	Indian Council of Agricultural Research
IE	:	Indirect energy
i.e.	:	id est (that is)
J	:	Joules
JNKV	:	Jawaharlal Nehru Krishi Vishwa Vidyalaya
K	:	Potassium
km	:	Kilo meter
kPa	:	Kilo Pascal
kg	:	Kilogram
kWh	:	Kilowatt hour
L	:	Length
lit.	:	Litre (s)

m	:	Meter
mc	:	Moisture content
M-hr	:	Man hour
Max	:	Maximum
min	:	Minute
M ha	:	Million hectares
MJ	:	Mega Joule
MJ/ha	:	Mega Joule per hectare
mm	:	Millimeter
MP	:	Madhya Pradesh
MPa	:	Mega Pascal
m/s	:	Meter per second
MT	:	Minimum tillage
MWD	:	Mean weight diameter
N	:	Nitrogen
NMR	:	Net momentary return
NT	:	No tillage
P	:	Phosphorus
RBD	:	Randomized block design
Rs	:	Rupees
RT	:	Reduced tillage
s	:	Second
SCPAFD	:	Seed cum pressurized aqua fertilizer drill
Sci	:	Science
SEm±	:	Standard error of means
S.No.	:	Serial Number
T	:	Time
TD	:	Tractor drawn
TE	:	Total energy

temp	:	Temperature
TJ	:	Tera Joules
TS	:	Treated seed
V	:	Volume
Wd	:	Weight of dry soil
WM	:	Weight of machine
wt	:	Weight
Ww	:	Weight of water
WTC	:	Water technology centre
ZT	:	Zero tillage
ZTSCFD	:	Zero till seed cum fertilizer drill
Viz.	:	Such as
Ø	:	Diameter
₹	:	Rupees
%	:	Per cent

INTRODUCTION

Water is a prime natural resource, a basic human need and a precious natural asset. The average annual water availability is 1869 billion cubic meters (BCM), while average annual rainfall of India is 1160 mm (Anonymous 2011). About three-fifth of country's cropped area depends exclusively on rainfall, most of which is concentrated in a few months of the year. Even where the overall annual precipitation is high, the available soil moisture during winter and summer is not adequate due to its uncertainness in distribution.

In India, the un-irrigated area was 63.30 % of net sown area during 2014-2015 which shows above 60% of net sown area is without assured irrigation (Anonymous 2015). The agricultural output, in this area depends on trends of monsoon. In fact, crop cultivation is a difficult task due to uncertainty and deficit of soil moisture during sowing time, which causes the problem in germination of seed and good establishment. For proper germination and growth of plant; precise placement of seed with optimum required soil moisture content, nutrients and other climatic conditions is necessary. In this, agro-machinery plays a vital role in seedbed preparation as well as in seed placement along with aqua fertilizer (Which also supplement the water) for healthy initial growth. Placement of aqua fertilizer also have greater significance for enhancing the agriculture production. But in moisture deficit areas the applied basal dose of fertilizer remains unavailable due to inadequate soil water to dissolve, dilute and convey it to root depth level in winter and summers.

Due to unavailability of sufficient soil moisture in form of irrigation, main winter crop like wheat cannot be cultivated despite the suitability of the soil. The major problem is deficit of soil moisture at sowing stage as at latter stages of crop growth some amount of rainfall is received due to westerly disturbances in Northern and Western part of the country. Timeliness is more important in rain fed farming, particularly at the time of sowing, to utilize the available soil moisture for crop establishment. For proper germination and healthy initial growth, seed vigour and timeliness in sowing are most important aspects. In fact, seed is one of the seven vital inputs for agricultural production along with fertilizers, irrigation water, plant protection chemicals, agricultural machinery, extension of scientific knowledge and credit. Research results have proved that the contribution of seed in attaining the potential crop yield is to the tune of 50 per cent. It has been established that the delay in sowing after optimum time causes a loss in the yield to the extent of 35 to 40 kg/ha per day (Hobbs, 1985). Thus seed bed preparation and sowing/planting should be completed within a short period under available soil moisture condition by using efficient tillage and seeding machinery. It is needless to state that the application of efficient machinery helps in timely farm operations, better input use efficiency and increasing productivity by about 30 per cent. Traditionally, in dry land areas seed-cum-fertilizer drill are not in use resulting into more input and less yield. A substantial advantage could be attained if farmers opt for seed-cum-fertilizer drill for sowing operation. The major problem in these areas is that at sowing depth moisture deficit exists and thus, seed cannot utilize the applied fertilizer dose.

This problem can be solved by using aqueous fertilizer, because these fertilizers are energy saving, economical and they can be applied uniformly with the flexibility in formation of different grades. This may facilitate successful germination and initial root and shoot development of the plants. Application of aqueous fertilizer at root zone depth can be achieved by using suitable aqua fertilizer Seeding/planting machine. To supplement soil moisture and nutrient requirements of different crops, a continuous or intermittent supply of aqueous fertilizer may be needed. A suitable technology is required for application of aqueous fertilizer alongside of seed.

Liquid fertilizers are in use in many developed and developing countries such as USA, UK, Denmark, Algeria, Cuba and Egypt because of the fact that these fertilizers are energy saving, economical and they can be applied uniformly with the flexibility in formulation of different grades. The studies on use of liquid nitrogenous fertilizer under various climatic conditions and on different experimental and demonstration crops have indicated that it is compatible with solid nitrogenous fertilizers. Its application is more uniform than the chemical granules and the nitrogen contained in it is available in three forms e.g. ammonical, amide, and nitrate as compared to only amide form in Urea. It is a non-pressure and neutral solution and therefore, its storage is safe. However, in India the use of solid fertilizer is more common because of their easy availability. One way out of using fertilizer in non-solid form is to go for its use in aqueous form.

Table 1.1 Effect of aqueous fertilizer on crop growth

Year	Crop	Yield (kg/ha)	
		Conventional sowing	Aqueous fertilizer sowing
1981-82	Wheat	1956	2697
1985-86	Mustard	739	1436
1985-86	Gram	913	1817

Source: Technical Bulletin, Water Technology Centre, IARI, New Delhi (2006).

Studies suggest that application of aqueous fertilizer at root zone depth results into higher productivity. Agronomists have worked out quantify the aqueous fertilizer required for different winter crops in specific agro-climatic situations (Anonymous, 1996). There are generally two types of mechanism used i.e. peristaltic pump and constant head gravity feed system with varying nozzle sizes (Kamal Kant 2008). These both systems are good for sowing of crops under deficit moisture content. But these machines have constrains as per their design, placement of aqueous fertilizer and precision point of view. Therefore, need for development of new system for tractor drawn pressurized aqueous fertilizer seed drill which can take care of these constraints.

Pressurized metering system will prove useful for precision seeding of different crops in deficit moisture condition areas by controlled application of aqua-fertilizer according to soil moisture. There is no pressurized metering system for aqueous fertilizer which could be utilized on seed drill or planter, therefore this study was taken up to develop such system with the following objectives:

Objectives

1. To determine the requirement and placement of aqua fertilizer under laboratory conditions for the germination of wheat crop.
2. To determine design values of pressurized aqueous fertilizer for metering mechanism.
3. To design, development & performance evaluation of a tractor drawn pressurized aqua fertilizer seed drill for sowing of wheat crop under vertisol.

REVIEW OF LITERATURE

This chapter includes a topical review on the research work done in the fields related to aqua fertilizer application. Research efforts have been made to analyze recommended agronomic practices and develop suitable seeder to solve germination problem of moisture deficit areas. Based on the content of information this chapter has been divided into different headings and sub-headings.

2.1 Constraints in moisture deficit areas

Moisture deficiency occurs at different stages of crop growth particularly at the time of germination. Moisture deficiency does not only inhibit germination but also hamper crop growth. The detrimental effect of stresses could be offset by moisture supply in a metered quantity through proper management technique and also by developing stress resistant varieties.

2.1.1 Influence of seed rate, sowing time and temperature on wheat crop productivity

A number of studies have been reported to show the importance of seed rate sowing time and climatic conditions particularly temperature at the time of sowing.

Singh et al. (1976) studied for effect of ambient temperature on the yield of different four varieties of wheat at different sowing time i.e. 15 Nov., 20 Nov., 15 Dec. and 30 Dec. which gave average grain yields of 3570, 3890, 3080 and 2870 kg/ha, respectively. For sowing on 20 Nov. when highest yields were obtained, the maximum, minimum and mean ambient temperature were 25.6, 7.2 and 16.2°C, respectively. A minimum temperature of 4.5°C together with mean temperature of 14°C was the critical lower temperature limit for sowing wheat. The yields were reduced markedly when the temperature was lower than this limit. The lower temperature delayed emergence, decreased tillering and increased the growth period.

Singh et al. (1985) carried field trials to study effects of sowing rates of 90, 130, 170 and 210 kg/ha and 2 types of drills on grain yield of spring wheat on a sandy loam soil. The difference in yield was not significant between sowing rates of 130 and 210 kg/ha. Yield compensation at low sowing rates was achieved by higher fertility of the side tillers and a large number of grains/ear. A high positive correlation existed between yield/m^2. The correlation between yield and number of ears/m^2 with drill. A helical fluted type nylon seed metering mechanism, working width of 2.05 m and 9-row cultivator with a row to row spacing of 22.8 cm was higher than drill with peg type nylon precision seed wheel, working width of 2.5 m and 21 row tiller with a row to row spacing of 11.9 cm.

Panwar et al. (1988) conducted field trials to assess the effects of sowing time on wheat crop variety WH 147 on 15 Nov., 30 Nov., 15 Dec. and 30 Dec. and found that the crop yield fell as the sowing date was advanced.

Naik et al. (1991) conducted a field experiment during the winter season of 1987-88 wheat crop varieties Lok 1, GW 89 and GW 120 produced grain yield of 2200, 1450 and 2540 kg/ha, respectively. Sowing wheat on 31 Oct., 18 Nov. or 15 Dec. reduced grain yields of 2330, 2570 and 2300 kg/ha, respectively. Increasing the sowing rate 25% above the recommended rate of 132, 110 and 78 kg seed/ha for Lok 1, GW89 and GW 120, respectively, increased average grain yields from 2350 to 2450 kg/ha.

Thakur et al. (1998) conducted a field experiment during 1993/94 and 1995/96 at Pusa, Bhiar, India, wheat cv. Sonali was grown in Rabi, with 6 wheat establishment methods and wheat sowing rates of 120, 150 and 175 kg seed/ha. Mould board ploughing once + rotavating once or twice + sowing behind the plough gave the highest wheat equivalent yields, net returns and benefit to cost ratios. Wheat and wheat equivalent yields increased with increasing sowing rate, and found to be that 150 kg/ha was the most economic rate.

Jena and Behera (1998) evaluated influence of different spacing, seed rate and fertilizer levels on yield components and yield of wheat in a trial at Chiplima, Orrisa in winter 1991/92. Closer spacing (15cm) between rows, use of higher seed rate (150kg/ha) and application of recommended level (120-60-40 kg/ha, N.P.K.) of fertilizer increased grain yield compared with wider spacing (23 cm), low seed rate (100 kg/ha) and farmers use of low fertilizer levels (60-30-40kg/ha, N.P.K.). Treatment interactions were also significant.

Tiwari et al. (1999) conducted three field trials during the 1996-97 and 1997-98 Rabi seasons in the farmer's fields under National Watershed Research Project in Madhya Pradesh, India. Wheat cv. Lok 1 was subjected to the following treatments: 4 sowing dates (third and fourth week of November and first and second week of December), 2 methods of fertilizer application (fertilizer mixed with seed and fertilizer placement below the seed) and 4 seed rates (100, 125, 150 and 200 kg/ha). Sowing wheat on the fourth week of November proved significantly better than the earlier or later sowing dates. The highest seed yield was found to be 4015 kg/ha. Seed rate of 125 kg/ha was found to be significantly superior to lower or higher seed rates. The highest value of seed yield of 4180 kg/ha was obtained from this seed rate treatment.

Patel et al. (1999) conducted a field experiment during the winter season of 1994-95 and 1995-96 to study the effect of different sowing dates on yield attributes, yield and uptake of nutrients by 4 wheat cultivars under a rice based cropping system in eastern Madhya Pradesh. Sowing wheat during the first week of December (5 December) was suitable during both the years. Yield averaged to 1803, 3522, 3003, 2330 and 1822 kg/ha with sowing on 25 November, 5, 15 and 25 December, and 5 January, respectively.

Ogiuchi et al. (2004) conducted study on winter wheat, usually sown in autumn, was sown before continuous snow cover to avoid the overlap between work for wheat sowing and rice harvesting. The optimum sowing rate and seedling density for winter wheat cv. Nanbukmugi were studied in Iwate, Japan. The crop was sown from early October to late November in 2000-2002. The number of ears and grain yield increased linearly with increasing seeding density, and the highest yield was 350 grains/$m^{2.}$

Thus optimum seed rate, appropriate sowing date and optimum average temperature are necessary for proper germination, growth and yield of wheat crop in different agro climatic conditions.

2.1.2 Wheat cultivation under excess moisture regime

Normally, excess moisture conditions exist in high rain fall areas with relatively flat topography and in the foot hills of Himalayas. Such conditions cause delay in sowing resulting in reduced yield. The zero till technology and development of late sown varieties are some efforts made to overcome the problems of excess moisture conditions.

Arya et al. (2003) conducted an experiment during 1996-97, 1997-98 and 1998-99 at Hill campus Ranichauri of G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India. The soil moisture treatments were: sowing at 10, 15, 20 and 25% moisture. The sowing techniques were: sowing immediately at harvest of proceeding crop; pre plough sowing at harvest of preceding crop; sowing after 1 week of harvesting of the proceeding crop; and sowing by zero tillage. The results observed on wheat variety HS-240 revealed that the highest average grain yield of 1817 kg/ha was obtained with sowing under 10% soil moisture level followed by 1545 kg/ha at 20% and 1544 kg/ha at 25% soil moisture levels. The highest average germination was recorded at 25% soil moisture. Sowing at moisture levels of 25% in normal and 20% in dry years produced lower yield. Weights of spike including number of grains per spike were also lowest at 15% moisture level. Broadcast sowing and zero tillage gave lower yield than other treatments. While sowing immediately after harvest of proceeding crop gave the highest grain yield (1.498 t/ha) and favored the plant height at harvest (80.5 cm), spike length (10.1 cm) and number of grains per spike (29.2).

Tripathi et al. (2005) conducted a study to determine a tilth index from tillage induced soil physical properties and grain yield to optimize tillage in rice wheat system. The experiment was conducted in a silty clay loam associated with a shallow water table fluctuating between 0.02 and 0.96 m from the surface. Tillage treatments for wheat were zero tillage (ZT) and conventional tillage (CT) superimposed over the plots of rice experimental fields. Measurements were made of puddling index and specific volume (only in the rice season). Bulk density, saturated hydraulic conductivity, infiltration rate, plasticity index, porosity and organic carbon in the rice and wheat seasons. Rice yield in the PR plots was highest and statistically equal to that in the ReP plots but wheat yield was highest in the DSWP plots under ZT condition and was statistically equal to that in the ReP plots. Tilth index (T1) was determined in two ways; one by the model suggested by Singh et al. (1992) and the second by a proposed regression model. The proposed regression model utilizes soil physical properties having significant influence on crop yield. As per the Singh et al. (1992) and the second by a proposed regression model. The proposed regression model utilizes soil physical properties having significant influence on crop yield. As per the Singh et al. (1992) model, wheat yield increased linearly with increasing T1 from 0.75 to 0.89 but rice yield decreased with increasing T1 from 0.67 to 0.81. Both T1 and its relation with rice yield were contrary to their observations the proposed regression model showed a value of T1 in the range of 0.74-0.87 for rice soils and 0.86-1.0 for wheat soils as indicators of T1 for optimum yields of rice and wheat. The optimum yield with minimum tillage operations coincided with T1 obtained in ReP plots of rice and in ZT plots of wheat under ReP conditions. Results, thus, show that the quality of soil puddle obtained by half the efforts in PR and CP was sufficient for optimum yields of rice. Similarly, wheat sowing by zero-till drill in such a reduced puddling plots of rice was sufficient for optimum yields of wheat in Tarai soils associated with shallow water tables.

2.1.3 Wheat cultivation under deficit moisture regime

Wheat grows well under deficit moisture regime conditions where adequate stored water promotes a deep, extensive root system. Irrigation practices that ensure ample soil water storage during early stages of crop development promote the development of this type of root system.

Parihar et al. (1975 observed the effect of initial profile water storage and soil compaction below the seed on the growth and the yield of dry land wheat in field experiments during two years. Compaction reduced water use from deeper layers and decreased grain yield during both the years. Compared with lower initial water storage, higher initial water storage in the profile resulted in more vigorous plants, deeper rooting, and greater water use from lower soil layers and higher yields.

Khare et al. (1989) conducted trials in rain fed areas in 1981-83, four wheat cultivars sown when soil moisture content had fallen to 24 (7-11 Dec.) or 22% (25-30 Dec.) gave average grain yields of 1490 and 1000 kg/ha, respectively. The higher soil moisture content increased spike length, number of grains/spike and 1000 grain weight. Crops sown at 100 or 125 kg/ha gave yields of 1400 and 1510 kg/ha in 1981-81 and 1190 and 860 kg/ha in 1982-83 (dry year), respectively. Crop variety Lok 1 gave the highest average grain yield of 1340 compared with 1150 with 1150-1280 kg/ha for 3 other cultivar.

Venter et al. (1993) determined that moisture and temperature stresses occurring in the seedbed of dry land wheat in the summer rainfall area of South Africa resulted in reduced emergence, even of undeteriorated seed lots. The usefulness of a number of single and multiple stress laboratory tests in predicting relative emergence of 18 undeteriorated seed lots of wheat (six wheat cultivars, each represented by three seed lots from different production localities) was examined at two field trails sites i.e. Pretoria and Bethlehem for the experiments. Single stress tests i.e. germination at 9°C and thermo tolerance induction response were better predictors of relative emergence than multiple stress tests i.e. accelerated aging and the complex stressing vigour test. Promising results were also obtained with the standard germination test which included a determination of germination rate.

Unger (1994) conducted field trials on Pullman clay loam at Bushlands. Texas during 1984-91 and compared 12 tillage systems ranging from no-tillage (herbicides only) to sweep tillage (no herbicides) for a dry land wheat sorghum fallow rotation. Tillage systems did not affect mean water storage during fallow or mean water use by either crop. Wheat grain yield averaged 2.92 t/ha and was not significantly affected by tillage system. Mean sorghum yield was highest (3.91 t/ha) with a system using reduced tillage after sorghum and no tillage after wheat, and was lowest (3.48 t) with reduced tillage after each crop. Sorghum stover yield was not affected by tillage. Panicle number harvested was highest (233 000/ha) and lower (212 000/ha) in the same treatments giving the highest and lowest sorghum grain yields. It's concluded that a wide range of tillage systems can be used for a dry land winter wheat-grain sorghum cropping system in the semiarid S. Great Plains.

Angus and Herwaarden (2001) determined water use efficiency, the ratio of grain yield to crop water use, which provides a simple means of assessing whether yield is limited by water supply or other factors. Based on this assessment, yield of commercial dry land wheat (Triticum aestivum) crops in southeastern Australia are usually not limited by water. Transpiration efficiency (TE), the ratio of yield to transpiration, is relatively stable for well managed crops, but the amount of water used is strongly affected by crop management. In a review of 13 comparisons of water use and wheat yield, providing optimum N fertilizer or suppressing cryptic root diseases with break crops increased water use by 23 mm and yields by 378 kg/ha, equivalent to 10% of the control yields. A possible means of increasing yield potential of dry land crops is to manage transpiration so that relatively more water is used during the vegetative phase when vapor pressure deficit is low and hence TE is high. However, based on budgets of soil water and soluble carbohydrates stored in the vegetative organs and available for retranslocation, this option provides lower TE than conserving soil water for transpiration until grain filling when assimilates are directed to grain. Increasing the proportion of water transpired during the vegetative phase with N fertilizer can lead to particularly inefficient water use because increasing N status generally reduces the soluble carbohydrate reserves available for retranslocation to grains.

Thus, availability of required soil moisture at root zone depth at the time of sowing is more critical. Once the germination and initial growth is established, the dry land condition may not be a serious limiting factor w.r.t. yield provided one life saving irrigation or rain due to local disturbances is received.

2.2 Seeding and sowing methods

Successful seeding and sowing depends on accuracy, precision and uniformity of seed placement. Indian farms have been traditionally sown by using manual and bullock drawn seeder. The most popular traditional methods of sowing like broadcasting, line sowing behind the plough, dibbling and transplanting are in wide use since time immemorial. Due to advances in agricultural production process particularly after the Green Revolution era, mechanization of agricultural production picked up. Seeding is one of the most critical operations which needs to be mechanized, keeping in view the efficiency and precision of seed and fertilizer placement and timeliness of operations for economical utilization and enhancement in production. The main constraint in dry land agriculture is limited availability of soil moisture in root zone. The average productivity of dry land areas is very less in comparison to irrigated areas, which needs to be enhanced. All efforts are being made to increase the productivity of these areas. In fact, moisture deficient conditions do not allow cultivation of certain crops even though the soil is suitable. Use of proper seeding equipment becomes helpful in mitigating this problem. Additional moisture supplement may become very helpful. Addition of aqueous fertilizer at root zone depth is efficient way of solving the problem. Some works in this area have been reported

Cheema et al. (1985) conducted the experiment for number of tillers of wheat cv. Bahawalpur-79 when soaked seeds were broadcast in standing irrigation water (T1). The other treatments, including (T2) dry sowing using a drill with irrigation immediately after sowing, (T3) broadcasting dry seed in standing irrigation water, or (T4) broadcasting dry seed, followed by planking and irrigation immediately after sowing also gave higher tiller densities than (T5) the traditional sowing method (sowing after soaking irrigation). High tiller numbers were related to high grain yield with 3.192, 2.570, 2.850, 2.941 and 2.067 t/ha for (T1)-(T2) respectively.

Dhiman *et al*. (1985) investigated the advantages of a seed-cum-fertilizer drill over the traditional wheat sowing method in field experiments. These advantages included: uniform seed and fertilizer distribution in the field, quantities of seed and fertilizer and distance between rows could be adjusted, seed and fertilizer could be placed at the required depth with fertilizer below or beside the seed. Field capacity of 1 and 4 ha/day could be achieved by bullock and tractor power, respectively. The drill gave a 17 % increase in wheat yield for normal sowing times.

Sharma *et al.* (1989) compared a 3 row bullock-drawn combined seed and fertilizer drill with the traditional sowing method of dropping seed manually into the furrow behind a wooden plough in Haryana State, India. Sowing with the mechanical drill produced a 10.4 % increase in yield, 49.1 % savings in energy expenditure and 49% savings in operational costs over the traditional method

Gogoi and Kalita (1995) conducted a field experiment of wheat cv. Sonalika was significantly higher with drilling in lines (0.92 t/ha) and cross-sowing (0.92 t/ha) than broadcasting (0.81 t/ha).

Bharadwaj *et al.* (2001) evaluated and compared the performance of four rainfed sowing equipment namely tractor operated adjustable furrow opener type planter (4-row); tractor operated reversible shovel type planter; bullock-drawn single-row planter, and indigenous wooden plough, behind which seed is dropped manually were tested for maize crop. The germination count (76 %) as well maize yield (2640.7kg/ha) of the plot sown with bullock drawn single-row planter was significantly higher than that of all other sowing equipment.

Jagvir *et al.* (2004) evaluated and compared the effect of using a no-till seed cum fertilizer drill on wheat crop yield, energy input, soil health and cost of operation in comparison with the conventional seed drill. The no-till seed drill resulted in a 17.09 % increase in yield, 83.22 % savings in energy and 80.34 % savings in the cost of production.

Gangwar et al. (2004) conducted a 3-year field study during 1998/99-2000/01 on the effect of tillage on crop growth. Yield and nutrient use in wheat (Triticum aestivam) grown after different methods of rice (Oryza sativa) seeding. Treatments comprised three methods in wheat (conventional tillage (CT). reduced tillage (RT), zero tillage (ZT) as subplots. Results indicated that tillage significantly reduced soil bulk density (1.59 Mg/m3) over the zero tillage system (1.69 Mg/m^3). Greater root density in terms of root dry weight (7.50 Mg/20 cm row length) was recorded in CT and the lowest root dry weight (5.8 Mg/20 cm row length) was obtained in ZT during 2000/01. CT resulted in significantly higher dry matter (253 g/m row) and leaf area index of wheat (3.02) than RT and ZT, respectively, during 2000/01. Among different tillage levels, CT recorded the highest mean yield of wheat (5.90 Mg/ha) followed by RT (5.82Mg/ha) and ZT (5.40 Mg/ha). The yield reduction was in the order of 11.28 and 6.31% under ZT and RT, respectively. Soil chemical analysis showed that available soil N, P and K contents were affected significantly due to seeding method and tillage after each cycle of rice wheat sequence. CT recorded significantly lower values of available soil N and lower values of available soil P and K, during the 3 years of study.

Seeding with the help of seed cum ferti drill is undoubtedly advantageous in wheat sowing. The special techniques like zero till are useful in rice, wheat cropping system from stand point of energy saving. Under dry land conditions design of seed drill may require certain changes in furrow opener, seed and aqueous fertilizer tube and ground drive wheel. Research efforts are needed to determine special design feature of aqua ferti seed drill.

2.3 Effect of liquid/aqueous fertilizer on the crop growth

Fertilizer is applied in three forms i.e. gaseous, liquid, or solid. Generally, solid fertilizer is applied in granular form. However, certain fertilizers are applied in pellet form also Liquid fertilizer makes nutrient rich moisture available at seeding depth during sowing time for successful germination and initial root and shoot development. Liquid fertilizers are used due to its ease in handling as well as in metering. Its use is also safe for the growth of the plants, as the concentration of the fertilizer is low.

Tidejens (1941) reported that fertilizer was readily available to the plants when applied in the liquid form. It was observed during the experiment that phosphate is greatly available when applied in the liquid form. This liquid fertilizer was a mixture of nitrogenous, phosphatic and potassium salts in the ratio of 13-26-13 and dissolved in water. It was noted that there was no danger of burning of plants, as the concentration of the fertilizer is low when applied in the liquid form. The gasoline barrels with pipes mounted on cultivators were used as a device for the application of liquid fertilizer.

Truska and Sedlak (1986) conducted experiment in which Maize hybrid CE 330 was grown after winter wheat or silage maize after sub-soiling. The experiment was carried out with or without liquid fertilizer application to the subsoil with a dose of NPK, or N, NK or NP with the remaining elements of NPK applied to the soil surface. Rates of application were 200 kg N, 53 kg P and 116 kg K. Sub soiling to 450 mm depth did not increase yields under dry conditions but subsoil application of liquid fertilizers increased grain yields, especially if maize was grown for 2 consecutive years. No-tillage wheat was the best preceding crop.

Kumar *et al*. (1996) developed a liquid urea injector based on an International Rice Research Institute (IRRI) design. The performance of the unit was evaluated in comparison with prilled urea, urea super granule (USG) applicator and broadcasting of urea. Application of liquid urea in subsoil at 10% concentration increased the nitrogen uptake by 24% more than the control. The grain yield was 22%, 15% and 15% higher than control, application of USG and prilled urea in the subsoil, respectively.

XinZheng *et al.* (2004) carried out experiments in 1999-2002 in Xinjiang, China. Acid liquid fertilizer is a new special fertilizer for drip irrigation. The yield of unginned cotton increased by 270 kg/ha (7.8%) as compared with the traditional fertilizer. Fertilizer rates of 900-930 kg/ha resulted in 1725 kg ginned cotton/ha and a reduction of 35% in fertilizer use, compared with the control.

Kaczor, and Brodowska (2005) conducted a pot experiment to determine the range and direction of changes in the content of different nitrogen (N) forms in spring wheat under different rates of sulfur (S). Fertilizer application with S also showed favourable influence on the metabolism of N, which was expressed as an increase of the percentage of protein N in total N and a decrease in the content of mineral forms of this element, particularly nitrates. This beneficial effect of fertilizer application with S was more significant in the series where wheat was fertilized with N in liquid form (RSM-30).

Under dry land condition aqueous fertilizer is needed not just for better physical form of fertilizer from use efficiency point of view, but from standpoint of moisture. The first objective of AFSD is to provide extra moisture at root zone depth.

2.3.1 Mode of fertilizer placement

It has been conclusively proved that placement of fertilizers by seed-cum fertilizer drill at an appropriate depth improved fertilizer use efficiency in all the crops. Placements of fertilizer have greater significance in dry land agriculture. It is of great importance for crops grown on receding soil moisture during post-rainy season. Efforts have been made to design and develop suitable tool with varying field capacity and field efficiency.

Peterson et al. (1983) designed, constructed and tested a minimum tillage drill called the Chisel-Planter for use in reducing erosion on steep slopes. Liquid fertilizer was metered into the furrow at the bottom of the chisel points and about 20 to 40 mm below the seed. Wheat yields had been nearly the same to 5% less than conventionally seeded fields while erosion was reduced by 75 per cent.

Oswal and Sarmath (1998) reported that phosphorous placement before pre-sowing irrigation improved the uptake and yield of the crop over the normal practice of placement of P after application of pre-sowing irrigation. It was also observed that information about use of aqua-placement of fertilizers in chickpea is very less.

Aguas and Godwin (1996) investigated the subsurface injection of sewage sludge in grassland conditions, showing that injection is a viable alternative technique to surface applications. This study considered the subsurface injection of sewage sludge in a growing crop of spring wheat. Using a 3-leg injector, with the outside tines bent, and placing gaps between rows for the tines and wheels, the crop showed a better agronomic response at the final levels of development.

2.3.2 Aqueous fertilizer application effect on losses

Surface fertilizer application is the most popular and the most inappropriate method for no-tillage fertilization. Without fertilizer incorporation, the fertilizer use efficiency is reduced, residues are prematurely decomposed, and surface soils become progressively more acidic (Mengel *et al* 1982). Urea fertilizer solutions applied on soil surface lost nitrogen through ammonia (NH_3) volatilization, and such losses might be influenced by tillage practices, environmental conditions and by the presence of crop residues. In an experiment conducted on two types of soil, NH_3 losses were found higher on zero-tillage field than conventional field. Increased NH_3 loss with zero tillage was attributed due to more crop residues than with conventional tillage. In a separate experiment to evaluate the effect of plant residues on NH_3 loss, chopped hay was used to provide a greater surface cover and a uniform spreading of residues and it was found a threshold level of hay between 750 and 1500 kg/ha to increase N losses compared to no added hay treatment (Kanani and MacKenzie 1992).

About 11% increase in ammonia loss from urea solutions occurred when urea was applied to soil covered with 4600 kg/ha hay as compared to soil not covered with hay (Tomar *et al* 1985**)**.

On silt loam soil, volatilization losses were considerably lower than those found on sandy loam soil (Keller and Mengel 1986). Ammonia loss peaked around noon, as straw temperatures were rising to a maximum, straw-water content was decreasing and wind velocity was high (McInnes *et al.* 1986). In an experiment on fertilizer N recovery in Nebraska, it was observed that about 7 to 13% of the labelled N was found in visible residues in case of no-till while it was less than 4% on ploughed fields. Similarly , 4 to 9% of the labelled N applied was found in partially decomposed residues of no-till during this period, compared to no more than 2% for the plow and subtill treatments (Power *et al* 1986).

Malhi *et al.* (1996) conducted field experiments to determine the influence of tillage, N source, method of N placement and simulated rainfall on the recovery of N-labelled fertilizers in spring barley (*Hordeum vulgare* L.) plants and soil. The recovery of N in plants was lowest for surface broadcast urea under ZT, particularly when no water was added after urea application. Surface broadcast urea under ZT was less efficient than the other N sources and its recovery improved considerably when placed in bands below the soil surface near the seed row.

Palma *et al.* (1998) conducted an experiment on NH_3 loss on conventional tillage and no tillage systems on a silty clay loam texture and found that higher losses of NH_3 occurred in the no-tillage treatments, with 11.5% and 6.2% of N-urea lost when the fertilizer was surface applied and incorporated, respectively. Multiple regression equations showed differences between surface applied urea and incorporated urea treatments due to the latter avoiding the direct exposure of the fertilizer to atmospheric conditions. In a similar study, Jones *et al* (2007) studied various soil and climate factors to affect urea volatilization and observed that by understanding how soil and climate factors influence volatilization, crop producers and their advisers can avoid applying urea in situations that may promote volatilization, or adopt best management practices to minimize the potential for loss.

The eight N management treatments for the wheat mulched with rice straw were evaluated at Ludhiana and found that fertilizer application with three split doses (50 % drilled at sowing + 25 % broadcast before each of the first and second irrigations) resulted in significantly higher grain yield, agronomic efficiency and N recovery efficiency than all other treatments (Singh *et al* 2008). In the presence of mulch, drilling the urea at sowing gave higher yields and efficiency than broadcasting. Grain yield, total N uptake and recovery efficiency with the recommended practice (with straw burnt and 60 kg N/ha broadcast at sowing and before the 1st irrigation) were significantly higher than with the same N management in the presence of residue.

However, drilling the 1st 60 kg N/ha at sowing in the presence of rice residue restored yield and N uptake to similar values to the control. It is further reported that greater immobilization or N losses from surface applied N in presence of straw than when the straw was burnt before sowing. Drilling part of the fertilizer below the soil surface at sowing might have reduced these losses due to reduction in fertilizer N contact with straw.

The effect of broadcasting urea on NH_3 emissions under no-till (NT) soils was investigated and found greater with mean cumulative NH_3 losses in NT (3.00 g N/ m^2) than in mouldboard plowed soil (0.52 g N/ m^2). The presence of crop residues at the surface of NT soils also decreased contact of the urea granules with the soil, possibly reducing adsorption of NH_4^+ on soil particles (Rochette *et al* 2009).

2.3.3 Fertilizer N placement effect on nutrient uptake

Daigger and Sander (1976) found the availability of residual N in the root zone greatly influences the amount of N fertilizer required to optimize winter wheat (*Triticum aestivum* L.) yields. A study was conducted on two soils to determine the availability of N at different depths in root zone and N placement in Western Nebraska. Ammonium nitrate was placed on the soil surface and at depths of 30, 60, 90, 120, and 150 cm. While N uptake tended to decrease as the depth of N application increased, total dry matter production was not affected by depth of N placement. Wheat plants easily obtained N placed at depths up to 150 cm. Band placement of liquid N gave significantly higher grain yields and agronomic efficiencies than the split broadcast method, irrespective of the type of crop establishment used (Schnier *et al* 1988). At harvest, the split USG point placement gave a total N recovery of 94 % compared with 82-90% with band placement and 52% with broadcast.

Rees *et al* (1997) studied the fate of urea applied to winter wheat in loess soils in north-west China, nitrogen was applied at rates of 0, 75 or 150 kg N/ ha, either to the surface, or incorporated by mixing with the top 0.15 m, or placed in a band at 0.15 m depth and observed that the recovery of fertilizer-derived nitrogen was considerably higher in the mixing treatments and banded placements (33 and 36%) than that from the surface applications (25%). The main loss of N was due to ammonia volatilization rather than leaching.

Blackshaw *et al* (2002) conducted a field study was conducted to determine the effect of various application methods (ammonium nitrate solution applied broadcast on the soil surface, applied in pools on the soil surface at 20-cm intervals between every second wheat row, and point injected 10 cm deep at intervals similar to those of the surface pools) of the nitrogen fertilizer on N uptake in spring wheat. In the presence of weeds, the N uptake was highest in case of point injected followed by surface pools and surface broadcast. While in the absence of weeds, wheat yields were similar across the three N application methods.

Petersen and Mortensen (2002) conducted an experiment was carried out to study the growth and nitrogen (N) uptake of spring wheat by placement geometry in a pot experiment. The fertilizer was banded in 12 combinations of depth (1, 5, or 10 cm) and distance from the crop row (1, 5, 10, or 15 cm), or broad spread on the soil surface. Regression analysis by distance from the crop row and depth from soil surface were carried out and found a negative effect of increased distance and a positive effect of increased depth for all parameters. They recommended that the distance from crop row should not exceed 6–7 cm and the depth below soil surface should exceed 4–5 cm to ensure a positive effect of N placement under adverse conditions (Schoenau 2003). By placing fertilizer in mineral soil beneath the thatch layer, the fertilizer was physically isolated from potential temporary nutrient tie-up by micro-organisms decomposing the surface residues.

Nyord *et al* (2008) used three fertilizer application techniques: a disc coulter injector, a spoke wheel injector and a newly developed high-pressure injector using a trailing shoe technique were compared and observed that when the liquid bio-fertiliser was surface applied, 20–35% of the applied total ammonical nitrogen (TAN) was lost as ammonia, whereas disc coulter injection into 5–7cm depth reduced the loss to 2–3% of TAN. In the laboratory study, it was seen that the high pressure injection reduced the ammonia volatilisation as much as disc coulter injection into 5–7cm depth, but in the field experiment the high-pressure technique was not able to inject deeper than 0–2 cm, thereby it had no reducing effect on ammonia volatilisation compared to surface application. Significantly higher grain yield was recorded from spoke wheel injection and high-pressure injection of bio-fertiliser compared to surface application.

Mahmood *et al* (2011) studied on combined effects of fertilizer application method (conventional broadcast vs. point injection in maize and wheat), two levels of wheat straw (applied to cotton) and nitrification inhibitor dicyandiamide (DCD) on the recovery of the fertilizer N were studied under greenhouse conditions in alkaline calcareous soil. The fertilizer N loss under wheat was least (16%) when urea solution was point-injected but increased (24–26%) due to use of nitrification inhibitor dicyandiamide. The point injection of urea solution without any amendment was more effective in conserving the fertilizer N as compared to the conventional broadcast method.

2.4 Crop response under point injection

Jackson and Dubbs (1987) conducted a field study at Montana, barley crop yields were approximately 10 bu/ha (272.5 kg/ha) higher when 75 lb N/ha (35 kg N/ha) was applied with the seed, rather than broadcast, although this difference was not significant. In no-till continuous winter wheat, spring wheat, and spring barley, subsurface urea application significantly increased grain yield compared to broadcast when the initial soil nitrate-N was less than 125 lb N/ha (57.5 kg N/ha), but significantly decreased grain yield when soil nitrate-N was greater than 150 lb N/ha (68.8 kg N/ha).

Kushnak *et al* (1992) studied the effect of nitrogen application methods on yield of no-till winter wheat, under both dry land and irrigated conditions was studied in northern Montana. Band, knife and point injected furrow application (PIFA) row spacing was 10 inch (25.4 cm). It was found that the yield differences between methods of application were not as apparent under dry land conditions while 67 Bu/acre (1823.4 kg/acre) grain yield was recorded with PIFA against 52 Bu/acre (1415.2 kg/acre) with broadcasting. The nitrogen loss (0.32 kg/acre) was reported lesser in PIFA than broadcasting (2.6 kg/acre).

Rao and Dao (1996) studied that there was no difference in yield or protein between 2.5 inch (6.3 cm) and 5.0 inch (12.7 cm) banding depths. Surface banded ammonium nitrate increased hard red winter wheat yields by an average of 14% over three years compared to broadcast applications, although the difference was not significant.

Jacobsen *et al* (1993) used different fertilizer placement techniques i.e. broadcast, banded (surface or subsurface), seed-applied, and foliar applications were evaluated and the results showed relatively few differences in yield response for different N application placement methods, although urea placed 2" (5 cm) to the side and 2" (5 cm) below the seed increased winter wheat grain yield compared to broadcast applications on dry soils with less than 50 lb N/ac soil nitrate. About 6% higher spring wheat yields were found when urea was banded 1" (2.54 cm) below the seed and between rows compared to broadcast, although this difference was not statistically significant.

Randall *et al* (1997) conducted different nitrogen application methods viz. point injected UAN, preplant injecting anhydrous ammonia, band placement of UAN and broadcast application of UAN were compared and found highest three-year yield average with pre-emergence point injection of UAN into the ridge. The yields from both pre-emergence spoke wheel injections of UAN were higher than for surface band treatments. Similarly, the greatest N uptake was found with point injection of UAN. The point injection of UAN, regardless of placement, gave greater total N uptake than did surface banding UAN on the row. Apparent recovery of N was highest (57 percent) with point injection of UAN into the ridge and 18 percent higher than broadcast UAN. In an experiment, Stone (1998) used point injection of NPK to supplement starter fertiliser applied to carrot, iceberg lettuce and onion and observed that supplementary fertilizer, whether broadcast or injected, did not enhance the early growth benefits of starter fertilizer but at maturity, supplementary injection had significantly boosted yield of onions by 20%.

Schlegel *et al* (2003) studies on fluid N (28% N as urea-ammonium nitrate solution, UAN) was injected and surface broadcasted at five rates along with a zero N control. Apparent fertilizer N recovery was consistently higher with N injection rather than broadcast UAN. Average grain yields were 8% greater from injected N than broadcast UAN.

Blackshaw (2004) conducted a field study was conducted to determine the effect of various application methods of nitrogen (N) fertilizer on weed growth and winter wheat yield in a zero-tillage production system.

The nitrogen treatments consisted of granular ammonium nitrate applied broadcast on the soil surface, banded 10 cm deep between every crop row, banded 10 cm deep between every second crop row, and point-injected liquid ammonium nitrate placed between every second crop row at 20 cm intervals and 10 cm depth. Density, shoot N concentration and the biomass of weeds were often lower with subsurface banded or point-injected N than with broadcast N. The wheat density was similar with all N fertilizer application methods but wheat shoot N concentration and yield were consistently higher with banded or point-injected N compared with broadcast N.

Kucke and Gref (2006) found the cereals showed in about half of the cases positive yield and quality response of point injection fertilization compared to conventional split surface application of fertilizers. The nitrate leaching was reduced by 20 to 30 % in cereal and vegetable production systems, and ammonia volatilization was less than 1 % of that from fertilizer surface application.

Stevens *et al* (2007) found in a study conducted at two Wyoming locations to compare the effect of different pre-plant N placement strategies on yield, quality, and N use efficiency (NUE), nitrogen was applied using three different placement strategies: broadcast and incorporated (BI), knife-banded (KB) 18 cm from the seed row, or point-injected (PI) 8 cm from the seed row. The point injection produced the greatest maximum yield in five of six N responsive site-years with an average advantage of 603 and 975 kg/ ha sucrose compared to BI and KB, respectively. Nitrogen use efficiency (NUE) was highest with PI and lowest with BI (28% less than PI).

Siemens *et al* (2011) conducted a study to determine the effect of spike wheel injection technology on plant growth, nutrient uptake efficiency and crop yield in lettuce and found that use of the spike wheel injector significantly improved mid-season lettuce plant weight and nitrogen uptake levels as compared to conventional knife blade fertilizer application systems. Despite these early advantages, crop yield was not significantly affected by fertilizer applicator methods. Additional study was needed to confirm/validate the results of this one year study.

Kubesova *et al* (2013) studied on the effect of plant nitrogen nutrition by CULTAN (Controlled Uptake Long Term Ammonium Nutrition) method on the yield of maize and the content of nitrogen in different soil climatic conditions was studied. The nitrogen fertilizer was applied by means of an injection machine, to the depth of 5 cm in the soil and compared with conventional fertilization, when Calcium Ammonium Nitrate was spread in a blanket manner on the soil's surface. The same dose of nitrogen 140 kg N/ha was applied in all variants. Statistically significant higher grain yield (15.5%) was observed by injection method in comparison with the conventional method.

2.5 Advances in design of seeding and planting mechanism

The seeding and planting technology has evolved from very simple and manual system to the present precision system like vacuum seeding. The sowing by broad casting was prevalent since ancient time which is still in vogue in certain parts of the country. Dibbler and Pora were other techniques which were used before advent of seed drills. The mechanism for seed fertilizer metering were the main concern of research engineers while designing a seed cum fertilizer drill. Starting from simple gravity feed with varying size holes in the bottom, the seed and fertilizer box, a number of mechanisms were designed and introduced. The main metering mechanism for both mass and single seed metering are fluted roller, internal double run, agitator and horizontal plate, inclined plate, vertical rotor, pneumatic seed metering respectively (Kepner *et al*,).

Varshney *et al*. (1991) developed and tested a power tiller drawn seed-cum-fertilizer drill in Bhopal in the laboratory and in the field. In the field, the drill performance in sowing wheat, bengal gram, soyabean, sorghum and pigeon pea was tested and compared with a 3 row animal-drawn seed-cum-fertilizer drill. Field capacity, plant emergence and yield were determined w.r.t this drill. The capacity of the drill was 5.5% higher for wheat and 24% higher for bengal gram than the animal-drawn seed drill.

Yield was greater for all crops.

Bhat *et al*. (1993) developed a low cost seed metering mechanism for an indigenous seed drill and its performance was evaluated for seeding rabi sorghum. In laboratory calibration of the prototype seed drill indicated a fairly uniform distribution of seed along rows with seed damage between 0.5 and 1.0 %. Field trials found that the field efficiency of the seed drill was 67.74 %. Analysis of plant count and spacing indicated no significant variations among the rows. The overall performance index showed a satisfactory value of 92.5 %.

Gupta *et al*. (2001) developed a single-row, multi-crop seed drill for use in hilly areas. It can sow a number of crops, such as maize and wheat, combined with fertilizer. The effective field capacity of the machine was 0.157 ha/h for maize and 0.064 ha/h for wheat, with average field efficiency about 76 %. The machine was efficient and economical compared with traditional sowing methods.

Wohab *et al*. (1999) designed, fabricated and tested a manually-operated multi-crop, multi-row seed drill to be used for sowing jute, wheat, pulses and oilseeds, which has an average sowing capacity of 0.13 ha/h. The field performance of the seeder was quite satisfactory.

Singh & Singh (2001) reported the development of a zero till ferti seed drill suited to the draught capacity of hill for direct seeding of wheat after harvesting rice with a capacity of 0.45 hectare per day.

Gupta *et. al.* (2001) developed and tested a seed cum fertilizer drilling attachment to the tractor drawn cultivator. A 20 to 30 per cent saving of precious seed and fertilizer was reported. Uniform seed placement without clusters was achieved by this machine and operations like furrow opening; fertilizer drilling, seed drilling and covering were obtainable in a single operation economically.

Varma and Tiwari (2001) designed and developed a power tiller operated till plant machine for enhanced wheat production. The unit contained a six-row seed drill, rotavator, fertilizer application unit and a seed covering cylindrical roller. Field performance of this machine was reported to be very good for seeding of wheat after rice in silt loam soil. Its average capacity was to the tune of 0.15 hectare per hour. The power tiller till plant machine gave about 23 per cent higher grain yield as compared to the conventional tractor farming system.

Singh *et al*. (2000) developed a pneumatic planter for commercial operation. The machine was test evaluated on different crops in the laboratory and in the field. The field capacity of the developed planter was reported to be 0.45 kg/ha compared to 0.5 kg/ha of the conventional seed drill. The mechanical damage to seeds was negligible in comparison to 4-5 per cent in seed drill and more than 90 % of the seeds were in the range of $\pm$ 1 cm for soybean, mustard, Kabuli gram and ground nut for which the designed spacing were 10 cm, 15 cm and 10 cm, respectively. It was that the seed requirement for this planter was half that of the conventional seed drill while yields under both the machine were similar.

Sahoo and Srivastava (2001) evaluated the performance of different metering systems for okra seed. The metering systems like vertical roller, horizontal plate(flat drop), horizontal plate(edge drop) and inclined plate were evaluated on the basis of their performance parameters i.e. average spacing, quality of feed index, multiple index, miss index, degree of variation and seed damage of metering okra seed at three different cell size and four different cell speed. It was reported that degree of variation was influenced highly by the cell speed and metering system. The effect of cell size was non-significant.

Alam and Ram (2002) compared the performances of pneumatic planter centralized sowing system with a mechanical seed drill (Jyoti planter) using mustard seeds to determine the most promising designs of pneumatic centralized sowing system for the planter. The criteria used in the comparison were uniformity of seed distribution, seed rate reliability, seed damage, draft and power requirement of the sowing systems and grain yield. The working quality of pneumatic centralized sowing system was better than that of the mechanical seed drill. The exact planting of single seed was obtained using the pneumatic planter.

Shukla *et al*. (2001) developed a nine row direct drilling machine with notched disc furrow opener. The machine is capable of performing sowing operation without any prior field preparation in a clean field as well as in standing stubble condition. It was found that the draft requirement for operating the machine is 30-40 % less than the no-till-drill with inverted T-type furrow openers.

Raheman and Singh (2003) developed a sensor based on a light interference technique for sensing the seed flow from the metering mechanisms of seed drill and planter. The sensor comprised of an infra-red emitter, a phototransistor, a voltage divider network, IC4033B and a seven segment display unit and was mounted on the seed delivery tube. The performance of the sensor was studied for wheat, mustard and maize seeds in a test-rig developed for testing different metering mechanisms used in seed drills and planters. The developed sensor successfully sensed the seed droppings for mustard and wheat seeds with a maximum error of 18 per cent.

2.6 Design of aqua fertilizer seeder

2.6.1 Liquid fertilizer application

It has been established that aqueous fertilizer enhances not only seed germination and initial growth, but also the overall yield. However, proper metering of aqueous fertilizer and its application are major hindrance. Application of aqueous fertilizer alongside the seed needs precise and proper method to avoid mixing of seed with aqueous fertilizer and making mud due to excess application of water at a place. Design must also take care of the furrow opener formation of proper furrow and ground drive wheel for uniform metering of seed. Efforts have been made to develop applicator for liquid fertilizer for specific purposes and situations.

Singh and Singh (1982) conducted experiments on wheat and paddy crop using a nitrogenous liquid fertilizer "Ankur" in different parts of Punjab. The study included performance evaluation vis-a-vis other solid fertilizers. It was concluded that the adoption of liquid fertilizer is limited due to absence of any proven technique for its application. It was suggested that the development of applicator is essential for promoting use of liquid fertilizer.

Minhas (1982) carried experiments on wheat crop using a liquid fertilizer “Ankur” in the Solan district of Himachal Pradesh. The results indicated that the liquid fertilizer has a potential for increasing grain yield but the application technology is costlier than those used for solid nitrogen fertilizers.

Singh (1982) conducted experiments in order to know the efficacy of different nitrogenous fertilizer by taking wheat, paddy, and bajra as a test crop. It was concluded that the liquid fertilizer was found to be at par in producing grain and straw yields of wheat and paddy.

National Fertilizers Limited (1982) a producer of liquid nitrogenous fertilizers “Ankur” has suggested that the proper incorporation of it into the soil is an important factor. A liquid fertilizer applicator was developed by them. However, suggestions were made for the modifications in applications technology to achieve perfection in methodology of application.

Anonymous (1996) conducted experiment on Variable rate technology used in a cotton and corn rotation to apply a liquid nitrogen solution (33% N) based on yield and soil maps to evaluate precision agricultural, variable rate application production versus conventional field averaged, constant rate application production. For clean-till, subsoil, the yield for constant rate application was significantly higher than for the variable rate application.

2.6.2 Pressurized pumping system

Guelle (1954) stressed on the qualities of the fertilizer application machinery. It was suggested that liquid fertilizer application machinery should have a longer life, more accurate metering system and should accurately place fertilizer in relation to both seed and growing plants in order to obtain, maximum return. It was also suggested that the machine should reduce the cost of application. It was indicated that the main problem with the fertilizer application machinery is the problem of corrosion due to which the life of the machine is shortened and the accuracy becomes less. It was recommended that the use of stainless steel, fiber glass, cadmium or chrome plated copper as materials for the fertilizer distribution system.

Panduranga and Chennabasavan (1982) designed gear pump, which is PTO-driven, consists of two sets of identical gears mounted on stainless steel shafts. Since both gears are driven, the teeth do not mesh with each other, clearance being deliberately achieved. As the driven gears are unlubricated except by water and operate under abrasive and corrosive conditions, wear of the teeth is thus avoided. The pump has a horizontal and vertical range of 15 m and 12 m respectively, produces an even spray and is versatile, simple and cheap to operate.

Zhang-Jun *et al*. (2003) aiming at the problems of drainage and irrigation machinery in China, the structure and the working principle of the rotator pump, which can be widely used in agriculture, were investigated. The instantaneous flow characteristics and the instantaneous flow pulsation of the pump were analyzed. The flow pulsation rate of the pump was far smaller than that of common gear pump. The engaging power of the pump was zero. The results that the new kind of pump has bigger displacement and higher pressure were obtained and on some conditions. It can be widely used in agricultural products processing in China. The research results will be applied to the design of a new type of water pump.

2.6.3 Design of aqueous fertilizer applicators

Ganntt *et al*. (1973) reported that a proper supply tank, pump, metering and distribution system should form the major units of a liquid fertilizer applicator. A pump having flexible plastic hoses mounted on a reel having rollers was developed. The diameter of rollers was 12.5 mm and the ends of rollers were slipped into babbitt bearings of 31.75 mm length. The outside diameter of rubber hose was 15.8 mm and inside diameter was 9.5mm. The main problem with the pump was short hose life. The pump had the advantage of corrosion resistance, easy driving from the ground wheel, constant rate of application regardless of ground speed of applicator and no bypass line. The efficiency of the pump depended on the expansion of the tubes over the rollers. The system had the advantage of simplicity freedom from leakage, no contact of the fluid with the housing, pumping member and seals. The major difficulties encountered with hose pumps were their inability to produce equal tension in all tubes and very low output pressure.

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. Metering was done by peristaltic pump. The pump was used to apply iron chelates mixed with water. The requirement for uniform distribution was that 0.028 kg be applied over a distance as great as 12-19 meters. The pump due to its low speed provided delivery of micro-nutrient at a constant rate independent of tractor speed.

Sinha, and Verma (1987) fabricated a liquid fertilizer applicator based on Peristaltic Pump. The experiment on this pump showed that the discharge of this pump increases linearly with an increase in the pump speed for the same head of the water in the tank but it decreases with an increase in the head of water in the tank. This pump was unable to lift the water when the pump speed was below 50 rpm. It was observed that the expected life of the pipe used was around 10 to 15 hours of actual pump use and the system worked satisfactorily in dispensing liquid fertilizers.

Anonymous (1996) fabricated a single tyne, bullock drawn gravity flow aqua-ferti-seed drill for rain fed farming at Water Technology Centre of Indian Agricultural Research Institute. The experimental results showed that for all the crops (wheat, mustard and gram) the use of AFSD increased the yield.

Mani et al (2004) developed a tractor drawn aqua seed drill with proper liquid fertilizer metering mechanism using peristaltic pumping system. This technology is able to include minimize the prevalent problems faced due to high cost of pump, frequency of pulsation, dryness problem, adjustment problems etc. A research prototype of peristaltic pump with 30 cm roller diameter, 15.7 cm roller spacing, and 96 mm tube diameter with a total of nine such tubes was fabricated and test evaluated. The study showed that a liquid head of 51 cm and roller speed of 150 rpm the pumping unit gave a discharge of 1764 l/h. The performance of the machine was satisfactory in terms of seed and aqueous fertilizer metering and germination of the crops.

Kamal Kant and Indra Mani (2008) developed a tractor drawn aqua seed drill for metering of aqueous fertilizer with constant head gravity fed system with varying nozzle sizes was developed. This technology consists of a rotary pump, two symmetrically mounted water tanks for supplying aqueous fertilizer to another centrally mounted water tank where a constant aqueous fertilizer head was maintained. The pumping system also consisted of nine nozzles connected to nine tube carrying aqueous fertilizer directly to the nine respective furrows. The developed mechanisms were capable of delivering a discharge range of 8000 to 10,000 l/ha. The field experiments revealed that aqueous fertilizer application advanced germination by at least two days. Increased rate of aqueous fertilizer gave enhanced growth performance parameters in addition to better germination. For 8000 l/ha aqueous fertilizer rate, increase in germination, number of shoot per plant, number of ear head, plant height, grain yield and straw yield were 514 %, 48, 38 %, 11 %, 38 % and 60 %, respectively in comparison to those in plots with no aqueous fertilizer. The use of aqua ferti seed drill is economical keeping in view its advantages.

In an aqua ferti seeder proper measurement of liquid fertilizer with minimum losses is necessary. Another important factor is that machine should deliver required discharge for a given crop in a given agro-climatic situations. This would mean that proposed design of aqua ferti drill should be capable of delivering a range of discharges. Pressurized metering system will prove useful for precision seeding of different crops by controlled application of aqua-fertilizer according to soil-moisture as well as crop conditions. Also pressurized metering system based aqua-ferti-drill using different nozzles will be able to supply aqueous fertilizer with different flow rates, which may further economize water requirement.

It would be prudent to conduct a study to determine the design values of all the design variables for designing and developing a suitable tractor drawn aqueous fertilizer based seeding machine using pressurized metering system.

2.7 Fertilizer Applicators in India and Abroad

Liu (1984) developed a Chinese applicator for USG or briquette N was evaluated in several countries. The applicator employed an inclined plate meter operated by ground wheel through a set of bevel gears to pick up one briquette at the hopper bottom and discharges this, through a spring, at the top of a delivery tube leading to the skid opening. Fertilizer was dropped through the skid hole into the 3-6 cm deep furrow created by a wedge underneath the wooden skid. While the operator pushed the device, the rear end of the skid exerted pressure on the soil surface for furrow closing.

Sunderman (1984) used a high pressure nozzle slot injection was developed to cut a slot in the soil and to place the bulk of the fertilizer material subsurface for no-tillage conditions. It had a trailing sled moved over the soil surface with a solid stream nozzle positioned just above the surface which directed a stream of liquid fertilizer at pressures around 140.6 kg/cm^2 (2,000 psi). It was noticed that residue and hard surface soil reflected portions of the fertilizer material. Tests conducted at Colby, Kansas reported that 50 to 70% of the fertilizer remained in the top 10.2 mm (0.4 inch) of surface. soil Performance of the injector was dependent on pressure, flow rate, and filtration of the liquid fertilizer.

Van de Sar and De Vries 1984) developed a manually operated pneumatic injection device (Fig. 2.1) for point placement of prills or granules at adjustable depths of 5-10 cm was developed by the Netherlands Fertilizer Institute, the Wageningen Agricultural University. Metering was activated with the upward movement of a piston to expose granules in an adjacent hopper to an opening in the rotary dosing wheel. The fertilizer and any sticking soil on the injection pipe could be forced into the soil pneumatically.

Bandel (1986) used a tractor-mounted three-point-hitch soil injector (Fig. 2.2) was developed and evaluated in corn fields. Solutions of ammonium nitrate, urea or UAN were placed between the rows about 15 inches from the plant, and about 4 to 6 inches deep. A plow coulter was used in front of the injection knife to cut plant residues. There was 20.3% higher grain yield with soil injector (152.8 bu/ac) in comparison to broadcasting of urea (127 bu/acre). But the energy required for nitrogen injection with this machine was more than that of surface application.

Morrison (1986) studied the performance of four different fertilizer applicators viz. coulter/nozzle, v-wheel and sweep, high-pressure nozzle slot injectors and spoke wheel point injector were evaluated at several locations, including Temple, Texas and observed that the vertical distribution of the fertilizers and plant use efficiency were better with these fertilizer injectors than broadcast fertilization. The slot injectors for liquid and dry fertilizers were found suitable to increase fertilizer use efficiency and minimize losses in surface runoff.

Giles *et al* (1988) conducted three liquid fertilizer applicators viz. a spoke wheel, a coulter nozzle injector and a drop tube with a straight nozzle mounted on the cut-away disc cultivator were evaluated for application of liquid nitrogen in sugar-beet and compared with a surface broadcast application of urea granules followed with cultivation for incorporation. The spoke wheel consisted of a set of spokes which injected liquid nitrogen 4 to 5 inches below the soil surface. The coulter nozzle injector consisted of a 20-inch diameter coulter mounted to cut a narrow 4-inch deep slot in the soil. At the trailing edge of the coulter a solid stream orifice was mounted which directed liquid nitrogen into the slot. The cut-away applicator had a solid stream orifice nozzle mounted to the V-bar of the cultivator and angled to direct liquid nitrogen at the base of the trailing edge of the disk. The liquid fertilizer was applied by all the applicators within 10 cm of the plants on one side of each row. A uniformly spaced application was achieved with the spoke wheel, but often the location of the material was not near a plant. The N fertilizer applied with the spoke wheel and disk coulter had the higher yield and recoverable sugar than other methods.

Baker *et al* (1989) studied on a rolling spoked-wheel, point-injector fertilizer applicator (Fig. 2.3) was developed, refined and field tested. It could inject fluid fertilizer in rows of points about 10 cm below the soil surface and with a 20 cm point-to-point spacing. It consisted of one spoke wheel per crop row, with an average wheel-to-wheel spacing of 76 cm. The measurable yield benefits in a variety of crops were also observed.

Bautista and Schnier (1989) studied on the development and evaluation of water dissolved nitrogen applicator for rice crop at International Rice Research Institute was carried out. The metering device used was a peristaltic pump driven by ground wheel. The pump supplied the liquid N into thin delivery tubes which ended beneath a narrow skid, with furrow opener and covering devices. One operator was needed to operate the applicator in the field. As the operator pushes the injector, the pump continuously meters N and forces it under pressure from an orifice 6 cm below soil surface. The injector had a lower labour input due to higher capacity of 0.5-1.0 ha/day compared with intermittent USG point placement at 0.2 ha/day field capacity

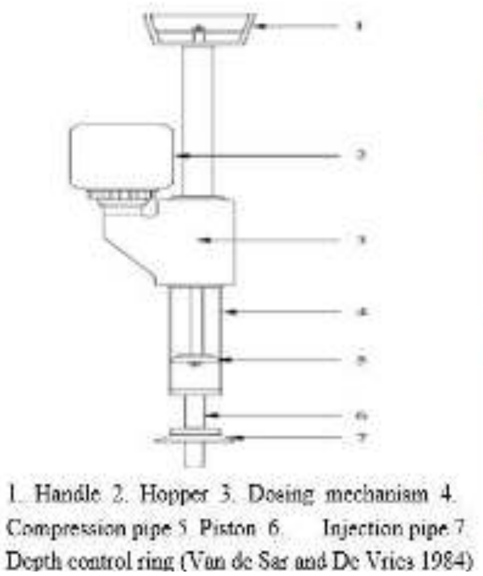


Fig 2.1 Pneumatic fertilizer injection device

Fig 2.2 Coulter Fertilizer Applicator

Janzen and Lindwall (1989) conducted a field study at two sites in Canada, to identify the optimum injection intervals and injection depth for point-injection of urea-ammonium nitrate solution in wheat crop. Based on all performance parameters, the optimum lateral (across-row) injection interval was equivalent of two row spacing (40 cm) in wheat crop. Higher intervals resulted in unacceptable variability in N availability because wheat in rows not directly adjacent to injections assimilated comparatively little fertilizer-derived N. The optimum longitudinal injection interval was also found 40 cm. It was found that crop uptake of fertilizer N was reduced when the injection interval was increased from 40 to 60 cm. The optimum injection depth was 10 cm. The field results showed that grain yield response and fertilizer N recovery in the crop increased four- and three-times, respectively, when injection depth was increased from 2.5 to 10 cm.

Injection of fertilizer at 15 cm rather than 10 cm demonstrated no additional advantage.

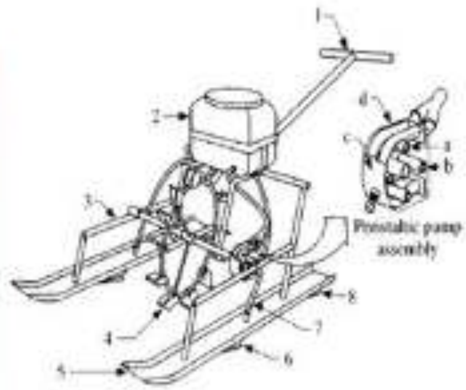
Tompkins and Womac (1990) conducted an experimental single probe type fluid fertilizer injector was developed and it had shown less soil disturbance than the spoke wheel. A variable injection interval of 203 to 609.6 mm (8-24 inches) could be achieved in the unit without significant soil disturbance. Penetration was about 63.5 mm.

Savant *et al* (1991) developed a plunger-type, hand operated applicator prototype (Fig. 2.5), made of polyvinyl chloride (PVC), for deep placement of urea briquettes (UB) was developed and evaluated in rice crop at Philippines. The average field capacity of the applicator was 0.20 ha per workday. The agronomic efficiencies of the applicator placed UB were found superior to those of split applied prilled urea.

Scholten 1992) studied on the manually operated pneumatic injection devices were evaluated in several countries and reported the results of tests towards its effectiveness in increasing N-use efficiency, with yield increased from 0.25 to 1.30 t/ha although its labour requirement of 40 h/ha was considered high.

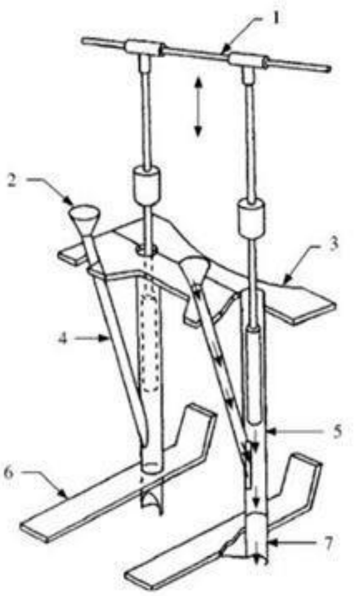
Belzer (1994) developed a single probe-type fluid fertilizer injector was developed at University of Tennessee. The hydraulically driven single-spoke injector enters and exits the soil as the unit moves forward. Field evaluation revealed that a variable injection interval of 8 to 24 inches at a depth of about 2.5 inches could be achieved without significant disturbance. Further engineering research was suggested to increase forward speed and improve soil penetration.

Fig 2.3 Spoke Wheel Injector



1. Handle 2. Fertilizer tank 3. Frame 4. Ground wheel 5. Skid 6. Furrow opener 7. Delivery tube 8. Furrow cleaner, a. PVC roller b. stainless-steel shaft c. semi-circular cover d. steel plate (Bautista and Schnier 1989)

Fig 2.4 Liquid Nitrogen Injector



1. Handle 2. Funnel 3.Wooden frame 4.delivery tube 5. Plunger assembly 6. Skid 7. Guide (Savant *et al* 1991).

Fig 2.5 Urea Briquette Applicator

1. Injection nozzle 2. Connecting- hose 3. Engine-pump assembly 4. Handle 5. Depth-control plate (Hiraizumi 1997)

Fig. 2.6 Hiraizumi liquid nitrogen injection device

Hiraizumi (1997) developed an engine-driven sprayer pump (Fig. 2.6) for application of liquid nitrogen in the soil was developed in Japan. The unit consisted of nozzle tips mounted on a frame and a lever for operating the nozzles just like a sprayer. The nozzle tips could inject up to a depth of 12 cm. With the pressing of lever, the N release in four directions simulates a spray. Liquid is metered and released using the pressure of 2.0-3.5 MPa generated by the pump.

Nyord *et al* (2010) studied on a simple tine in conjunction with the disc injector (Fig. 2.7) was developed to reduce crop damage and to penetrate the soil more easily. Two experiments were carried out in a soil bin in order to find the optimal placement of the tine in relation to the discs and the best working depths for the tine and discs. A field study was also done to evaluate the amount of crop damage caused by operating a prototype injector in a growing winter wheat crop. It was found that running the double discs at approximately 40 mm and the tine at 100 mm below the soil surface gave the best results. The tine should be placed as close as practically possible to the discs, with a rake angle of 40°. At this adjustment, the horizontal force demand was reduced to 30–40% of what has been reported for comparable injectors. No significant crop damage was found compared with the untreated control crop.

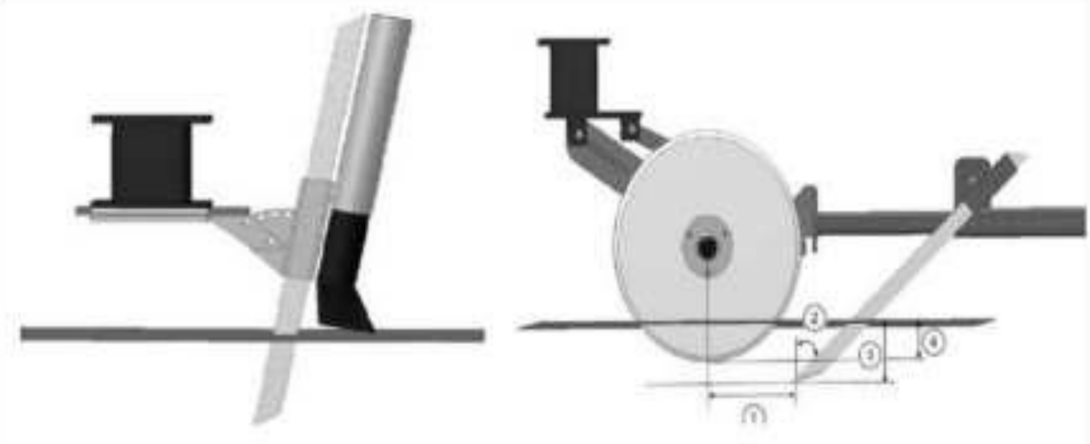


Fig. 2.7 Simple tine and the experimental slurry injection system used for the study of draught force requirements

MATERIALS AND METHODS

Due to the moisture stress, germination and initial growth of wheat crop in moisture deficit areas is greatly hampered. The problem can be surmounted by supplying required additional moisture on both side of the seed while sowing the crop by using a suitable machine. A study was undertaken to design, development and evaluation of tractor drawn seed cum pressurized aqua fertilizer drill. The first step required in this direction was to estimate the amount of additional moisture is required for the germination of seed, based on the amount of available soil moisture. Once the soil moisture deficit is determined, the capacity and other relevant design features of aqueous fertilizer metering and disbursing system could be worked out; which in turn, would facilitate design and development of required aqueous fertilizer applicator. The proposed machine consisted of main frame, metering system for pressurized aqueous fertilizer both side of seed dropping mechanism, aqueous fertilizer tank, furrow opener, ground wheel drive and a power transmission system. The design of a suitable pumping system to meter and disperse required amount of aqueous fertilizer in the furrow along with the seed was main innovative job of this study. The aqueous fertilizer metering was attained by designing a suitable pumping system to deliver a measured quantity of aqueous fertilizer.

Main emphasis of the study was on design of pressurized metering system for precise and controlled application of aqueous fertilizer according to soil moisture as well as crop conditions. All the design variables of pressurized pumping system were investigated to find out their effect on discharge from pump and uniformity of application of aqueous fertilizer from different nozzles. An experimental set up was designed and fabricated with process varying pump rotational speed, pressure and nozzle size. Different variables were studied to work out their influence on pattern and range of discharge from tubes of different nozzle sizes in order to calibrate the experimental set-up for different combination of design variables. The design and fabricated set-up was mounted on exiting 9 tyne tractor operated seed drill with the necessary modifications. The machine was evaluated for its performance of system in terms of water application capacity, field capacity and field efficiency along with power requirement of machine.

This chapter deals with material used and methods followed in design and fabrication of experimental set up used for investigation of pressurized pumping system, techniques of conducting experiments on experimental set up, method of data acquisition and data analysis, development of aqueous fertilizer seeder based on above developed mechanism and its test evaluation.

The study was conducted in the following sequence:

1. Determination of requirement and placement of aqua fertilizer under laboratory conditions for germination of wheat crop.
2. Determination of design values of pressurized aqueous fertilizer for metering mechanism.
3. Design and development of tractor drawn seed cum pressurized aqua fertilizer drill.
4. Performance evaluation of a tractor drawn seed cum pressurized aqua fertilizer drill for sowing of wheat crop under vertisol.

The material and methods used to accomplish the above research program of the study is presented below.

3.1 Estimation of aqueous fertilizer requirement for selected soil-moisture-crop conditions

3.1.1 Determination of available soil moisture (ASM)

To enhance proper seed germination and growth of crop, timely sowing is more important. Available soil moisture is basic requirement of seed germination. In dry land areas the moisture availability at time of sowing is a major problem. To begin with, determination of available moisture at sowing depth was done and based on that estimation of aqueous fertilizer requirement in given area was determined. The available soil moisture is the moisture that plant can use and it depends on soils texture. The available soil moisture was calculated by using the formula:

ASM, (%) = FC, (%) - WP, (%)   (Ratliff et al. 1983)   …eq. (3.1)

Where,

ASW = Available soil moisture, %;

FC = Field capacity, the upper limit of available moisture at which drainage ceases (Occurs at soil moisture tensions of 1/10 bar (10 centibar) for sandy soil and 1/3 bar (33 centibar) for other soils; and

WP = Wilting point or lower limit of the soil moisture at which plant wilt permanently (Permanent wilting point occurs at 15 bars of soil moisture tension).

The volumetric per cent of soil moisture content at field capacity, wilting point and available soil moisture for various soil textures is presented in Table 3.1. Field capacity and wilting point was also evaluated for the selected soil type and the similar procedures were also used by Sengar 1990. This calibration will be helpful in determining moisture requirement if soil type and soil texture pattern is known for dry land areas. With the help of above data total water and available water for different texture soils were also determined. Water holding capacity, in terms of available water in per cent, for different soil texture designation was determined with the help of field capacity and wilting point levels of various texture of soils.

Table 3.1 Volumetric per cent of soil moisture content at field capacity, wilting point and available soil moisture for various soil textures

Soil texture	Field capacity, %	Wilting point, %	Available mc, %
Sand	10	4	6
Loamy sand	14	7	7
Sandy loam	20	9	11
Loam	27	12	15
Silt loam	30	15	15
Silt clay loam	36	20	16
Clay loam	32	18	14
Sandy clay loam	29	18	11
Sandy clay	28	15	13
Silt clay	40	20	20
Clay	40	22	18

Source: Ratliff et al. 1983

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3.1.2 Determination of aqueous fertilizer requirement

The requirement of aqueous fertilizer in a given soil moisture environment depends on the soil texture, field capacity, wilting point and available moisture in a particular soil. The first step in this direction was to estimate the requirement of additional soil moisture which is sufficient to meet the moisture requirement for the germination of seeds. It is not possible to provide extra moisture abundantly, because moisture applicator has its own limitations w.r.t. water carrying capacity and mode of aqueous fertilizer application. Also any excess volume of water would be a hindrance in proper sowing of seed along the aqueous fertilizer. The estimation of requirement of aqueous fertilizer was done by using the following formula: (Ratliff et al. 1983),

$$V_1 = (FC - WP) \times \rho \times d \times w \times n \times W \quad \text{...eq. (3.2)}$$

Where,

V_1 = Amount of aqueous fertilizer, vol. l/ha;

FC = Field capacity, %;

WP = Wilting point, %;

ρ = Density of soil, g/cc;

d = Depth of seed placement, cm;

w = Width of root spread per meter row length, cm;

n = No. of turns of seed drill per hectare and

W = Width of seed drill, cm

3.1.3 Determination of placement of aqueous fertilizer

Laboratory studies were made to determine the exact dropping position of aqueous fertilizer with reference to seed, at recommended depth of sowing under vertisol. Three lateral distances and three depths were taken and provided with equal amount of water i.e. 1.59 l/m, to check the both lateral and longitudinal movement of water. For this particular study, the observations were taken in the laboratory under controlled conditions for all the 27 treatments, each treatment had separate tray having uniform size. The soil moisture content was measured at the seed vicinity after interval of 3^{rd}, 6^{th} and 9^{th} day after water application to determine the longest period, when the maximum soil moisture could be maintained. The plan of experiment is given in Table 3.2

Table 3.2 Plan of experiment

S. No.	Independent Variables	Levels of variables	Dependent variable Measured parameter
1.	Lateral distance from seed	3 level (2.5, 5.0 and 7.5 cm)	Moisture content of soil (db)
2.	Depth from top	3 level (0, 2.5 and 5.0 cm)	
3.	Treatments	9	
4.	Replications	3	
5.	Design	FCRD	

Plate no 3.1(a) shows the line diagram of placement of seed and aqueous fertilizer. Whereas, the Plate 3.1(b) shows the actual lateral and longitudinal movement of water into the soil under laboratory conditions. Dark colour profile of the soil shows the lateral movement of water after application of aqueous fertilizer.

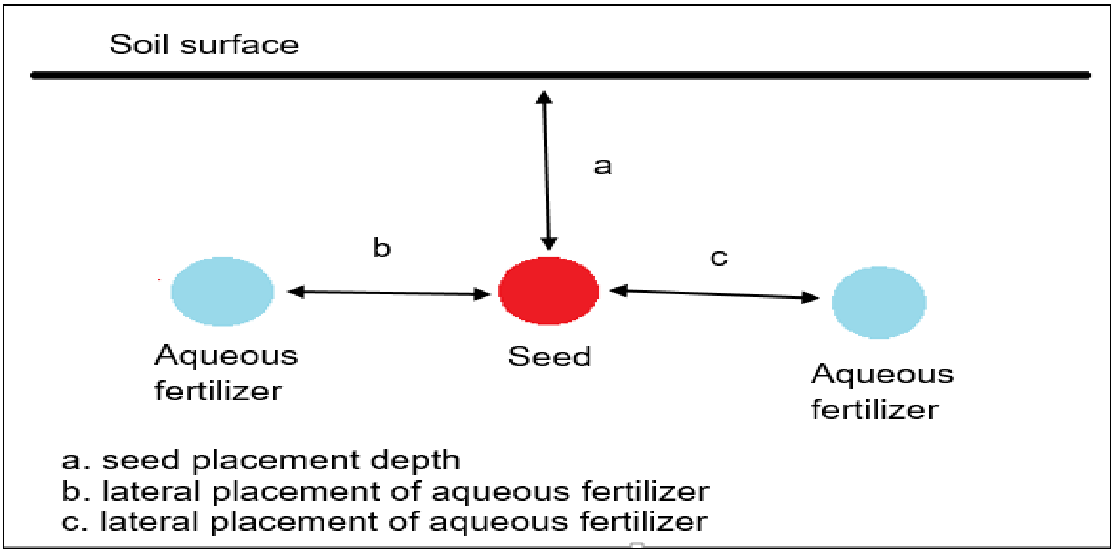


Plate 3.1(a) Line diagram showing placement of seed and aqueous fetilizer

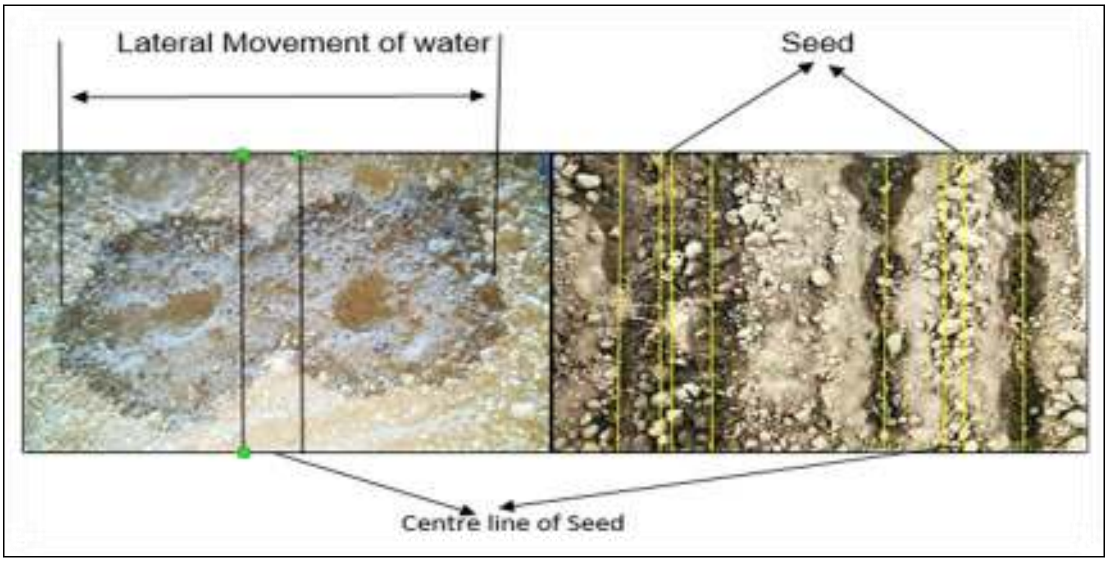


Plate 3.1(b) Lateral movement of water

3.1.4 Moisture absorption by soaked seed after different time interval

Moisture absorption by individual seed over a given interval is of interest in aqueous fertilizer application. The applied moisture in aqueous fertilizer form will be absorbed by seed and soil. The absorption of moisture by seed in moist soil medium and soaked condition was determined to know the behavior of individual seed with regards to soil moisture absorption. An experiment was laid to determine amount of moisture absorption by seed with time, for this, 50 gm seed sample was dipped into water and allowed to remain for periods of 5, 10, 15, 30, 60, 120, 240 and 480 minutes. The increase in weight was measured and moisture content after soaking was determined. This process was replicated three times for every sample and average of the data was calculated. Plate 3.2 depicted the view of soaked wheat in water.

Plate 3.2 Soaked wheat in water

The absorption of moisture by seed is prime and very important physiological phenomenon for the sprouting or say germination of seed within field condition. Therefore, study have been conducted to find out the moisture absorption by seed under laboratory or field condition. Results of lab conditions may be utilized for the designing of supply of water system in seed drill.

3.1.5 Determination of moisture absorption by seed in moist soil

The water requirement of individual seed for proper germination depends upon moisture loss by the soil with time after application of aqueous fertilizer and moisture gained by seed during the same period, in addition to the other soil physical and environmental factors. So, need to study the pattern of loss and gain of moisture by seed with time before reaching saturation. An experiment was conducted under controlled conditions i.e. under seed germinator to simulate the environment for wheat crop of temperature 24^{o}C and relative humidity 99% (plate 3.3), to determine moisture absorption by seed at different time intervals after sowing. A sample of 100 seeds of wheat seed were sown at 5 cm depth with 11.5, 9.0 and 5.25% of soil moisture content respectively in controlled conditions. The moisture content of the sample was determined after 1st, 2nd and 3rd days of the sowing. The initial moisture content of seed was also determined for all the three samples and weight increment due to water absorption was measured on three consecutive days after sowing and the resulting increase in seed moisture was determined. Every set of experiment was replicated three times and an average value was taken. It is given in the result and discussion section 4.3.1.

Plate 3.3 Moisture absorption by seed in soil & seed germinator

3.1.6 Determination of root spread

An experiment was conducted in the field for determination of pattern of root spread after 21 days of sowing. This was done to know the volume of soil coverage by a plant. This would help in determining total soil volume in contact of root system of a plant. This further helped determining additional moisture required per plant or per unit area provided field capacity and wilting point are known for the given plant environment. The details are given in the section 3.1.2. The root coverage was measured by digging 10 plants up to its entire root coverage and washed the roots with water to separate soil from the root. The root growth in terms of length and width was measured for all the plants and an average was taken.

Plate 3.4 Root spread after 21 days

3.2 System parameters

The aqua-fertilizer seed drill consisted of mainly two components of system.

1. Seed metering system along with furrow opener and seed tubes and
2. Aqua-fertilizer metering system.

As the major emphasis was on determination of design values of different variables of pressurized metering of aqua fertilizer, the study concentrated on designing of different components of aqua fertilizer metering system based on pressurized pumping system. Aqueous fertilizer metering by pressurized pumping system will be able to supply aqueous fertilizer with different flow rates.

Major requirements of pressurized metering system are as follows:

1. The system supply aqueous fertilizer at different flow rates.
2. The aqueous fertilizer should not corrode the pumping housing.

3. The entire system should be leak proof to prevent losses due to pressurized flow and also to save costly fertilizer.
4. Aqueous fertilizer should be free from any contamination, so that system works properly without clogging.

Keeping above considerations in view, it was decided to select pressurized metering system for aqueous fertilizer metering. The pressurized metering system consisted of main frame, centrifugal pump to control supply rate and to meter aqueous fertilizer from different nozzles, cone pulleys (step pulleys) to vary pump rotational speed, pressure valve to control flow rate as well as pressure for calibration known as calibrated pressure ($P_{calibrated}$), flow distributor with different nozzle sizes for allowing uniform flow through tubes. All design variables of aqueous fertilizer system were investigated to establish their relationship with discharge rate. The influence of different variables on pattern and amount of discharge from nozzles was studied. The experimental set up was used to optimize different pump variables for required discharge rate. Based on above, pressurized pumping system was designed and developed for metering of aqueous fertilizer. This aqueous fertilizer metering mechanism with suitable modification was fabricated and mounted on tractor operated seed cum fertilizer drill. The power to operate pressurized pumping system was derived from its PTO. The prototype seed drill was evaluated for its discharge rates of aqueous fertilizer. The Plate 3.5 shows the prototype of seed cum pressurized aqua fertilizer drill.

3.2.1 Main Structure

Main structure of the pumping system consisted of three frames one each for aqueous fertilizer tank, centrifugal pump and nozzle system. The structure of the pumping system was designed to accommodate different components. The frame of the aqueous fertilizer tank had overall size of the frame 1250×2000 mm and was made of 50×50×5 mm angle iron. The frame was designed keeping in view that the required area of the platform and load expected due to the soil stresses bending moment and shear stresses also calculated for size of MS angle box and match that the load required for seed drill can easily accommodate within their bending moment, torsion and shear stress developed at section of frame. This available size of angle iron (50 x

50 x 5 mm) was selected as per the calculations of loads.

The aqueous fertilizer tank was placed on the separate angle iron frame having the size 400×400×800 mm as shown in fig 3.11 and this frame was fastened on the main from. Another frame for the distribution of aqua fertilizer through the nozzle which were controlled by control valves, was mounted at the height of 900 mm from the main frame of the seed drill. The frame was designed keeping in view the required area of the platform and load expected (Fig 3.1).

The centrifugal pump was mounted on a right hand side of the main frame as shown in the fig. 3.11.

Frame was subjected to torsion and bending due to induced draft. Design was based on the stresses produced in the frame, the following assumptions were taken. (Sharma D.N.)

Width of furrow opener = 6 cm

Depth of furrow opener = 8 cm

Soil resistance = 0.5 kg/cm^2

Cross- section of furrow = 6 x 8

Cross -sectional area =48 cm^2

Draft = soil resistance (kg/cm2) x cross- sectional area of furrow (cm)

= 0.5 x 48

= 24 kg

Torque produced on toolbar (T) = 0.5 × 8 × 6 × 0.4 (clearance from ground) × 9 (no. of tyne)

= 86.4 kg-cm

In addition to torque the bending moment is also produced in the toolbar. The toolbar can be assumed as simply supported frame. The maximum bending moment will be at the centre. The reactions at each of the two supports is = 24 × 9/2 = 108 kg

The maximum bending moment at the centre is calculated as

$M = 3.5\ P \times 2.5\ x - 3Px - 2Px - Px$

$= 9.15\ Px - 6Px = 3.15\ Px$

$= 3.15 \times 24 \times 45 = 3400$ kg-cm

$T_e = (M^2 + T^2)^{1/2}$ …………………………………….. eq. 3.3

$= [(3400)^2 + (8640)^2]^{1/2}$

= 9284 kg-cm

The maximum shear stress developed at the centre of toolbar is given by

$S_s/y = T_e/I$ …... eq. 3.4

Where,

S_s = shear stress at section

Y = distance of outermost fibre from neutral axis

T_e = equivalent torque

I = moment of inertia ($bd^3/12$ for rectangular section and for square section b = d)

Let Ss = 500 kg/cm^2

$I = bd^3/12$ …. eq. (3.5)

$= d^4/12$

Therefore,

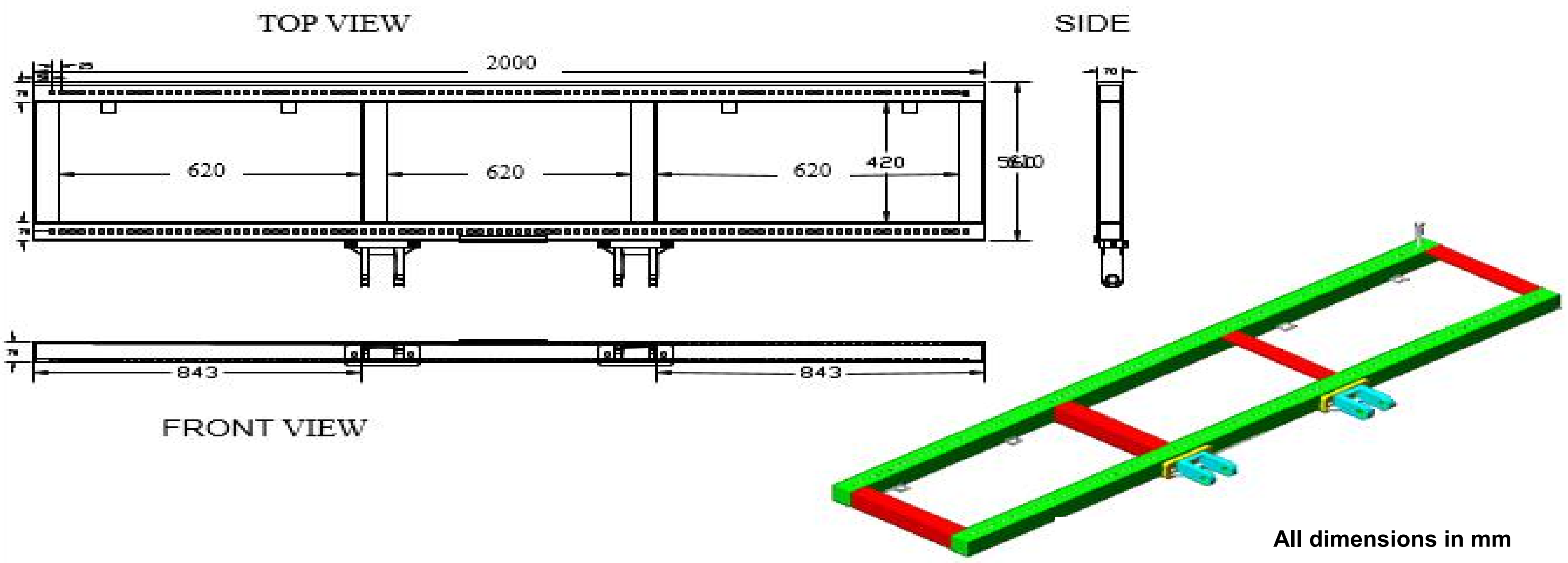
$I/Y = (d^4/12)/d/2 = d^3/6$ …. eq. (3.6)

$d^3 = 6\ Te/Ss$

$= 9284 \times 6/500 = 111.4\ cm^3$

d = 4.81 cm or 5 cm.

So, size of toolbar is 50 × 50 mm.



FRONT & BACK FRAME	MS ANGLE BOX	**50 × 50 × 5**	2 No.
SIDE & MIDDLE FRAME	MS ANGLE	**50 × 50 × 5**	4 No.
BOLT WITH NUT	MS	12 mm dia	44 No.
HEIGHT OF FRAME FROM GROUND	-	470 mm	

Fig 3.1 Main frame of seed cum pressurized aqueous fertilizer drill

3.2.2 Design of tyne shank

The shank is designed to withstand the bending and torsional stresses due soil resistance acting on the furrow opener (Bernacki et al., 1972). Maximum depth of tyne was considered as 50 mm. width of cut of shovel and the boots (ws) was taken as 45 mm. (D.N. Sharma) the mild steel (MS) flat section was selected as material for shank. (Fig. 3.2)

Force exerted on the tyne as calculated from the following:

Draft of tyne (Ds) = 250 N

Taking factor of safety = 3 (Verma et al. 2007)

Total draft exerted on the opener = 3 × 250 = 750 N.

The section modulus of the shank can be computed by following formula

$$Z = \frac{\text{Max. bending moment (M)}}{\text{Bending stress } (\varsigma)} \quad \text{....eq. (3.7)}$$

Where,

Z = Section modulus of shank, m^3;

M = Maximum bending moment, N-mm; and

ς = Bending stress, kg/cm^2 (=55 N/mm^2 for mild steel).

The length of tyne = 500 mm was taken. Assuming tyne as a cantilever, the maximum bending moment for a cantilever beam of length, h_s = 500 mm.

Bending moment (M) = Draft × Moment arm length …eq. (3.8)

$$M = Ds \times (h_s - a_s)$$

Where,

h_s = Length of cantilever beam, mm;

a_s = Height at which maximum force act, mm, taken as $h_s/3$;

Therefore, $M = 750 \times (500-166.7) = 249975$ N-mm

$Z = 249975/55 = 4545\ mm^3$

Again, section modulus of the rectangular section is given as follows:

$$Z = t \times b^2/6 \quad \text{.... eq. (3.9)}$$

Where, t = thickness of shank, mm; and

B = width of shank, mm.

The thickness of shank for available single tyne range from 16-20 mm.

Assuming thickness of shank = 20 mm.

From equation 3.09, we get

$Z = 20 \times b^2/6$

$4545 = 20 \times b^2/6$

$b^2 = 1363.54\ mm^2$

$b = 36.92$ mm (say 40 mm)

Therefore, the standard MS flat of size 40 × 20 mm was used for fabricating the shank of the furrow opener.

Maximum deflection of shank is given by

$Y_{max} = Dl^3/3EI$ ….. eq. (3.10)

Where,

Y_{max} = Deflection produced due to loading, mm;

D = Draft force, N;

l = Length of the shank, mm = 460 mm;

E = Modulus of elasticity for mild steel = 210 kN/mm^2; and

I = Moment of inertia, mm^4

Moment of inertia is given by the following formula:

$I = bh^2/12$ …..eq. (3.11)

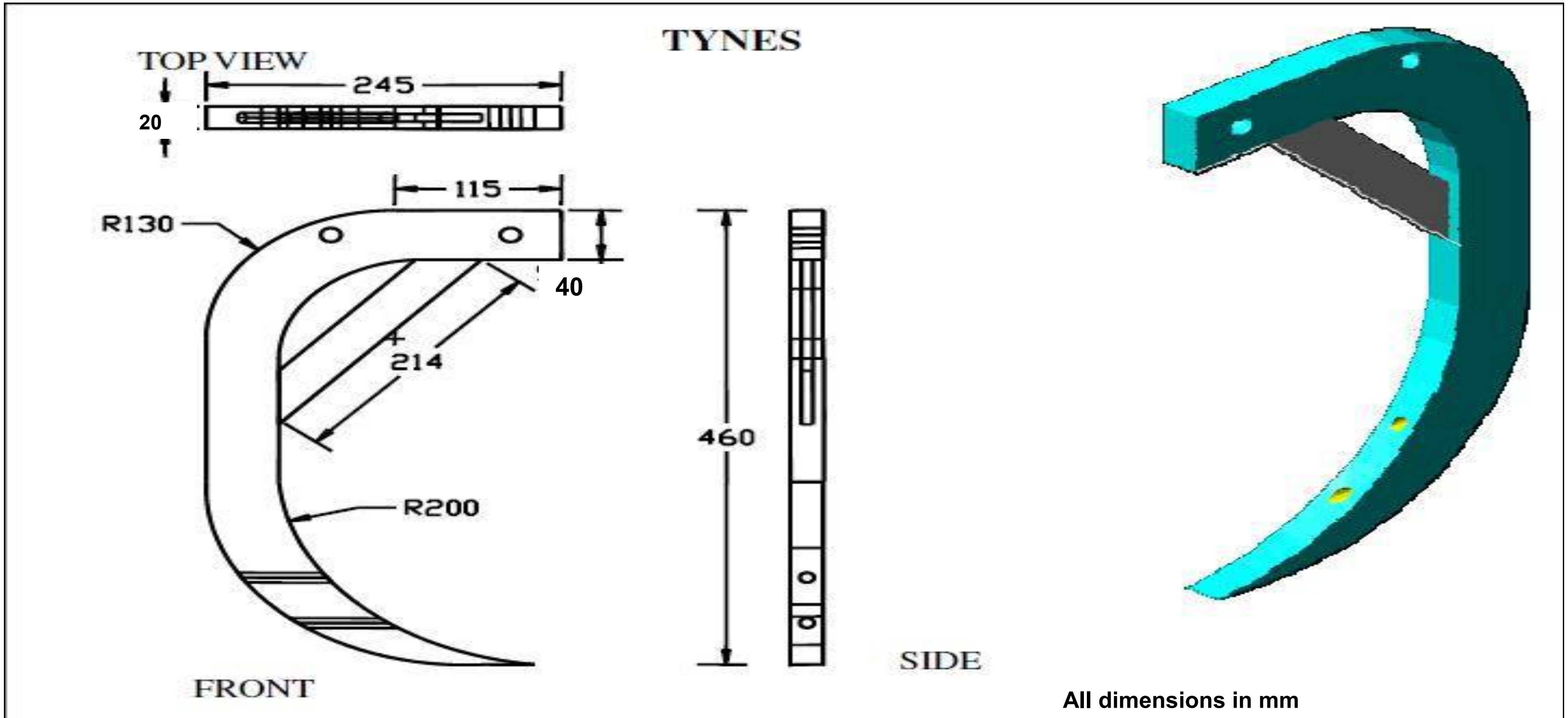
$= 53333.33\ mm^4$

Therefore,

$Y_{max} = 750 \times (460)^3/\ 3 \times 210 \times 10^3 \times 53333.33$

$= 2.17$ mm

Therefore, the MS shank tyne of 40 × 20 mm size and 460 mm length was selected. Which can withstand the maximum deflection of 2.17 mm



BACK TYNES	MS PLATE CUTTING	460×245×20 mm	09 No.

Fig 3.2 Tyne of seed cum pressurized aqueous fertilizer drill

3.2.3 Design of furrow opener

As per the design by Bosai, 1987 and G. Singh, 1989 the considering the available draft of 60 kgf being exerted on the tip of the furrow openers of 34 cm length.

Bending moment = draft x length of shank

= 60 x 34.5 kg-cm

= 2070 kg-cm

Bending stress $f = M \times c / I$ ...eq. (3.12)

Where,

f = Bending stress, kg/cm^2;

I = Moment of inertia, cm^4;

M = Bending moment, kg-cm; and

c = Distance from neutral axis to the point at which stress is determined, cm

The section modulus axis is computed by using formulae

$Z = I / c$ … eq. (3.13)

From equation 3.12 and 3.13

Assuming the bending stress is equal to 1120 kg/cm^2

Z = 2070/1120

= 1.85 cm^3

Section modulus of the furrow

$Z = bh^3 / 6$ … eq. (3.14)

Width of shank was considered as 1:4 i.e. (h: 4b)

$z = b \times (4b)^2 / 6$

$1.85 = (b^3 \times l6)/6$

$b^3 = 1.85 \times 6/16$

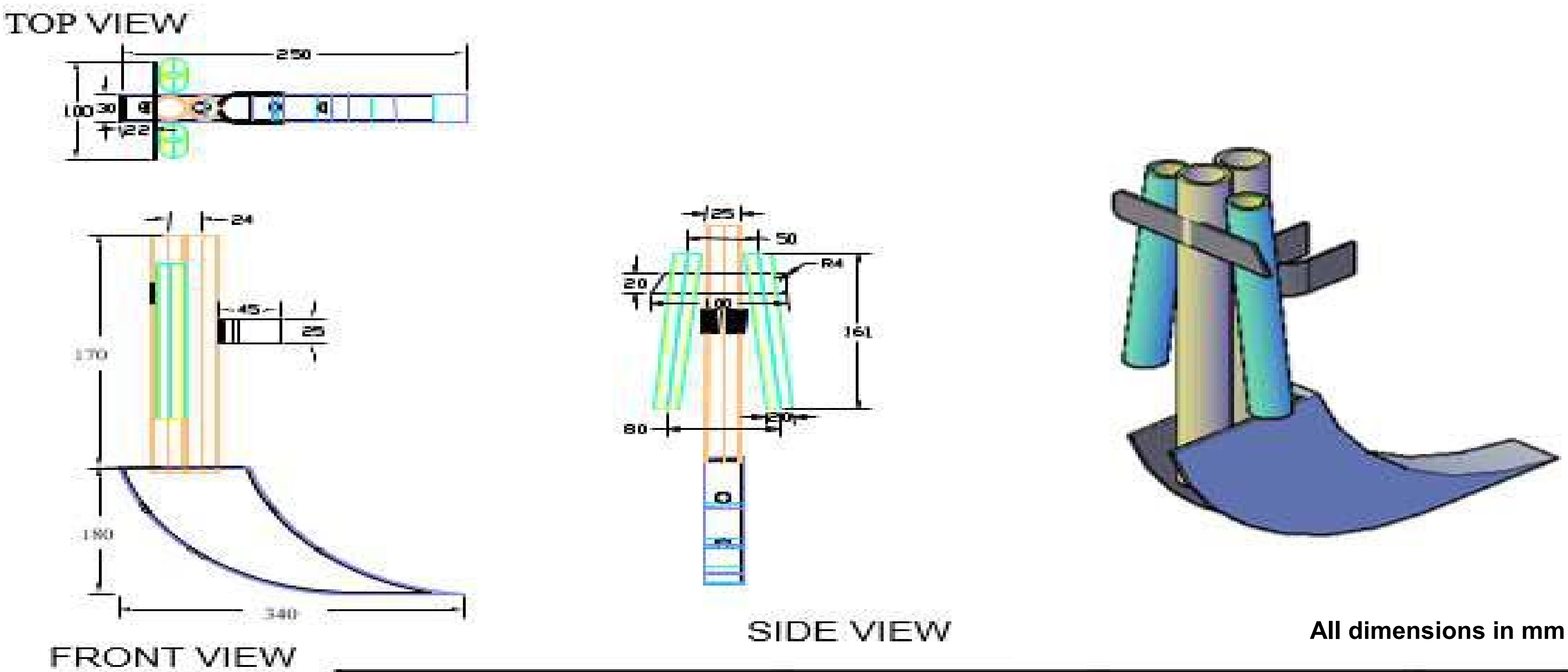
$b^3 = 0.4218$

b = 0.75 cm

b = 7.5 mm

Considering the factor of safety and availability of material of standard size. The thickness of shank furrow opener was selected = 7.5 mm

Therefore, the width of the shank = 4 x 7.5 = 30 mm



All dimensions in mm

FURROW OPENER	MS SEET	180x340x2 mm	9 No.
CONDUIT PIPE	MS PIPE	240x25Ø mm	18 No.
AQUA CARRING TUBE	MS PIPE	161x20Ø mm	18 No.

Fig 3.3 Furrow opener of seed cum pressurized aqueous fertilizer drill

3.2.4 Seed hopper design

Seed box was of trapezoidal cross section. The feed rollers were mounted on the box bottom. The bottom of the box was flat and rounded at the corners. The inclined guiding plates were fitted at the base to help movement of seed towards the inlet opening of the metering device. The location of box in seed drill was kept 145 mm above the ground. The appropriate height helps preventing the excessive bending of seed delivery tubes. On the basis of various seed properties and sowing requirements all the relevant information were taken into consideration for designing of hopper. The hopper was designed based on the basic data for wheat seed e.g. bulk density of seed (0.77g/cc), moisture content of seed (12%), thousand seed weight (45 g), germination percentage, angle of repose (33^0) and row to row spacing (20 cm). The slope of the hopper wall needed to be kept less than the angle of repose of wheat seed. The maximum angle of repose was 33.1 degrees at 14% (Dey A.K. 2004) moisture content, hence the slope of hopper wall was kept at 15 degrees.

The following steps were followed in the design of seed hopper.

i. The following data was assumed for wheat seed

   Capacity of box (Q) = 80 kg

   Density of seed (p) = 770 kg/m^3

   Angle of slope of box sides (α) = 15^o

ii. The capacity of box was determined by

   $V = Q/p = 80/770 = 0.1038\ m^3$

iii. Area of the cross section, (A) of trapezoidal box was determined by

   $A = V/L_B$ … eq. (3.15)

iv. Length of seed box was calculated by

   $L_B = Wr\ (n+1)$ …. eq. (3.16)

   Where, Wr = inter row width = 17 cm = 0.17 m

   N = no of furrow opener = 9

   $L_B = 17\ (9+1) = 1.7$ m

So, cross sectional area, (A) = 0.1038 m^3/1.7m = 0.061 m^2

v. The output opening area (A_o) securing continuous seed feeding should be 0.002 m^2, so the length and width of the rectangular cross section were kept as 70 and 25 mm respectively.

The output opening area (A_o) = .07*0.25 = .00175 = .002 m^2

vi. Bottom width was given by

B_2 = length of opening + gap both sides

= .07 + 2*.035 = 0.14 m

vii. Top width was given by

$B_1 = B_2 + 2\ h \tan \alpha$ …. eq. (3.17)

Where, h = height of seed box

$B_1 = 0.14 + 2 \tan 15$

viii. Height of the seed box

Area of the seed box is also given by

$A = (B_1 + B_2)/2*h$ …. eq. (3.18)

0.061 = [0.14 + 0.14 + 2 h*0.268]/2*h

$0.268\ h^2 + 0.14\ h - 0.061 = 0$

Thus, height of the seed box

h = [-0.14 ± v {$(0.14)^2$ – (4*0.268*-0.061)}]/2*0.268

= 23 cm = 0.23 m

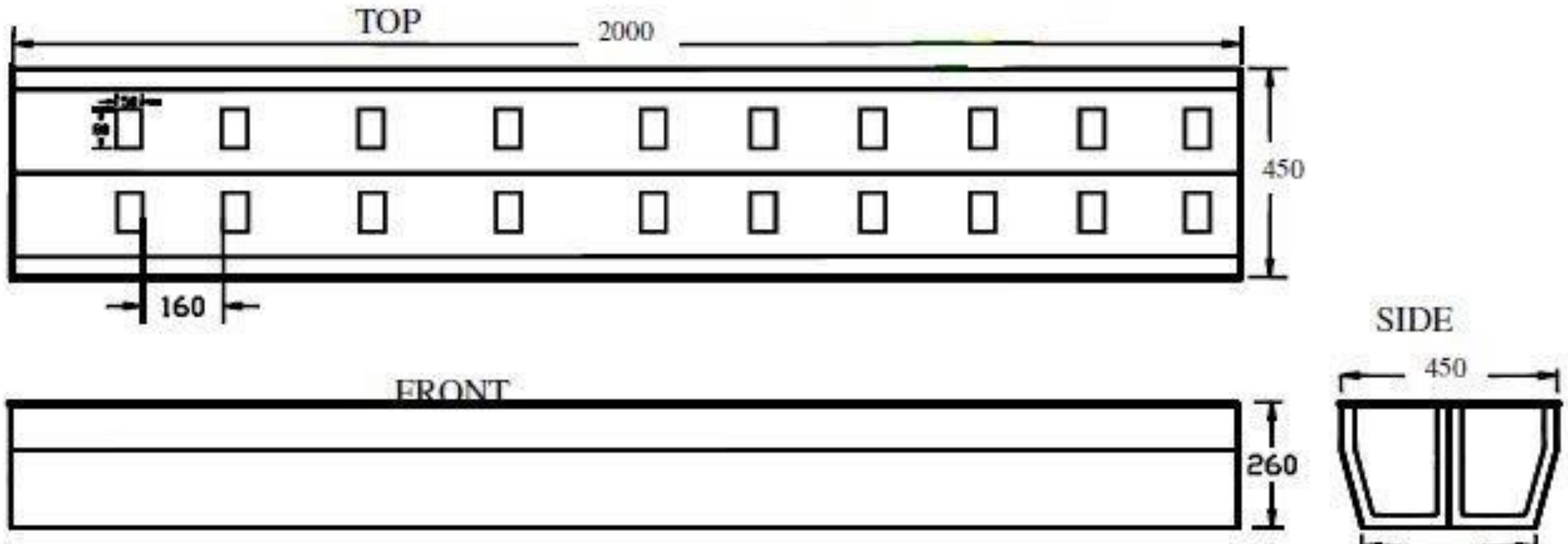
Total height of the seed box = 23 + margin (3 cm)

= 23 + 3 = 26 cm = 0.26 m

Hence, top width, B_1 = 0.14 + 2 h tan 15

0.14 + 2*0.32*0.268 = 0.457 = 0.45 m

Total volume of the trapezoidal box is 0.1038 m^3 and it is sufficient for filling 80 kg of grains but in actual prototype this capacity for filled up seeds was enhanced for 200 kg.



SEED BOX	MS SHEET	2000×450×260	1 No.
SEED BOX LID	MS SHEET	2000×450×15	1 No.
PORT		50x80 mm	18 No.

All dimensions in mm

Fig 3.4 CAD design of seed box of seed cum pressurized aqueous fertilizer drill

3.2.5 Design of seed metering mechanism

The design of seed box and fluted roller is similar as designed by RNAM, 1991 and it's evaluated in the existing seed cum fertilizer drill.

The volume of seed dropped per meter length of row was given by

$$Vs = S \times r / 10 \times p \qquad \text{…eq. (3.19)}$$

Where,

S = Seed rate, kg/ha;
p = Bulk density of seed in g/cm^3; and
r = Row spacing, m

The area of semi-circular flute is given by

$$Af = \pi \times d / 8 \qquad \text{…..eq. (3.20)}$$

Where,

d, = diameter of flute, cm

The delivered volume per revolution of roller is given by

$$Vd = A f \times N f \times L f \qquad \text{… eq. (3.21)}$$

Where,

Nf = Number of flutes
Lf = Exposed length of fluted, cm

The number of rev. of a fluted roller, nf is given by

$$n f = i \times n g \qquad \text{…..eq. (3.22)}$$

Where,

i = Transmission ratio
ng = Number of rev. of ground wheel

The distance Dg covered by the ground wheel/ rev. is given by

$$Dg = \pi\, dg \qquad \text{...eq. (3.23)}$$

Where,

Dg = Diameter of ground wheel, m

The volume of seed /m traveled by the ground wheel is given by

$$Vs = Vd \times I / \pi\, dg \qquad \text{…..eq. (3.24)}$$

This is a standard metering mechanism and having standard size.

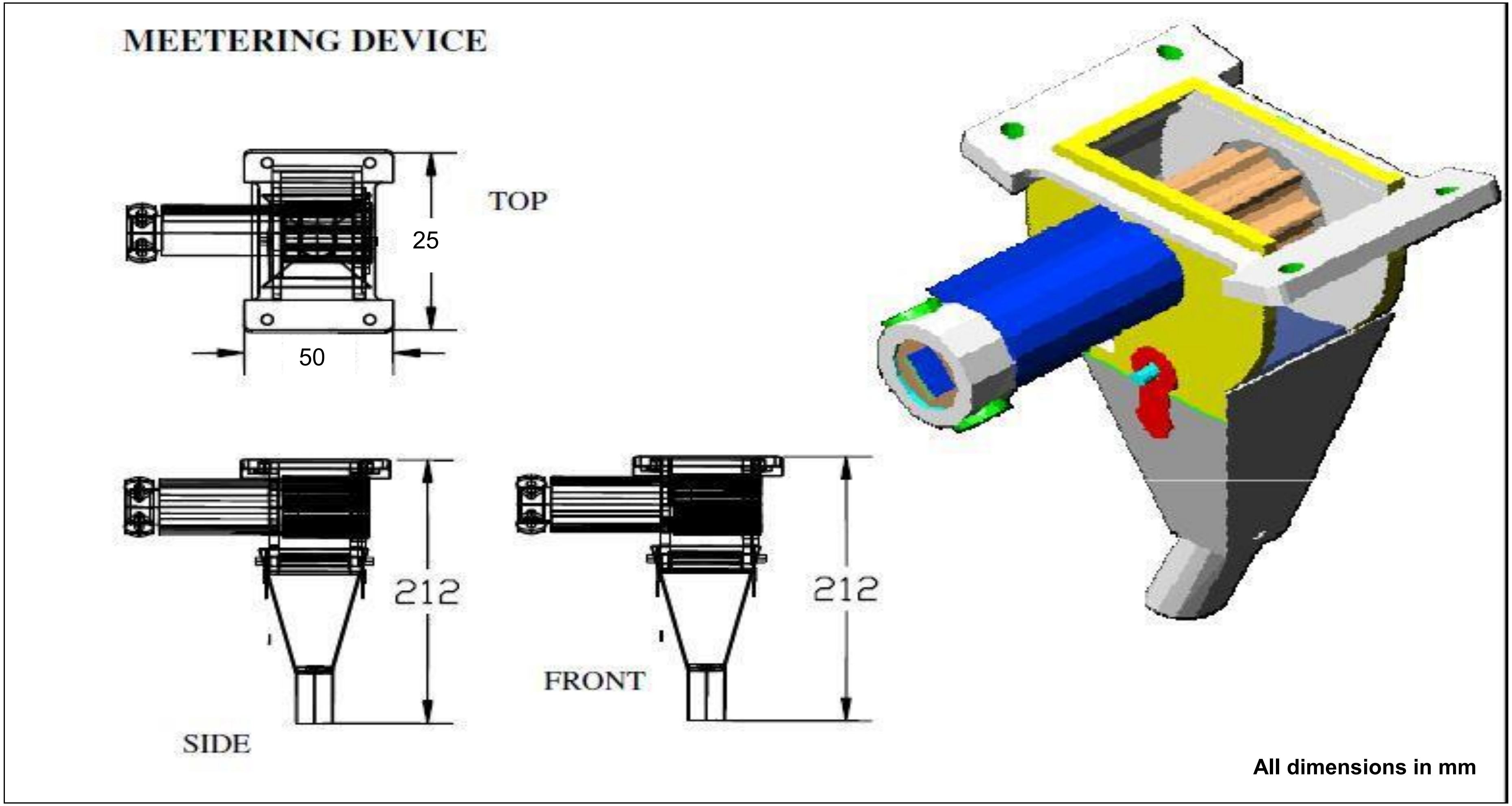


Fig 3.5 Seed metering (fluted rollers) of seed cum pressurized aqueous fertilizer drill

3.2.6 Tank for liquid fertilizer storage

The aqueous fertilizer needs to be carried along with the pressurized aqua fertilizer seed drill for the continuous application in the field. One of the main tasks to be accomplished for proper operation of this machine was to mount these tanks. The balance of the machine both lateral and vertical, likely to be disturbed particularly during operation of the machine. Mani et al. (2004) mounted the aqueous fertilizer tank of 500 litre capacity at the rear of the peristaltic pumping based aqua fertilizer seed drill. The machine during its operation in the field faced serious instability problem in vertical direction. To counter the challenge in the present design of the experimental set-up two tanks were mounted on a platform made of MS flat of size 40×10 mm on the both sides of aqueous fertilizer metering pumping system. Available space on the seed drill on both side of the three point linkage is 55×55x88 cm. The same size plastic drums are available in the market with diameter of 55 cm. Plastic drums were selected to counter the corrosiveness nature of the fertilizer.

Hence the volume of the drum $= \pi r^2 h$ …………………………….. eq. 3.25

$= 3.14 \times 27.5^2 \times 88$

= 200 litre.

Two cylindrical tank of 200 litre capacity each with a vertical opening were mounted on main frame (Fig. 3.6). Total carrying capacity of the aqueous fertilizer tank is 400 litre.

3.2.7 Selection of pump

The selection of pump was based on output discharge rate, ability to handle viscous fluid without much frictional losses. A mechanical centrifugal pump was selected to handle the aqueous fertilizer. The system demanded a continuous supply of pressurized aqueous fertilizer to each flow carrying tube through flow distributor with uniformity. Also pump is able to supply different flow rates according to need with positive response to rotational speed and also accommodate in the main frame of seed drill. Thus, the pump of centrifugal type of capacity 60 l/minute was selected for pressurized metering of aqueous fertilizer as per availability and as per demand on the same (Table 4.3). Centrifugal pumps are useful for handling viscous liquids.

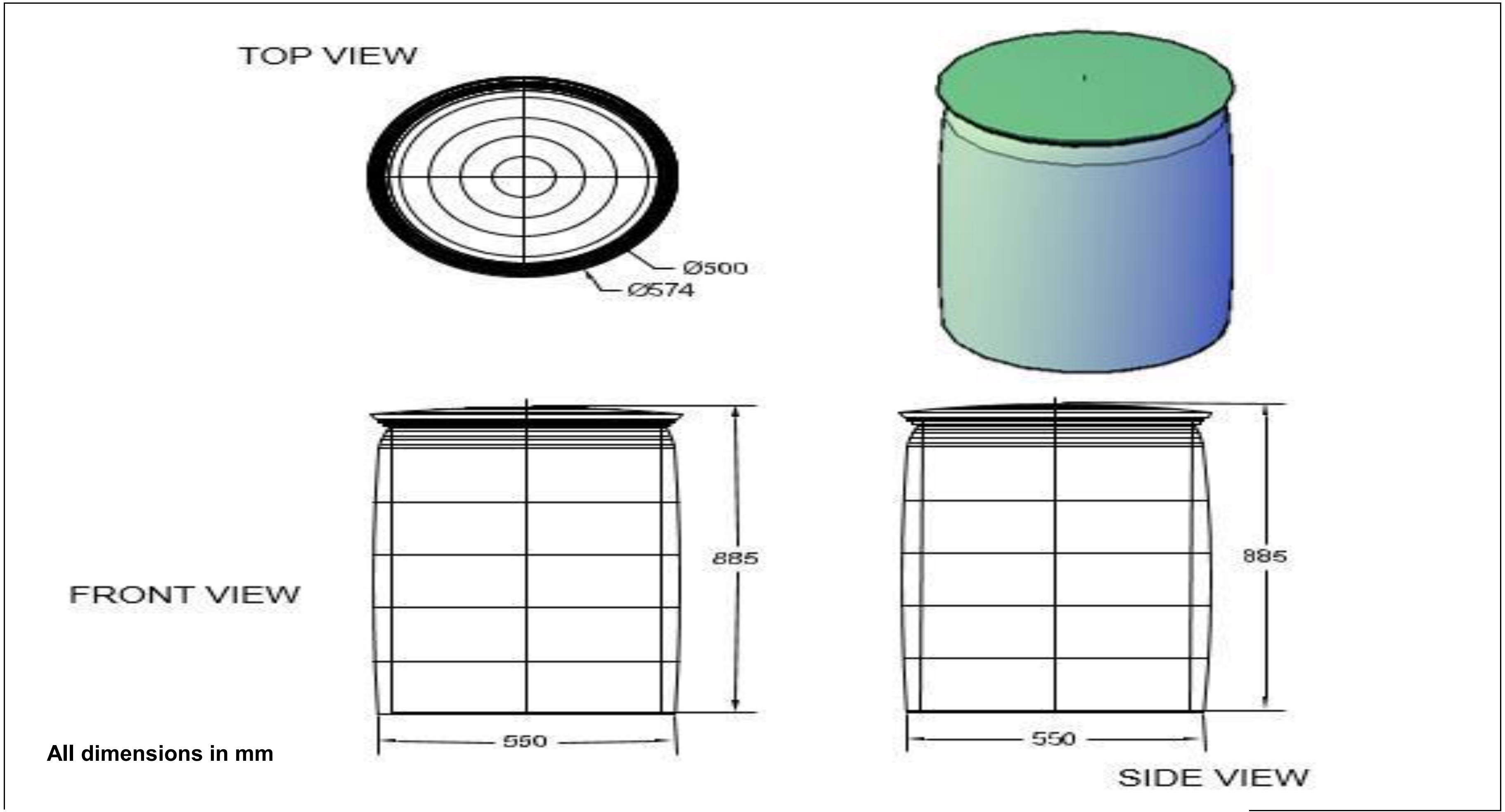


Fig 3.6 Aqueous fertilizer tank of seed cum pressurized aqueous fertilizer drill

3.2.8 Working principle of the Centrifugal pump

Centrifugal pumps are a sub-class of dynamic axisymmetric work-absorbing turbo machinery. Centrifugal pumps are used to transport fluids by the conversion of rotational kinetic energy to the hydrodynamic energy of the fluid flow. The rotational energy typically comes from an engine or electric motor. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radially outward into a diffuser or volute chamber (casing), from where it exits. Centrifugal pump converts rotational energy, often from a motor, to energy in a moving fluid. A portion of the energy goes into kinetic energy of the fluid. Fluid enters axially through eye of the casing, is caught up in the impeller blades, and is whirled tangentially and radially outward until it leaves through all circumferential parts of the impeller into the diffuser part of the casing. The fluid gains both velocity and pressure while passing through the impeller. The doughnut-shaped diffuser, or scroll, section of the casing decelerates the flow and further increases the pressure.

As per the requirements, centrifugal pump model MBG 12 is available in the market. Overall view of the pump is shown in fig. 3.7

Table 3.3 Brief specification of centrifugal pump

Model	Size	Speed (rpm)	Min Capacity	Max. Pressure
MBG 12	1 HP	1660	60 lpm	12 kg/cm^2

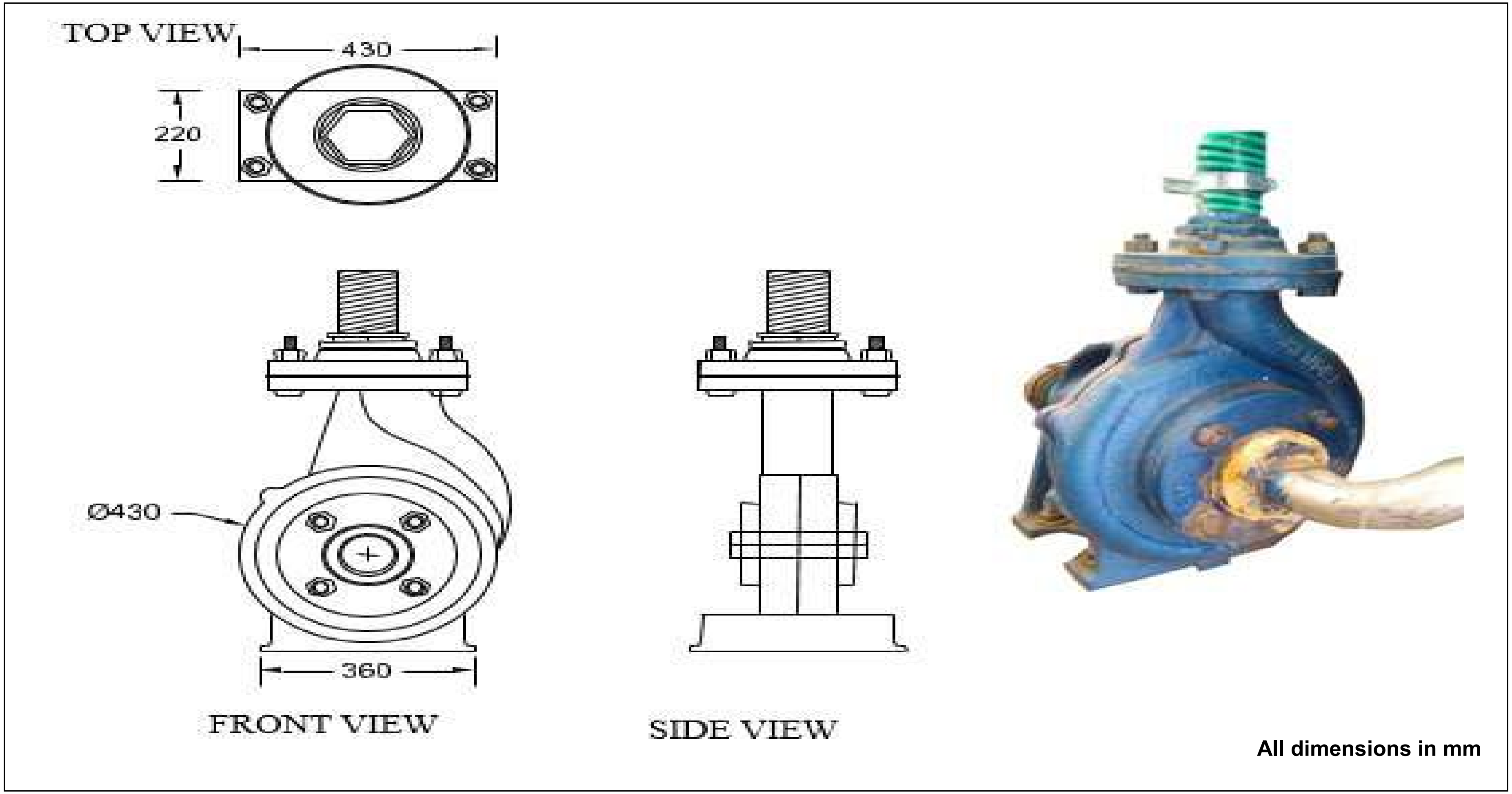


Fig 3.7 Centrifugal pump

3.2.9 Mechanism for control of flow volume

Aqueous fertilizer metering was done to enable to applying control volume of mixture of fertilizer and water in the field. A simplest mechanism was chosen to allow preset volume of aqueous solutions. The aqueous solution was allowed to flow down to the furrow through a plastic tube of 10mm dia. The flow was controlled by varying the opening size of the nine control valves for respective eighteen rows of the aqueous fertilizer delivery. The nozzle opening sizes varied from 5-10 mm and eighteen nozzles were spaced 200mm apart from one another. For the nine tyne aqueous seed drill the nine control valves were fixed on the iron flat of size 60 × 10 mm, connected to the tank by means of tubes. A lever for metering of aqueous fertilizer was pivoted on the angle iron for controlling the discharge by opening and closing of the nozzles (Fig 3.8).

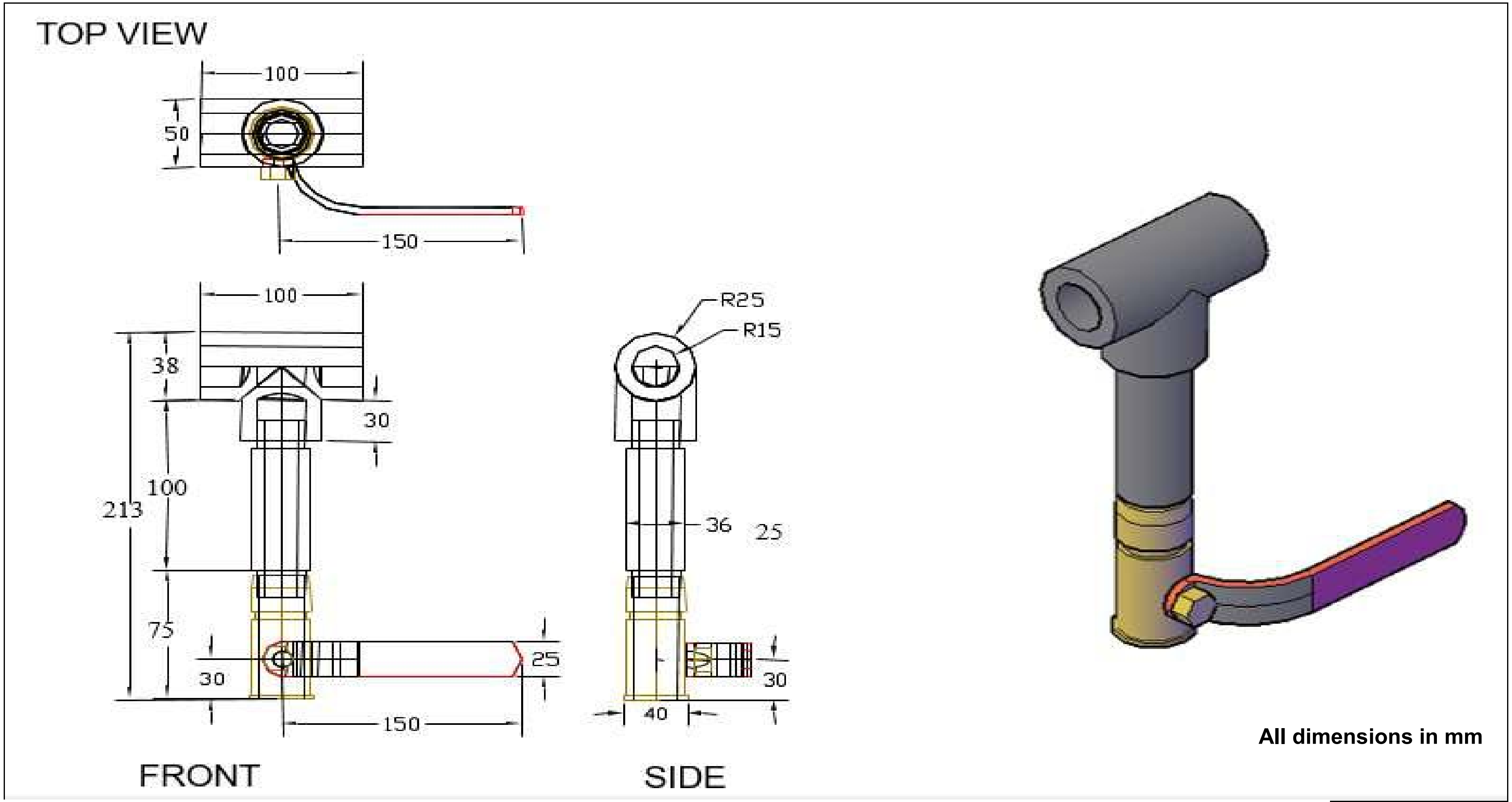


Fig 3.8 Control valve assembly

3.2.10 Design of aqueous fertilizer metering system

The aqueous fertilizer metering and its application in the field while sowing the wheat crop was the most important and innovative part of the study. Dey et al. (2007) reported an aqueous fertilizer metering system based on peristaltic pumping system. This system had some operational difficulties. So, to make the operation easier, a pressurized aqueous fertilizer metering system was designed for accomplishing metering of aqueous fertilizer in a most convenient way. The major components of this metering system were,

1. Two storage tank for storing aqueous fertilizer.
2. A centrifugal pump for supplying aqueous fertilizer drawn from two storage tank.
3. A system of nozzles with variable opening sizes operated by control valve.
4. Connecting lines to allow free flow of aqueous fertilizer to be applied in the furrow.
5. Power transmission system to operate centrifugal pump with the PTO of the tractor.

3.2.11 Experimental set up for a pressurized metering system

As the major goal of this study was to determine the design values of the relevant parameters of pressurized metering system of aqueous fertilizer, hence, it was necessary to design and fabricate an experimental set up which should have provision to vary (a) rotational speed of pump, (b) pressure and volume of aqua fertilizer delivered by pump, (c) desired nozzle sizes along with tubes. Thus, an experimental set up suitable to meet the above requirements was fabricated. The system consisted of mainly aqueous fertilizer regulator i.e. pressurized metering system. The important consideration was design and fabrication of an experimental set up to conduct experiment to determine design values of different component of pressurized system for mounting on exiting seeder. The experimental set up for pressurized metering system consisted of the following components, Fig. 3.9:

a) Pump frame

b) Tank for liquid fertilizer

c) Rotary centrifugal pump

d) Flow distributor

e) Pressure and volume control valve

f) Pressure gauge

g) Nozzles

h) Drive mechanism of the pump

i) Power source

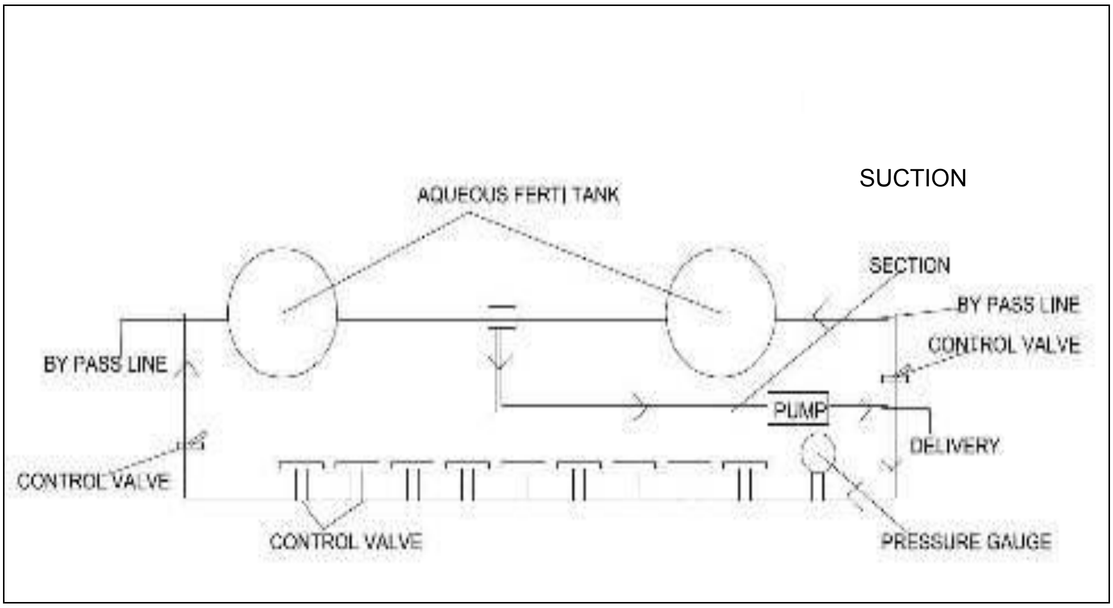


Fig. 3.9 Schematic diagram for design of experimental set up

3.2.12 Transmission system of the pump

This aqua fertilizer seed drill was planned to be operated by a 45 hp tractor. Different moving component of the machine were supplied power from the tractor. The centrifugal pump used to supply aqueous fertilizer to the nozzles was powered by the PTO drive of the selected tractor with speed of 540±10 rpm. A suitable power transmission system was designed and fabricated to accomplish this task. The power transmission designed taking universal coupling fitted to PTO, cone pulleys, two shafts of dia. 32mm, four bearings (P207), followed by two cone pulleys of cast iron of size 2016-1004 mm dia. and connected to another cone pulley of size 2540-762 mm through v-belt drive and further it is connected to the centrifugal pump as per the requirements and availability in the machine.

3.2.12.1 Length of open belt

Let provide V belt between counter pulley and shaft pulley. The length of belt (L_1) between the main shaft pulley (D_1) and the counter shaft pulley (D_2), when centre to centre distance between these pulleys is 75 cm is given by

$L_1 = 2C + \pi/2\ (D_1 + D_2) + (D_1 - D_2)^2/\ 4C$ ……………. Eq. 3.25

$L_1 = 2 \times 75 + \pi/2\ (32+32) + (32-32)^2/4\times 75$

$L_1 = 250.4$ cm

Centrifugal pump requires 1665 rpm to give desired discharge, hence following calculations were done to attain the required speed.

Driven pulley diameter size (inch) = Driving pulley diameter (inch) × Driving speed/ Driven speed

Driving pulley diameter	= 8 inch
Driving speed	= 150 rpm
Driven speed	= 1665 rpm
Driven pulley size	= 8 * 150/1665
Driving pulley diameter	= 3 inch

It was not possible to reduce directly 8 inches to 3 inches due to lack of space in the existing seed drill, hence driving pulley reduced to 4 inches and followed by another 10 inches pulley, driven pulley reduced to 3 inches. Shown in fig.3.10.

This power transmission system operated the centrifugal pump which supplied requirement of aqueous fertilizer from two storage tanks. The platform was rigidly bolted to the main frame. For smooth transmission of power from the reduction unit to the main pumping shaft a V-belt was used. The entire drive mechanism is shown in fig.3.10

Table: 3.4 The specifications of designed seed cum pressurized aqua fertilizer drill

S.No.	Components		Size/Material
	Seed drill	Working width of drill	1.80 m
		No. of furrow openers	9
		Spacing between furrow openers (adjustable)	20
		Draft requirement	270 kg
		Field capacity	0.63
	Seed box	Cross-section	Trapezoidal
		Seed box capacity	200 kg
		Length of seed box	130 cm
		Bottom width of seed box	34 cm
		Top width of seed box	45 cm
		Height of seed box	26 cm
		Angle of repose available	75°
		Thickness of seed box	3.15 mm
		Type of material	MS sheet
	Seed metering	Type of seed metering	Fluted roller
		No. of slots/roller	9
		Length of roller	80 mm
		Diameter of roller	50 mm
		Radius of curvature of slot	8.90 mm
	Aqueous fertilizer metering unit	Type	Centrifugal pump
		Nozzle sizes	8, 10, 12 mm
		No. of nozzle	18
		Max. capacity	60 (l/min)

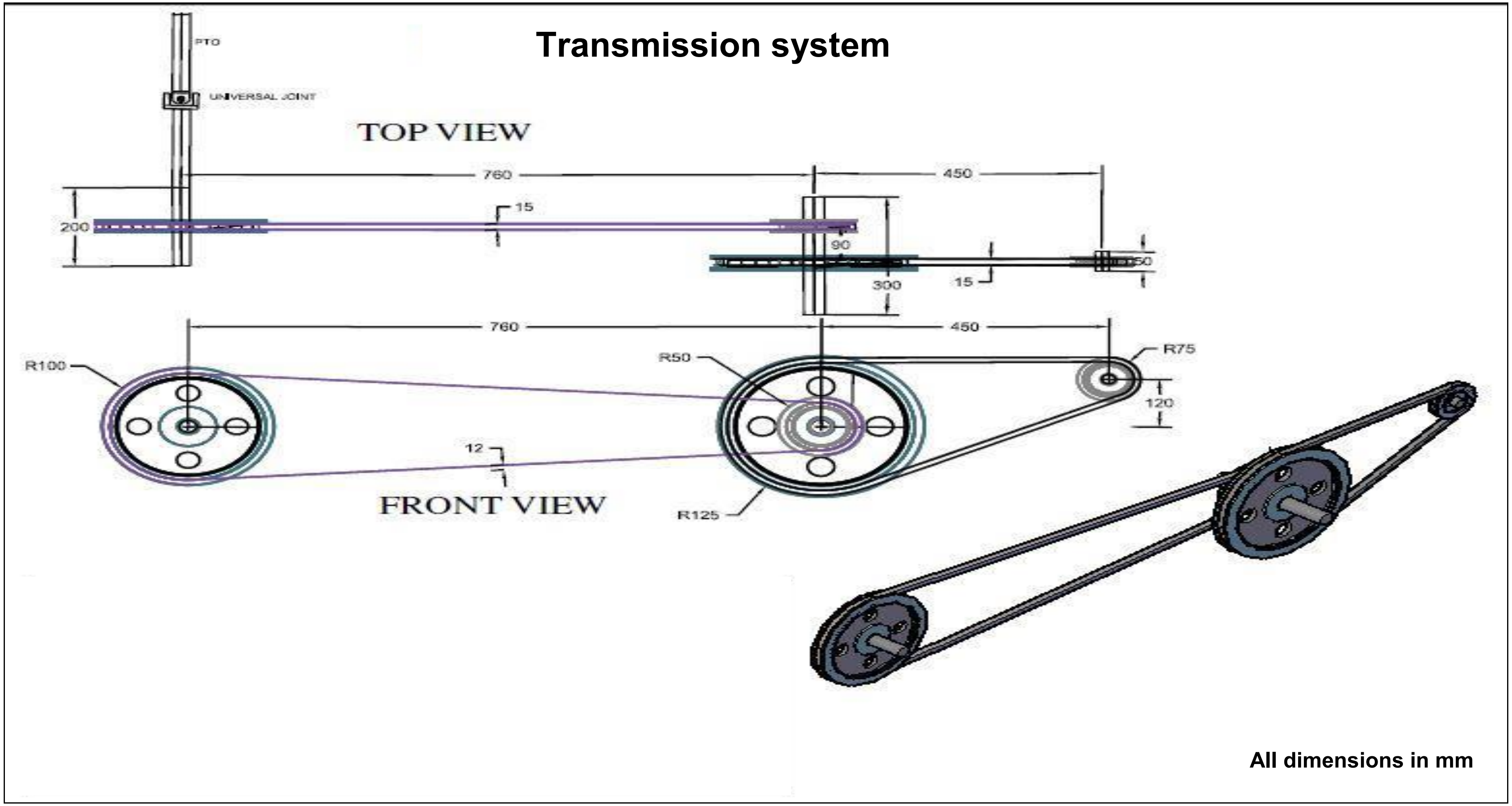
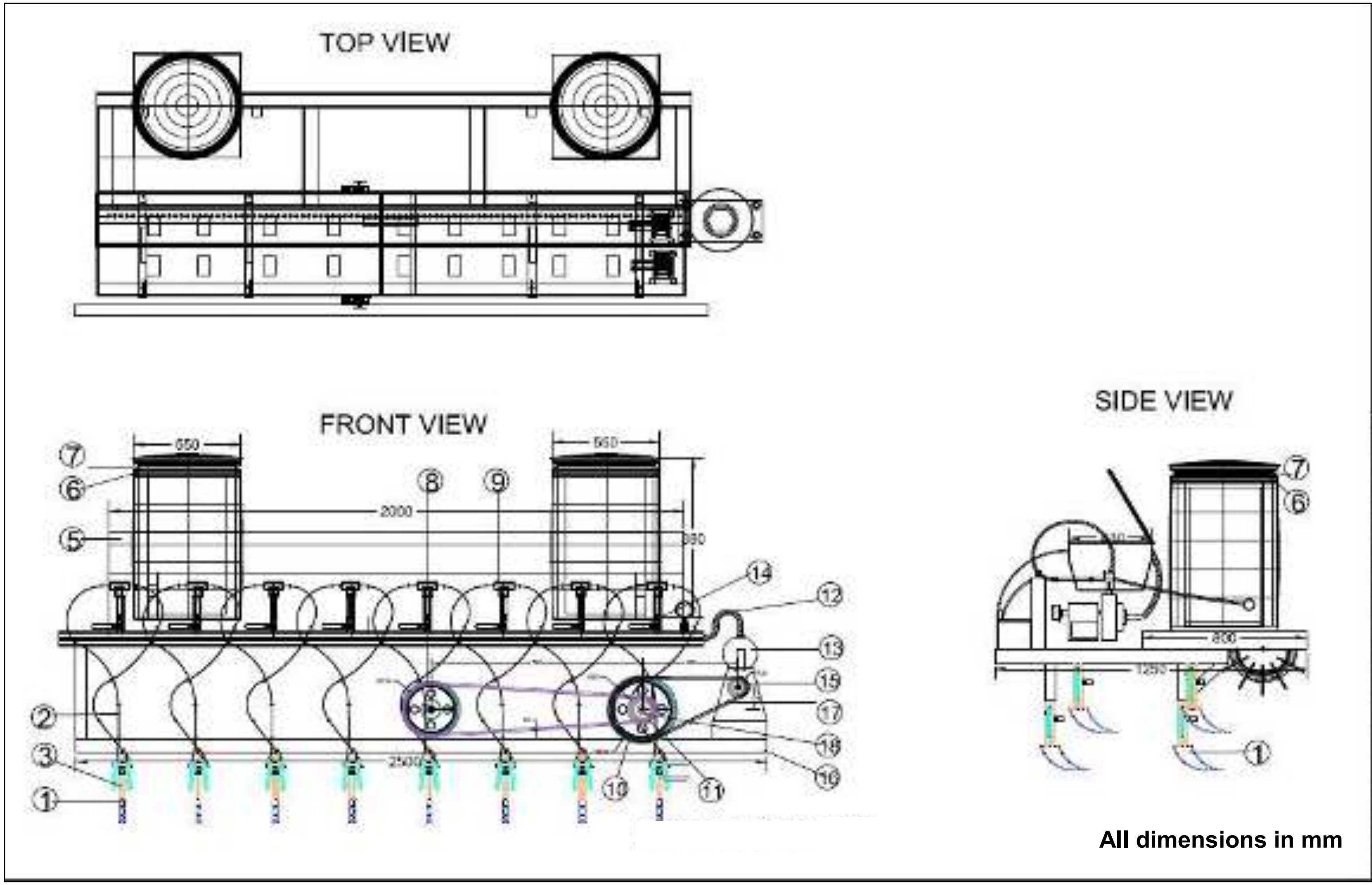


FIg 3.10 Transmission system of seed cum pressurized aqueous fertilizer drill



Designed by:

Avinash Kumar Gautam

S.N.	COMPONENT	NOS.
1	TYNE	9
2	AQUAL FERTUBE	18
3	SEED TUBE	18
4	SEED METERING	9
5	SEED HOPPER	5
6	TANK FRAME	2
7	AQUA. FOR TANK	2
8	DRIVE PULLEY	1
9	DRIVEN PULLEY	1
10	DRIVEN PULLEY	1
11	DRIVEN PULLEY	1
12	DELEVERY PIPE	1
13	CENTRL PUMP	1
14	CONTROL VALVE	9
15	DRIVEN PULLEY	1
16	FRAME	1
17	'V' BELT	1
18	BEARING	4

Fig. 3.11 Design of seed cum pressurized aqueous fertilizer drill

3.2.13 Nozzles of distributor along with plastic tubes

Three different sizes of nozzles along with tubes of dia. 8, 10 and 12 mm were used for carrying aqueous fertilizer.

3.2.14 Fitting of the pipes with pressure-volume control valve

This type of aqueous fertilizer metering was continuously subjected to the pressurized flow under pump operation a pipe of G.I. material was used instead of plastic for fitting. A G.I. pipe having a diameter 5 cm was used to facilitate flow through distributor from tank with the help of pump. The pressure and volume control valve was fitted in between the pump and the distributor for calibration of discharge w.r.t. pressure.

3.2.15 Test evaluation of pressurized pumping system

The designed and fabricated set up was calibrated with varying process parameters i.e. pump rotational speed, pressure and nozzle size for determination of discharge from tubes at different diameter of the nozzles. The pumping system was test evaluated to optimize the design parameters of pressurized metering of aqueous fertilizer. The plan of experiment is given in Table 3.5

3.2.16 Design of experiments

Factorial design was used for conducting experiments of this study. As the aim of the study was to investigate the effects of each number of variables or factors on some response variable factorial experiments are conducted. The plan of experiment included four variables at their different levels. This was observed highly efficient experimental design as observation supplied information about the factors included in the experiment. This design had the added advantage of studying the main as well as the interaction effect of more than one factors. Here, asymmetrical factorial design was used because of the number of levels of all the variables were not same, Table 3.3

Total number of experiments = $3 \times 5 \times 4 \times 3 = 180$

Table 3.5 Plan of experiment

S. No.	Independent Variables	Levels of variables	Dependent Measured parameter
1.	Nozzle size	3 levels (8, 10 and 12 mm)	Discharge (lit/ sec)
2.	Rotational speed of pump	5 levels (1998, 1665, 1332, 999 and 666 rpm)	
3.	Line pressure	4 levels (0, 2, 4 and 6) kg/cm^2	
4.	Design	FCRD	

3.2.17 Test procedure for experiment

The experimental set-up of pressurized metering system of aqueous fertilizer thus designed and fabricated was tested for its performance of dispensing aqueous fertilizer under different levels of variables.

The instrumentation for measurement of rpm, time and discharge are tachometer, stopwatch, beaker and measuring cylinder respectively. The study included determination of discharge rate from the all tubes for various levels of nozzle size, rpm and pressure.

3.2.18 Rotational speed of pump

Different levels of pump rotational speed i.e. 1998, 1665, 1332, 999 and 666 rpm were obtained by varying PTO rpm from 300, 250, 200, 150 and 100 with the help of throttle adjustment.

3.2.19 Pressure levels

Provision of pressure-volume control valve was made to restrict flow of aqueous fertilizer which creates relative pressure between pump and valve. Four levels of line pressure, starting from fully opened valve i.e. gauge pressure of 0 kg/cm^2, similarly 2, 4 and 6 kg/cm^2 were maintained in order to vary discharge rates for each level of pump speed.

3.2.20 Measurement of discharge w.r.t time

The discharge from tubes was measured with three replications to minimize error. Discharge from eighteen tubes was measured with 1000 ml beakers were placed at the discharge end of the tubes. Discharge was measured w.r.t. time with help of measuring cylinder of 1000 ml of capacity. Precise measurement of time was done by Stopwatch. Its results are given in Result and Discussion section 4.4.

3.2.21 Experimental procedure

In the laboratory, the experimental set up was made ready for actual experimentation. A mock run test were made to ensure the functioning of all the system. The experimental setup was powered by 45 hp tractor. The rotary centrifugal pump was connected to the PTO of the tractor through a power transmission system. In a separate tank 86 kg of urea and 130 kg of DAP was dissolved in the 1000 litre of water. The mixture was thoroughly stirred to make proper solution of aqueous fertilizer. The amount of fertilizer and volume of water for making solution was selected based on standard recommendation of fertilizer application during sowing operation of wheat crop i.e. 60 kg N, 60 kg P_2O_5 and 40 kg K_2O. This solution had the concentration level of 216 gram. Fertilizer per litre of water. This was a concentrated solution, the actual volume of aqueous fertilizer to be applied in the field was determined keeping in view the moisture deficit expected in the field and volume of water required to bring the moisture level up to sowing moisture level. The final solution of aqueous fertilizer which was poured in the storage tank met both the criteria's i.e. 60 kg N, 60 kg P_2O_5 amount of ferti/ha and approximately 4500-8000 litre of water per hectare. As the storage tank had capacity of 200 litre each. 20 litre of concentrated solution was poured in 180 litre of water in the tank to make 200 litre of aqueous fertilizer in each tank. For measuring discharge from nine different nozzles, flask of capacity of 1 litre was used. As stated earlier, the discharge from eighteen different nozzles through delivery tubes was measured at five different rpm, pressure and nozzle sizes. This set of treatments were replicated thrice.

3.3 Method of data analysis

The discharge thus obtained from the experiments on testing of pressurized metering system was formatted and presented in tabular and graphical form in MS EXCEL package. The data was statistically analyzed for different levels of variables. Statistical tests were conducted using appropriate package to test the effect of individual parameters as well as their interactions on discharge.

3.4 Selection of nozzle size

The selection of nozzle size depends on the amount of aqua fertilizer delivered by nozzle for satisfying maximum as well as minimum aqueous fertilizer requirement for given texture of soil w.r.t. forward speed of aqua fertilizer seed drill for different levels of pump rotational speed and line pressure. The desired discharge could be obtained by selecting desired level of line pressure, pump rotational speed and forward speed of seed drill for a given nozzle size.

3.5 Fabrication of tractor operated nine row pressurized aqua fertilizer system

The final design values of different component were determined. The fabrication of different component and their assembling was done in the workshop of College of Agricultural Engineering, Jabalpur. Thus, the prototype was ready for performance evaluation (Plate 3.5).

Plate 3.5 Fabricated seed cum pressurized aqueous fertilizer drill

3.6 Performance evaluation of tractor operated seed cum pressurized aqua fertilizer drill

The field experiments for the performance evaluation of the tractor drawn seed cum pressurized aqua fertilizer drill designed and developed after laboratory testing was carried out in the College of Agricultural Engineering farm at JNKVV, Jabalpur during the period October to March 2015-16 and 2016-17. The detailed of performance evaluation procedure have been presented in the following sections.

3.6.1 Description of the experimental area

The experiment was conducted at horticultural research farm, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, (M.P).

3.6.2 Climatic condition

Jabalpur is situated at 23°9’ North latitude and 79°58’ East longitudes with an altitude of 411.78 meters above the mean sea level. The climate of the locality is characterized as typically sub-tropical and sub-humid, which is featured by hot dry summers and cool dry winters. It comes under “Kymore Plateau and Satpura Hills” agro climate zone of Madhya Pradesh and is broadly known as rice-wheat crop zone. The annual rainfall of Jabalpur region ranges between 1000 to 1500 mm. most of rains of a year mainly are received between mid-June to end of September. The minimum temperature goes down to the limit of 4°C during December and January months, while the maximum temperature reaches as high as 44°C during the month of May and June. Generally, relative humidity of the locality remains very low (15 to 30%) during summer season, moderate (60 to 75%) during winter and it attains high value (80 to 95%) during rainy season.

During the period Oct-March 2015-16, the lowest temperature observed was 8.6°C whereas the highest temperature was of 33.87°C in the month of October. Similarly, for 2016-17 the lowest temperature observed was 6.58°C whereas the highest temperature was 31.03°C of in the month of October. There was no rainfall during October, November, December and February where as in January and March a nominal rainfall of 12.2 and 14.5 mm was received in year 2015-16. Similarly, for 2016-17 there was no rainfall during October, November, December, February and March where as in January nominal rainfall of 2.6 mm was received.

Table 3.6 Mean Monthly meteorological data for the year 2015-16 at CAE

Months	Temperature, °C			Relative Humidity, %			Rainfall, mm
	T_{max}	T_{min}	T_{mean}	RH(M)	RH(E)	RH_{mean}	
October	33.87	18.70	26.28	88.25	45.25	66.75	1
November	29.82	15.42	22.62	89.50	33.75	61.62	0
December	27.40	9.97	18.68	87.80	31.00	59.40	0
January	21.60	8.60	15.10	88.75	37.40	63.07	12.2
February	26.02	10.32	18.17	88.50	35.25	61.87	0
March	32.20	13.87	23.03	69.60	34.00	51.80	14.5

Table 3.7 Mean Monthly meteorological data for the year 2016-17 at CAE

Months	Temperature, °C			Relative Humidity, %			Rainfall, mm
	T_{max}	T_{min}	T_{mean}	RH(M)	RH(E)	RH_{mean}	
October	31.03	19.00	25.01	87.75	28.60	58.17	0
November	28.90	8.95	18.92	89.25	35.25	62.25	0
December	25.40	6.58	15.99	90.75	30.60	60.67	0
January	24.16	8.50	16.33	90.50	45.00	67.75	2.6
February	28.62	9.47	19.04	88.50	34.50	61.50	0
March	30.20	10.85	20.52	80.80	23.00	51.90	0

Mean monthly meteorological data recorded at the meteorological observatory at CAE, Jabalpur for 2015-16 and 2016-17 for the Rabi season in presented in table 3.3 & 3.4 and Fig. 3.2 & 3.3

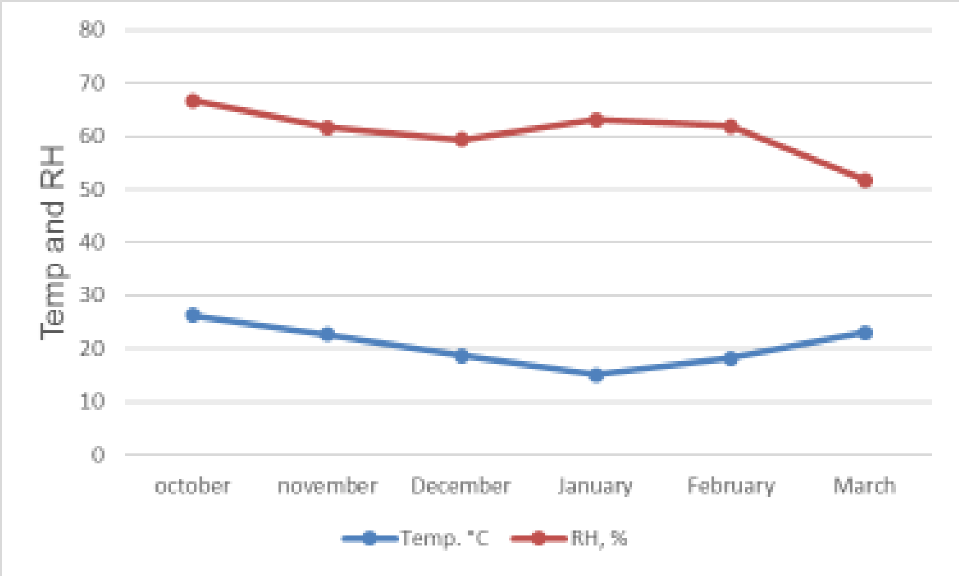


Fig. 3.12 Mean monthly Temp and RH in selected month of the year 2015-16

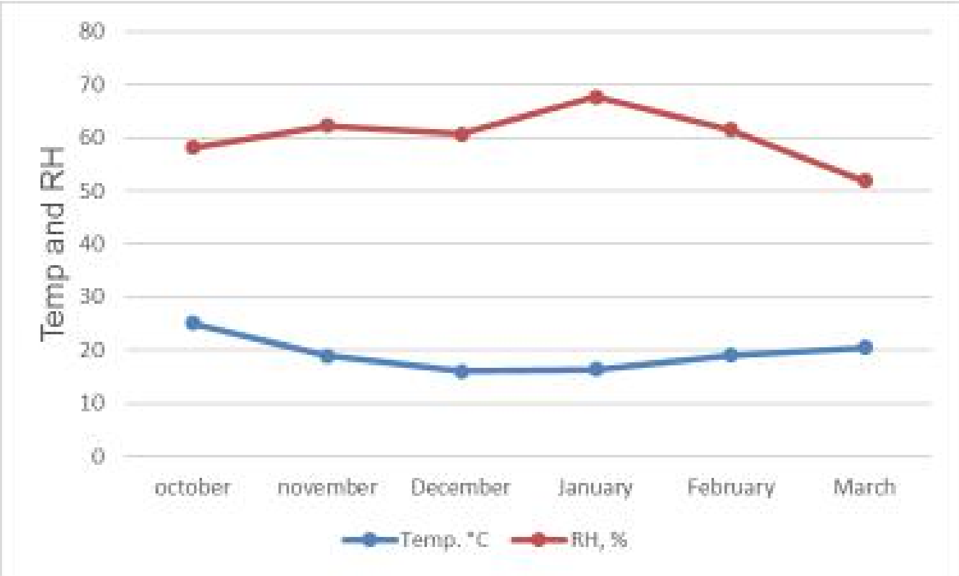


Fig. 3.13 Mean monthly Temp and RH in selected month of the year 2016-17

3.6.3 Soil

The soil of the Jabalpur region is broadly classified as vertisol as per norms of U.S. classification. It has medium to deep depth and black in colour. It has ability to swell after wetting and to shrink after drying. Thus, it develops deep and wide cracks on the surface during summer season. It has poor workability under excessive dry as well as wet conditions. The physical composition of the soil in experimental field was clay (50.75%), silt (20.15%), and other (29.10%).

3.6.4 Design of field experiments

The performance evaluation of pressurized aqua fertilizer seed drill was undertaken in the experimental farm of the College of Agricultural Engineering, JNKVV, Jabalpur as stated above. To determine the influence of aqueous fertilizer application rate on crop, six different treatments were taken. The test field was sub divided into six plots of size 38×6 m^2. Randomize block design was used for conducting experiments of field study with three replications of each treatment. Experimental layout is given in Fig. 3.14

3.6.5 Details of treatments

Following combinations of sowing system and rate of aqua fertilizer were used to determine the influence of pressurized aqua fertilizer seed drill:

$T_1S_1D_1$ = Conventional tillage + Pressurized aqua fertilizer seed drill + 6500 lit/ha (aqueous fertilizer)

$T_1S_1D_2$ = Conventional tillage + Pressurized aqua fertilizer seed drill + 5500 lit/ha (aqueous fertilizer)

$T_1S_1D_3$ = Conventional tillage + Pressurized aqua fertilizer seed drill + 4500 lit/ha (aqueous fertilizer)

T_1S_2 = Conventional tillage + Conventional seed cum fertilizer drill

T_2S_3 = Conventional tillage + Zero till seed cum fertilizer drill

T_1S_4 = Conventional tillage + Pressurized aqua seed drill with granular fertilizer

The nomenclature details are given below:

T_1 – Cultivator with one pass + Disc Harrow with two pass + Scraper

T_2 – No Tillage

S_1- Pressurized aqua fertilizer seed drill

S_2- Conventional seed cum fertilizer drill

S_3- Zero till seed cum fertilizer drill

S_4- Pressurized aqua seed drill with granular fertilizer

3.6.6 Experimental details

Design	: RBD
Replications	: 3
Net plot size	: 12 × 6 m
Plot area	: 72 m^2
Distance between replications	: 1.0 m
Distance between plots	: 3.0 m
Total number of plots	: 18
Variety	: GW 273
Date of sowing	: 14th Oct, 2015 & 20th Oct 2016
Seed rate	: 80 kg/ha
Recommended dose of fertilizers application	: 120 kg N, 60 kg P_2O_5 & 40 kg K_20 /ha

a) Seed cum pressurized aqua ferti drill

b) Zero till seed cum fertilizer drill

C) Conventional seed cum fertilizer drill

Plate 3.6 Different sowing systems on experimental field

The plate 3.6 shows the operating view of different sowing machineries in the farm.

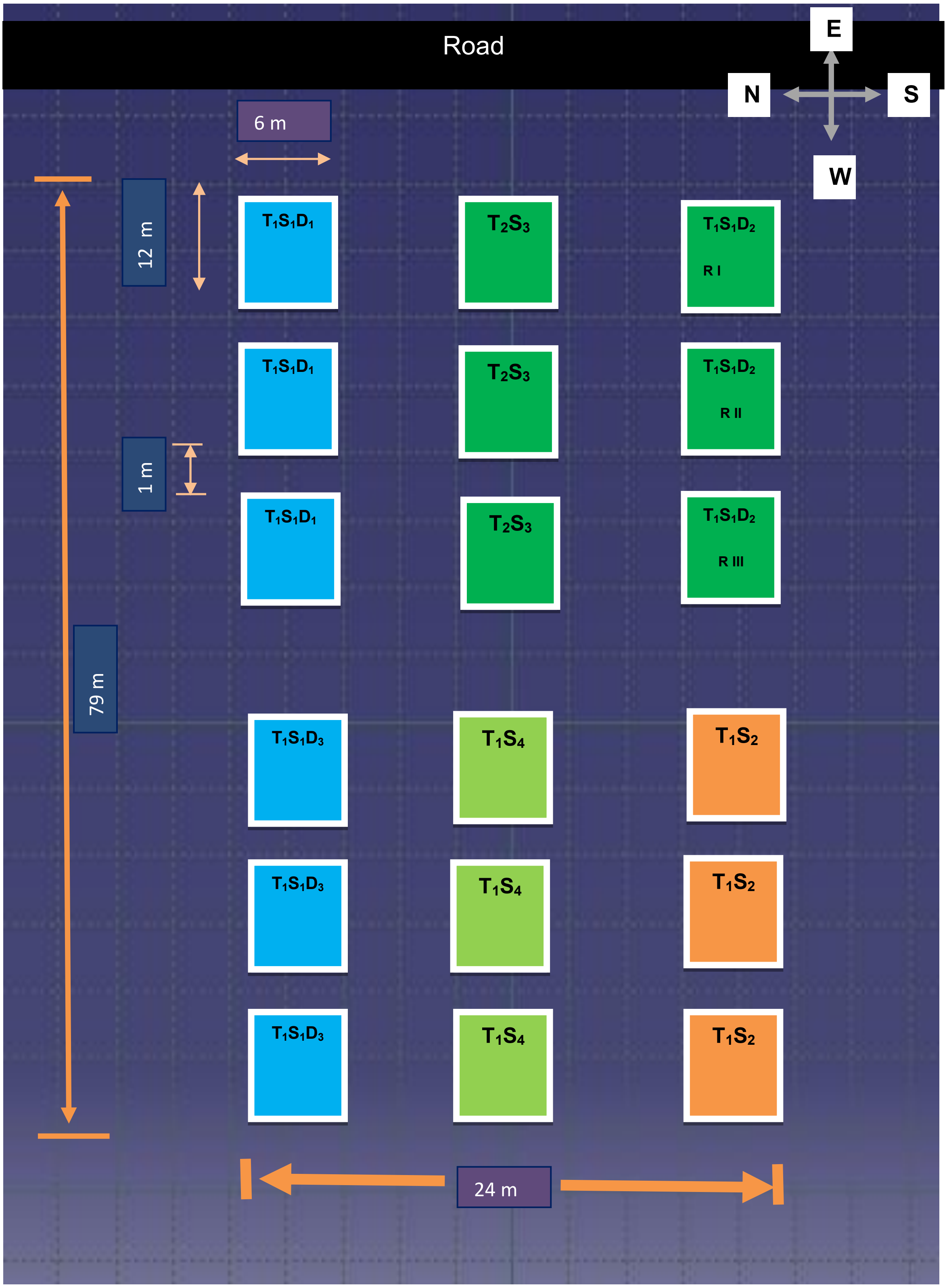


Fig.3.14 Layout plan of experiments

3.7 Measurement of machine parameters

3.7.1 Soil pulverization

The soil pulverization is the process of breaking of soil into smaller aggregates and is determined by mean mass diameter. In order to measure degree of soil pulverization sieve analysis was done in a setup consisting of set of six sieves placed on a sieve shaker. The sieving was done for 15 minutes. The sieves having mesh size of 11.2, 8.0, 5.6, 4.75, 2.8 and 2.0 mm were used. The soil samples were collected randomly from an area within 150×150 mm to the 150 mm depth of tillage in the treatment T1. There was no soil pulverization in zero tillage sowing system such as T2 treatment. The soil samples were gently passed through set of above sieves and weight of soil retained in all the sieves was measured. The following relationship was used to determine the mean mass diameter.

$$MMD = \frac{\text{WD}}{\text{W}} \quad \text{...eq. (3.26)}$$

Where,

MMD = Mean mass diameter (mm);

W = Sum of weight of the soil clods or weight of the soil held by particular sieve (kg); and

D = Equivalent diameter of clods or size of sieves (mm).

3.7.2 Theoretical field capacity

The theoretical field capacity was calculated by using the relationship given below:-

Theoretical field capacity (ha/h) =

$$\frac{\text{Width of equipment (m)} \times \text{Speed of operation (km/h)}}{10} \quad \text{…eq. (3.27)}$$

3.7.3 Actual field capacity

The actual field capacity was also calculated as per equation

Actual field capacity (ha/h) =

$$\frac{\text{Width of field coverage (m)} \times \text{length of field coverage (m)}}{\text{Time for covering total area (h)} \times 10000} \quad \text{…eq. (3.28)}$$

3.7.4 Field efficiency

The field efficiency is the ratio of actual field capacity (ha/h) to the theoretical field capacity (ha/h).

$$\text{Field efficiency (\%)} = \frac{\text{Effective field capacity}}{\text{Theoritical field capacity}} \times 100 \qquad \text{...eq. (3.29)}$$

3.7.5 Fuel consumption

For the measurement of fuel consumption (l/h) the intake and over flow fuel line was connected to a cylindrical container from bottom and top. The cylindrical container has the capacity of 3.0 lit. and having the marking in 50ml apart. In each treatment, the time of operation, area covered and fuel consumed (ml) was observed and fuel consumption was estimated as given below:

$$\text{Fuel consumption}\left(\frac{l}{ha}\right) \frac{\text{Fuel consumption}\left(\frac{ml}{s}\right)}{\text{Area covered}\left(\frac{m^2}{s}\right)} X\, 100 \qquad \text{…eq. (3.30)}$$

3.7.6 Draft

To determine the draft of implement load cell was used. Dynamometer was placed in between two tractors and implement was hitched by the rear tractor (plate 3.7). The gear of the rear tractor was kept in neutral position and implement hitched behind the tractor and desirable depth was given with hydraulic control lever. Front tractor pulled the rear tractor with implement. The reading of load indicator was recorded from dial gauge. The difference of calculated draft and rolling resistance was taken as draft of implement for further calculations.

Plate 3.7 Draft measurement of seed cum pressurized aqua fertilizer drill

3.8 Energy requirement

In each treatment the energy consumed in the form of direct energy, Indirect energy, renewable energy, non-renewable energy, commercial energy and non-commercial energy was calculated taking into account all the inputs like seed, fertilizer, machines, human labor, diesel, etc.

3.8.1 Energy from direct sources

$$DE = HLH \times 1.96 + BPH \times 14.07 + FC \times 56.31 + EC \times 11.9 \quad \text{.eq. (3.31)}$$

Where,

DE = Direct Energy (MJ);

HLH = Human Labour Hour used (h/ha);

BPH = Bullock Paired Hour used (h/ha);

FC = Fuel Consumption (l/ha); and

EC = Electricity Consumption (kWh/ha).

3.8.2 Energy from indirect sources

$$IE = C \times WM \times OA + FYM \times 0.3(MJ/kg) + S \times 14.7(MJ/kg) + CH \times 120(MJ/kg) \times Fertilizer\ (N \times 60.0 + P \times 11.1 + K \times 6.7) \quad \text{….eq. (3.32)}$$

Where,

IE = Indirect Energy input from machinery (MJ);

C = Energy Coefficient (MJ/kg);

WM = Weight of Machinery used/h (kg);

OA = Operation Area (ha);

FYM = Farm Yard Manure (kg/ha);

S = Seed (kg/ha);

CH = Chemicals (l/ha);

N = Nitrogen (kg);

P = Phosphorous (kg); and

K = Potash (kg).

3.8.3 Total Energy

TE = DE + IE ….eq. (3.33)

Where,

TE = Total Energy (MJ);

DE = Direct energy (MJ); and

IE = Indirect energy (MJ).

3.8.4 Indices of energy

The energetic efficiency of the agricultural systems can be evaluated by the relation between energy inputs and output. Based on the energy equivalents of inputs and outputs, the indices of energy use efficiency, energy productivity, specific energy and net energy were calculated by using the following equations:

1. $$\text{Energy Ratio} = \frac{\text{Energy Output (MJ/ha)}}{\text{Energy Input (MJ/ha)}}$$ ...eq. (3.34)

2. $$\text{Specific Energy} = \frac{\text{Energy Input (MJ/ha)}}{\text{Grain Output (kg/ha)}}$$ ...eq. (3.35)

3. $$\text{Energy Productivity} = \frac{\text{Grain Output (kg/ha)}}{\text{Energy Input (MJ/ha)}}$$ …eq. (3.36)

4. Net Energy = Energy Output – Energy Input ...eq. (3.37)

3.9 Cost of operation

The objective of estimating cost of farm machinery operation is to serve as a basis for planning and management. The cost of operation under each treatment was estimated as per IS: 9164 – 1979.

The cost of using farm machinery consists of expenses for ownership and operation, overhead charges. It may also include a margin for profit. Ownership costs are independent of use and are often called as fixed costs. Costs for operation very directly with use and are referred as variable cost.

3.9.1 Fixed costs

3.9.1.1 Depreciation

This cost reflects the reduction in value of a machine with use (wear) and time (obsolescence). While actual depreciation would depend on the sale price of the machine after its use, on the basis of different computational methods depreciation can be estimated by straight-line method as given below.

$$D = \frac{P - S}{L} \qquad \text{...eq. (3.38)}$$

Where,

D = depreciation cost, average per year;

P = purchase price of the machine;

S = residual value of the machine; and

L = useful life of the machine in years.

The depreciation cost per hour can be estimated by dividing D by the number of hours the machine is expected to be utilized in a year. Residual value if the machines may be taken as 5 per cent of the purchase price.

3.9.1.2 Interest

An annual charge of interest was calculated by taking 12 per cent of an average purchase price. Average purchase price was calculated using the formula given below.

$$A = \frac{P + S}{2} \qquad \text{...eq. (3.39)}$$

Where,

A = average purchase price;

P = purchase price of the machine; and

S = residual value of the machine.

3.9.1.3 Insurance and taxes

Insurance and taxes were estimated by taking 2% of average purchase price of machine into consideration.

3.9.1.4 Housing

It was calculated on the basis of 1.5 per cent of the average purchase price of the machine.

3.9.2 Variable cost

3.9.2.1 Fuel

The actual fuel consumption in each treatment was observed and estimated was done accordingly.

3.9.2.2 Oil

The cost of engine oils and lubricants was estimated as 3% of fuel consumption cost.

3.9.2.3 Repair and maintenance

The IS: 9164-1979 indicates that the percentage of accumulated repair cost of seed cum fertilizer drill is 100.3% for a usable life of 8 year. Hence, the repair and maintenance cost of seed cum fertilizer drill used in the experiment was estimated taking by it to be 12.54% per year.

3.9.2.4 Wages and labour charges

The cost of labour was estimated by; taking the prevailing rate of 22.87 ₹/h (as per M.P. Govt. rate).

3.10 Measurement of soil parameters

3.10.1 Moisture content of soil

Soil moisture content on dry weight basis was determined randomly before tillage and after sowing and 30, 60, 90 DAS in different treatments. The soil samples were taken from the experimental plots, at a depth 0-150 mm. with the help of an auger. The soil samples were weighed using an electronic balance having least count of 0.001g. The 30g soil samples were placed in a hot dry air oven at 105ºC for 24 hours. The dried samples were weighted and difference in weight was recorded. The moisture percent (dry basis) was calculated using the relationship given below.

$$\mathrm{Mc(db)} = \frac{\mathrm{Ww} - W_d}{\mathrm{Wd}} \text{ X } 100 \qquad \text{....eq. (3.40)}$$

Where,

$Mc(db)$ = Moisture content dry basis, (%)

W_w = Weight of undried soil (g); and

W_d = Weight of oven dried soil, (g).

3.10.2 Bulk density of soil

The bulk density was determined on dry weight basis randomly before tillage and 0, 30, 60 DAS and harvesting of crop i.e. 90 DAS in different treatments using a core cutter. The diameter and length of core cutter was 10 cm and 17.5 cm respectively. Soil samples were collected from each experimental plot. The samples for drying were placed in an oven at 105°C for 24 hours. The dried samples were re-weighed in an electrical balance and the difference was recorded. The bulk density of soil was determined by using following formula.

$$BD = \frac{M}{V} \quad \text{...eq. (3.41)}$$

$$V = \frac{\pi D^2}{4} \times L \quad \text{...eq. (3.42)}$$

Where

BD = Soil bulk density (g/cc);

M = Dry soil mass in the core cutter (g);

V = Volume of cylindrical core cutter (cm^3);

D = Diameter of cylindrical core cutter (cm); and

L = Length of cylindrical core cutter (cm).


Plate 3.8 Bulk density in the experimental field

3.10.3 Cone index of soil

The cone index of soil is the ability or capacity of a particular condition to resist or endure an applied force. Penetration resistance is a composite parameter that involves several independent properties of a soil but it is generally considered to reflect the strength of the soil, the cone index of soil was measured by the cone penetrometer as shown in plate 3.9. The cone index of soil is determined before and after tillage operation For measuring the cone index of soil, firstly the cone penetrometer was calibrated to known the relation between the load and deflection of dial gauge, for that the handle of cone penetrometer was removed and one plate was tight on the same place kept the standard weight for calibration. Then the penetrometer was placed on flat surface vertically and dial gauge set a zero position, then placed 500 gram weight on the plate and recorded the deflection. The same procedure was repeated with different weights and check the deflection. The graph was plotted for deflection v/s load for the cone index was calculated.

Plate 3.9 Cone index in the experimental field

3.11 Measurement biometrics of plants parameters

To evaluate field performance of pressurized aqua fertilizer seed drill, different crop parameters particularly those which are related to crop growth like germination start, germination count, no of plant/m, number of shoot/plant, number of ear head/m length, plant height, length of ear head, grain yield and straw yield. The parameters were measured for different rate of aqueous fertilizer application in the soil at the time of sowing. The crop parameters were determined in the field experiment at CAE farm for both the years i.e. 2015-16 and 2016-17. Appendix 8.

3.11.1 Determination of germination start

The germination start was observed after sowing in plots with application of aqua fertilizer and control plots. For this germination start was observed every day after sowing and whenever sprouting of seed emerged out from the soil the data was noted down in terms of days after sowing (DAS).

3.11.2 Determination of germination count

The germination count was done after 11 and 18 days of sowing (DAS) from one meter row length of sowing. For this, in every replication of the treatment at three places, 1 meter length of crop was randomly selected and germination count was made. Arithmetic mean of these three counts gave average germination of that plot. These test locations were marked for futher study.

Plate 3.10 Determination of germination count in the experimental field

3.11.3 Determination of tillering count

The tillering count was noted after 90 days of sowing (DAS). The procedure was same as that of germination count. This count was done at the locations earlier marked for germination count.

3.11.4 Determination of number of spike per meter

The number of spike per meter was determined at the time of harvesting. With the same procedure and same locations the numbers of spikes were counted.

3.11.5 Determination of plant height

Plant height is important parameters from stand point of growth parameters. For this ten plants were selected randomly from each marked space and height of plants was measured using standard procedure. Then average heights of plants were calculated.

Plate 3.11 Determination of germination count in the experimental field

3.11.6 Root length

The depth and distribution of roots are important parameters governing water and fertilizer uptake by plants. Root and plant growth is also influenced by the depth of fertilizer placement. Single randomly selected plant was uprooted and rot was separated from the stem. Roots were washed to get rid of all soil particles and allowed to dry. After drying root length was measured with a meter scale and expressed in mm.

Plate 3.12 Root length of wheat crop

3.11.7 Root weight

The dry root was measured with the help of weighing balance as shown in plate 3.13

Plate 3.13 Dry root weight

3.11.6 Determination of spike length

Spike length is greatly influenced by soil moisture and fertilizer availability. Ten spikes were selected randomly from each marked space and length of spikes was measured using standard procedure. After that average length of spikes was calculated.

3.11.7 Determiantion of grain and straw yield

A crop cutting experiment was conducted to know the grain and straw yield from different plots. The crop within 1×1 m size M.S. bar frame was harvested at the grund level by sickle. The crop was weighed and threshed manually. The grains were separated form threshed crop using a blower. The weight of clean grain collected was measured by a balance and straw grain ratio was calculated. The process was repeated at least three times in each plot. The average grain and straw yield were calculated using the following relationship:

Average crop grain yield, kg/ha = (Average weight of grain collected from one square meter area, kg)$\times 10^4$

…eq. (3.43)

Average straw yield, kg/ha = (Average weight of straw collected from one square meter area, kg)$\times 10^4$

…eq. (3.44)

All the observations are measured, calculated and present in the chapter 4 in Result and Discussion.

RESULTS AND DISCUSSION

This study conducted to determine the design parameters of a tractor drawn 9-tyne seed cum pressurized aqua fertilizer drill useful for moisture deficit areas. This would help in proper germination of the crop and initial growth. The main components of the machine were aqueous fertilizer metering mechanism, seed metering mechanism, furrow opener, power transmission system and aqueous fertilizer tanks. The heart of the machine is aqueous fertilizer metering mechanism consisting of centrifugal pump having capacity range of 60 l/min and delivering aqueous fertilizer from two aqueous fertilizer storage tanks mounted on two sides of the machine. Discharge to different furrows were taken out through eighteen tubes of equal diameter. Initially, the design parameters of the machine were determined keeping with the consideration of wheat crop.

The requirement of aqueous fertilizer for selected soil moisture conditions, to allow proper seed germination for wheat crop, was determined. In addition, to better understand and evaluate soil moisture environment of seed for application of measured aqueous fertilizer for sowing of wheat in moisture deficit areas, soil moisture distribution in the seed zone and moisture absorption pattern by seed, with and without soil medium, was also determined. The aqueous fertilizer requirement for a given soil and moisture condition on per hectare basis was, thus, determined which helped determining the discharge capacity of aqueous fertilizer metering system on both per hour and per hectare basis.

The study basically concentrated on design of pressurized aqueous fertilizer metering system to be useful for the seed drill. An experimental set-up with provision of varying pump rotational speeds, line pressures and nozzle sizes was developed. The experimental set-up facilitated mounting of storage tank, centrifugal pump, pressure gauge, control valve and nine nozzles in three different sizes i.e. 8, 10 and 12 mm. The variable flow was obtained by five levels of rotational speeds of centrifugal pump i.e. 666, 999, 1332, 1665 and 1998 rpm respectively. Discharge from different nozzles was measured at different levels of study variables. The data was analyzed and the optimized design values of different designed variables were selected. Suitable statistical test were applied to ascertain the influence of the variables over discharge from different nozzles.

Based on the results of the experiments, both in laboratory and field conditions, the seed cum pressurized aqueous fertilizer drill was fabricated. An existing 9-tyne seed cum fertilizer drill was modified to suit to mount the pressurized metering system. Thus, the aqua fertilizer seeder using designed pumping system and modified seeder was fabricated. This system was powered with tractor to operate both pumping of aqueous fertilizer as well as seeding system. Finally, tractor drawn seed cum pressurized aqua-fertilizer drill was test evaluated for required discharge from different tubes. The crop response to aqueous fertilizer application in terms of germination, initial growth and yield were also determined for wheat crop.

The results of this study are presented and discussed in this chapter under the following headings:

1. Estimation of aqueous fertilizer requirements for selected soil-moisture-crop conditions.
2. Pattern of soil moisture distribution in seed zone after application of aqueous fertilizer.
3. Design parameters of pressurized pumping system.
4. Development of tractor drawn seed cum pressurized pumping based aqua fertilizer seed drill.
5. Test evaluation of seed cum pressurized aqua fertilizer seed drill.
6. Economics and energy requirement of the machine.

4.1 Estimation of aqueous fertilizer requirements for selected soil-moisture-crop conditions

The major problem in crop production was uncertainty and deficit of soil moisture at sowing time. This inhibits germination of the crops and their initial establishment. For applying required amount of discharge, it was necessary to estimate the moisture requirements for selected soil-moisture-crop conditions. As aqueous solution of fertilizer was planned to be applied, we may assume same volume of water and solution. An estimation of required aqueous fertilizer for selected soil types was done, based on the available secondary information on soil, soil-moisture, seed environment and plant growth process. The variation in water requirement with different levels of depth of application of water e.g. 2.5, 5, 7.5 and 10 cm were assumed. The range of aqueous fertilizer requirement for different soils was estimated for maximum germination moisture as follows (Kamal Kant et. al. 2008).

4.1.1 Extra water requirement to acquire germination soil moisture at given initial moisture for different soils

Soils with varying texture possess different soil physical characteristics including water holding capacity. The areas facing water deficit situations normally possess soil type like loamy sand, sandy loam and loam soil. These are basically, the soils type where wheat cultivation is done effectively. Different areas face different levels of moisture deficit. At the same time, there is possibility of crop germination and growth over a small range of soil moisture level. With these facts in view, an analysis was done to evaluate water requirement for given initial soil moisture to obtain germination moisture for three different soil types namely loamy sand, sandy loam and loam soil. A brief description in respect of above is presented below for different soils, separately.

4.1.1.1 Loamy sand soil

The water requirement was estimated for raising the soil moisture level to 14 %, suitable for germination in loamy sand soil, from the assumed soil moisture of 3, 5 and 7 per cent. The water requirement ranged from 0.15-0.23, 0.29-0.46, 0.44-0.69 and 0.44-0.92 liter per meter for depth of application of

2.5, 5, 7.5, and 10 cm, respectively for variation initial moisture from 7 to 3 per cent. The maximum water requirement observed was 0.92 lit per meter for depth of 10 cm and initial moisture content of 3% and minimum requirement was 0.15 liter per meter for 2.5 cm and initial moisture of 7 per cent. It was noticed that for loamy sand soil an application range of aqueous fertilizer was 0.15-0.92 liter per meter. Table 4.1 and Fig. 4.1 shows the requirement of aqueous fertilizer for loamy sand soil.

Table 4.1 Estimation of requirement of aqueous fertilizer for loamy sand soil

	Aqueous fertilizer, l/m			
	Sowing depth			
Initial moisture, %	d = 2.5 cm	d = 5 cm	d = 7.5 cm	d = 10 cm
3	0.23	0.46	0.69	**0.92**
5	0.19	0.38	0.57	0.76
7	**0.15**	0.29	0.44	0.59

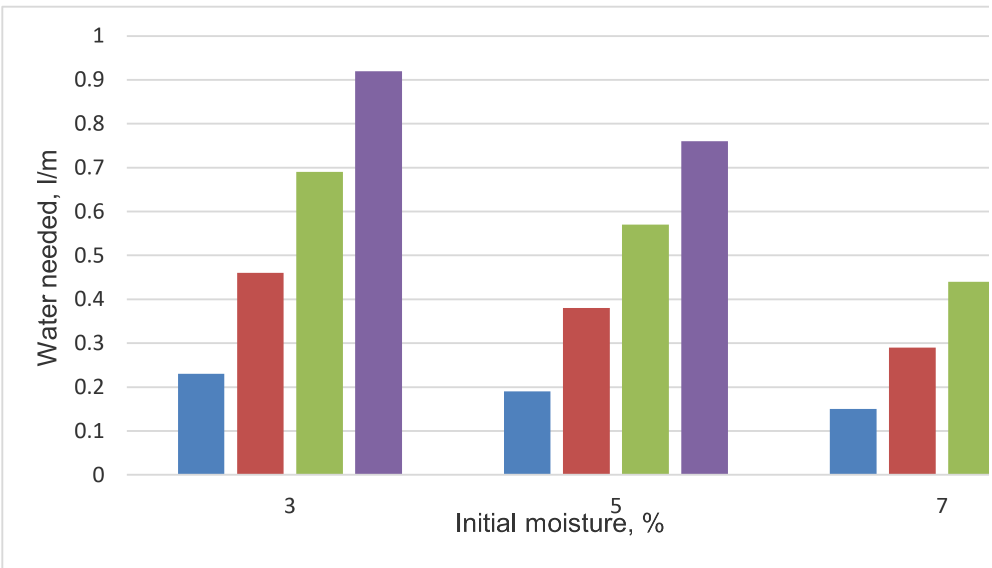


Fig. 4.1 Requirement of additional moisture for different depth of sowing (AGM, 14%)

4.1.2 Sandy loam soil

The water requirement was estimated for raising the soil moisture level to 20 %, suitable for germination in sandy loam soil, from the assumed soil moisture of 4, 8 and 12 per cent. The water requirement ranged from 0.17-0.34, 0.34-0.64, 0.50-1.01 and 0.67-1.34 for depth of application of 2.5, 5, 7.5, and 10 cm, respectively for variation initial moisture from 12 to 4 per cent. The maximum water requirement observed was 1.34 lit per meter for depth of 10 cm and initial moisture content of 3% and minimum requirement was 0.17 liter per meter for 2.5 cm and initial moisture 12 per cent. It was noticed that for loamy sand soil an application range of aqueous fertilizer was 0.17-1.34 liter per meter. Table 4.2 and Fig. 4.2 shows the requirement of aqueous fertilizer for sandy loam soil.

Table 4.2 Estimation of requirement of aqueous fertilizer for sandy loam soil

Depth	**Aqueous fertilizer, l/m**			
Initial moisture, %	**Sowing depth**			
	d = 2.5 cm	**d = 5 cm**	**d = 7.5 cm**	**d = 10 cm**
4	0.34	0.67	1.01	**1.34**
8	0.25	0.50	0.76	1.01
12	**0.17**	0.34	0.50	0.67

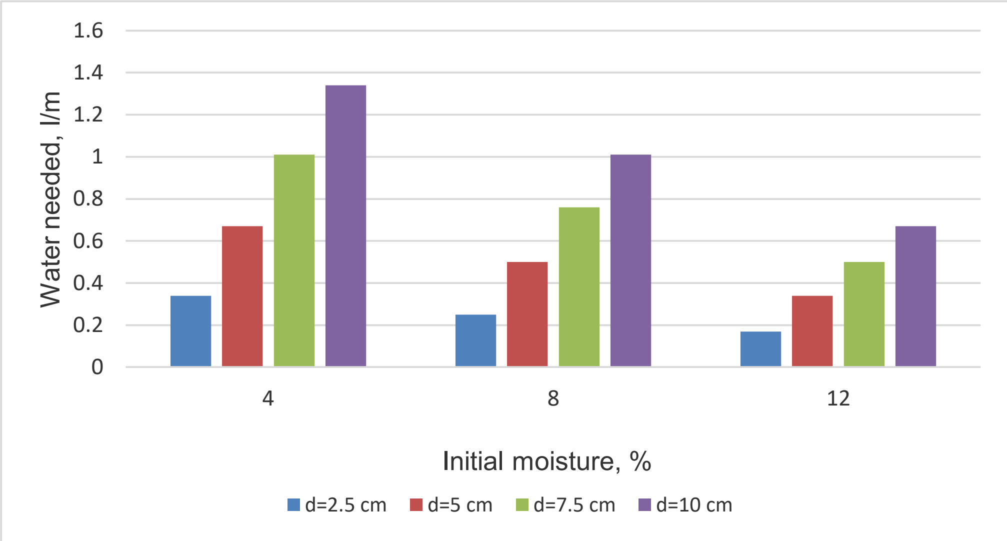


Fig 4.2 Requirement of additional moisture for different depth of sowing (AGM, 20%)

4.1.3 Clay Loam soil

The water requirement was estimated for raising the soil moisture level to 27 %, suitable for germination in loam soil, from the assumed soil moisture of 8, 12 and 16 per cent. The water requirement ranged from and 0.23-0.40, 0.46-0.80, 0.69-1.20 and 0.92-1.59 liter per meter for depth of application e.g. 2.5, 5, 7.5 and 10 cm, respectively for variation initial moisture from 16 to 8 per cent.. The maximum water requirement observed was 1.59 lit per meter for depth of 10 cm and initial moisture content of 8% and minimum requirement was 0.23 liter per meter for 2.5 cm and initial moisture 16 per cent. It was noticed that for loam soil an application range of aqueous fertilizer was 0.23-1.59 liter per meter. Table 4.3 and Fig. 4.3 shows the requirement of aqueous fertilizer for clay loam soil.

Table 4.3 Estimation of requirement of aqueous fertilizer for clay loam soil

Initial moisture, %	Aqueous fertilizer, l/m			
	Sowing depth			
	d = 2.5 cm	d = 5 cm	d = 7.5 cm	d = 10 cm
8	0.40	0.80	1.20	**1.59**
12	0.32	0.63	0.95	1.26
16	**0.23**	0.46	0.69	0.92

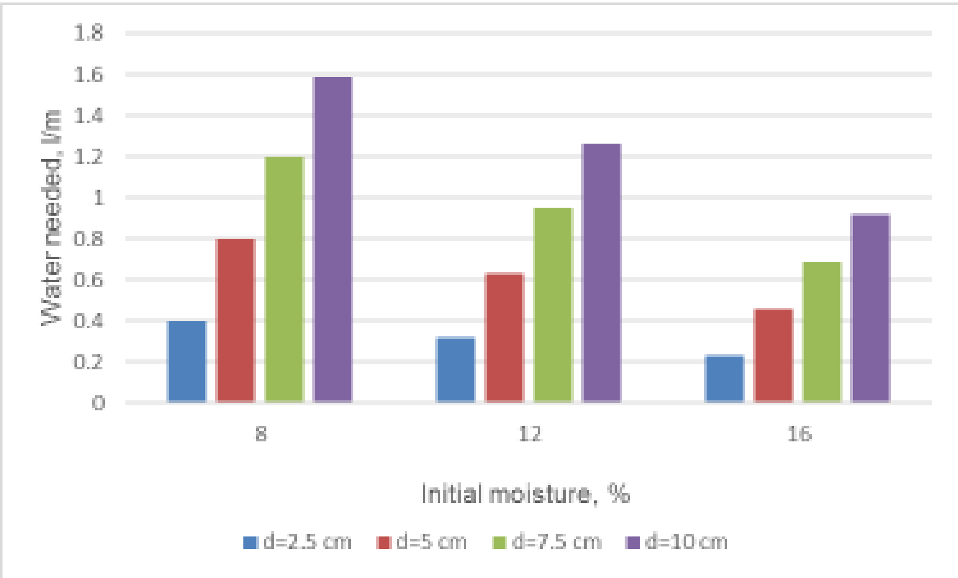


Fig 4.3 Requirement of additional moisture for different depth of sowing (AGM, 27%)

4.1.4 Aqueous fertilizer requirement for clay loam soil of experimental field

The proposed aqueous fertilizer applicator at the time of sowing is to provide maximum additional moisture to facilitate germination in soil. Thus, keeping in view the available moisture at about wilting point and minimum germination moisture of above 8% and also the limitations of seed drill to carry large volume of aqueous fertilizer, the aqueous fertilizer requirement with clay loam soil was finalized as 5500-7500 l/ha. Kamal Kant et al.,

(2008) estimated aqueous fertilizer requirement with sandy loam soil was 8000-10000 l/ha. Anonymous (1996) also estimated same requirement in their experiment at WTC, IARI, New Delhi.

4.2 Estimation of placement of aqueous fertilizer with respect to seed

To meet the exact position of dropping of aqueous fertilizer with seed drill, a laboratory test were conducted. Three lateral distance were taken i.e. 2.5, 5.0 and 7.5 cm and the three depths 0, 2.5 and 5 cm were considered for test. Moisture content of soil was recorded for 3rd, 6th and 9th day after the application of aqueous fertilizer. For 0 cm depth maximum moisture content at seed vicinity could be maintained in between 2.5 and 5.0 cm lateral distance, whereas at 7.5 cm lateral distance moisture deficit rate was higher than the other two, Fig. 4.4(a) - 4.4(c) shows the moisture content at different depth.

From the obtained results some polynomial equations were developed to predict the values of moisture content at various depths. Equations are given in the following table:

Table 4.4 Polynomial equations for different treatments

Depth (cm)	Lateral distance (cm)		
	2.5	5.0	7.5
0	$y=-2.1843x^2+12.236x-1.26$	$y=-1.6929x^2 + 9.3271x + 0.904$	$y=-1.4607x^2+7.8393x + 1.84$
2.5	$y=-2.3136x^2+13.026x-1.784$	$y=-1.7586x^2 + 9.8134x + 0.408$	$y=-1.7186x^2+9.4174x+0.536$
5.0	$y=-2.3064x^2+12.984x-1.754$	$y=-1.7964x^2 + 9.9636x + 0.496$	$y=-1.5536x^2+8.4084x + 1.48$

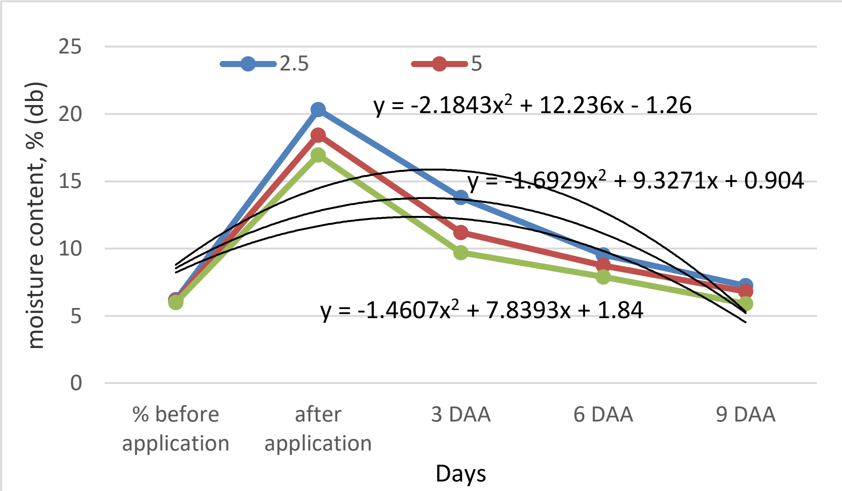


Fig. 4.4(a) Moisture content at 0 cm depth

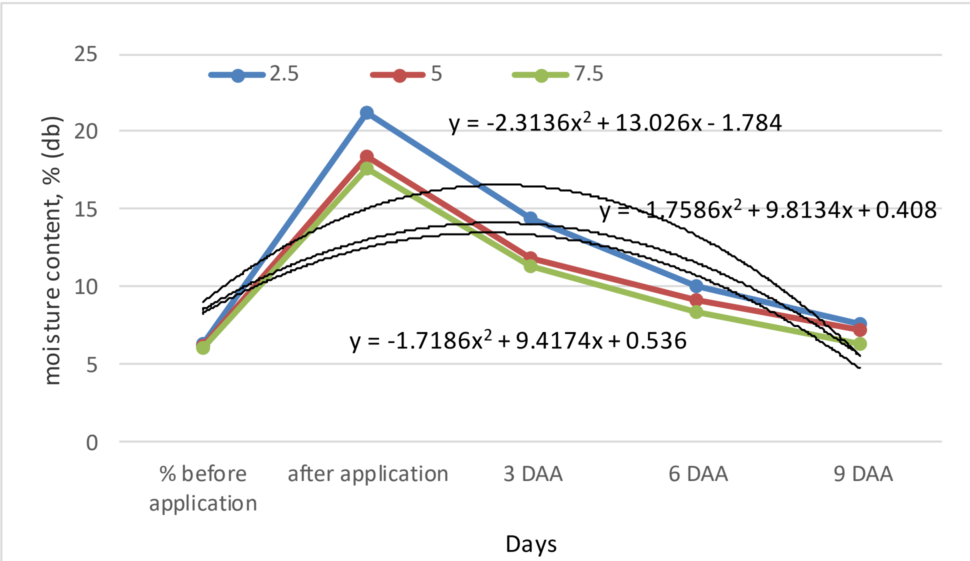


Fig. 4.4(b) Moisture content at 2.5 cm depth

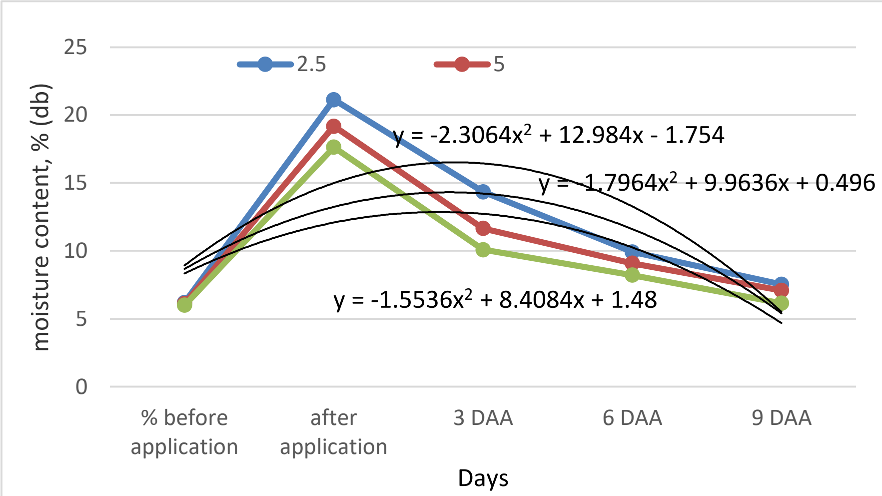


Fig. 4.4(c) Moisture content at 5 cm depth

Similar trend were observed for the other two depths of aqueous fertilizer application i.e. 2.5 and 5.0 cm. All the laboratory tests were significant with 1% significance level. On the basis of the test results, it was decided to apply aqueous fertilizer in between 2.5 to 5 cm on both sides of the seed to acquire germination moisture of the seed. Hence, water can be move vertical and longitudinal direction, it will reach to the root zone of the seed that is why 0 cm depth was decided to deliver the pressurized aqueous fertilizer.

4.3 Pattern of moisture absorption by seed

An experiment to determine moisture absorption pattern by seed with time was conducted by placing wheat seed in water and moist soil separately. In fact, it was felt prudent to know the pattern of moisture absorption by seed when the latter is kept under sufficient moisture. On one hand, it provided information on moisture absorption pattern by seed on the other hand it gave information regarding period of moisture availability in the soil after application of aqueous fertilizer. So, necessary care needs to be taken to ensure the presence of sufficient soil moisture in the soil for a minimum period of time to allow proper germination. It is further stated that if the prevailing soil and climatic parameters do not allow the seed to retain applied moisture for a certain minimum periods of time necessary for germination, seed may not get opportunity to germinate even after application of aqueous fertilizer at the time of sowing.

4.3.1 Moisture absorption pattern by seed under soaked condition

To begin with, the bone dry moisture content was determined for the 50 g sample of seed following the standard experimental procedure. The average bone dry moisture content of the seed was determined as 3.3% on dry basis. Taking this bone dry moisture as reference point, increase in weight of seed and resulting moisture content after time lapse of 5, 10, 15, 30 minutes and 1, 2, 4, 6 hours was determined. As expected, the weight of 50 g of sample seed increased with time from 54.7 to 74.4 g during first 6 hours. The increase in weight was relatively higher up to first 30 minutes in comparison to one hour and more time lapses. A 100% variation in incremental weight was observed during first 5 to 30 minutes. However, in next 6 hours, the increase in incremental weight was observed as 158 per cent. Thus, the moisture absorption rate during first 30 minutes was 0.12 g/min, whereas the same was 0.0487 g/min beyond this period. Table 4.4 shows the moisture absorption pattern by seed under soaked condition.

Initial weight of grain: 50 g. Bone dry initial moisture of seed 3.3 per cent.

Table 4.5 Moisture absorption pattern by seed under soaked condition

Time after (min)	Average increase in weight, gm	Average mc after soaking %	Overall mc
5	3.7	7.4	10.5
10	4.5	8.9	12
15	6.2	12.1	15.3
30	7.3	14.3	17.4
60	8.9	17.7	21.1
120	13.1	26.3	29.4
240	19.2	38.1	41.5
360	23.4	46.5	49.9

Overall moisture content includes average moisture content after soaking and initial bone dry moisture.

The seed sample had bone dry moisture content of 3.3%. After the lapse of during first five minutes the same was reached to 7.4 per cent. The seed attained a moisture level of 12.1 and 14.3 per cent at the lapse of 15 and 30 minutes, respectively. It is important to note that the approximate germination moisture for wheat in loamy sand soil, sandy loam soil and loam soil are 12-14%, 16-20% and 23-27%, respectively (Ratliff et al., 1983). It is interesting to note that at germination time of moisture of seed and seed bed should be almost same. The result shows that the soaked seed attains moisture levels of 12.1, 14.3 and 17.7% after 15, 30 and 60 minutes after soaking. Thus, after placement of seed in the soil, irrespective of field capacity, the seed will reach germination moisture level within one hour. These results will be helpful to determine, the required moisture at sowing depth and the minimum duration of time.

4.3.2 Water absorption by seed placed in soil

Water absorption pattern by seed placed in the seedbed was evaluated under controlled condition in the soil. The three different levels of soil moisture i.e. 12.1, 9.24 and 5.25% were taken and the increase in weight in the sample of seed after 1, 2 and 3 days was determined for the above said three respective moisture contents, Table 4.5 shows the pattern of moisture absorption by seed from soil. The initial bone-dry moisture of sample seed was measured as 3.3% on dry basis. For the first two moisture levels of 12.1 and 9.24%, the water absorption by seed from the soil followed almost same pattern, however, as expected the increment in weight was slightly more in case of higher moisture i.e. 12.1 per cent. With time weight increment increased during all the three days for different moisture condition. The soil of the experiment was clay loam with limited water holding capacity that is why the soil moisture could not be retained at sufficiently high. It was assumed that seed would attain optimum level for germination by the end of 3^{rd} day. A maximum increment of 15.6, 13.4 and 11.6% in moisture content was observed after three days of sowing for three soil moisture levels of 12.1, 9.24 and 5.25 per cent, respectively. On the basis of observations, it could be inferred that for attaining optimum germination moisture for seed, a moisture level of above of 9.24-12.1% need to be maintained in the soil of moisture deficit areas. If the initial moisture content is less than the required, it would be difficult for seeds to attain germination moisture. It may be further inferred that any delay in sowing operation adversely affect the process of attaining optimum soil moisture by seed during given period of time.

Table 4.6 Pattern of moisture absorption by seed from soil

S. No	Average moisture content (Wb) of soil %	Average moisture content of seed, % (Wb)		
		After 24 hours	After 48 hours	After 72 hours
1	12.1	13.2	14.4	15.6
2	9.24	11	12.32	13.4
3	5.25	9.2	11	11.6

4.3.3 Time of emergence of wheat at different soil moisture levels

The time of emergence of wheat crop was determined with different soil moisture level for four different seeding depth of 2.5, 5, 7.5 and 10 cm at four different levels of soil moisture of 15.7, 13.53, 10.41 and 8.1 per cent on dry basis. For given depth of 2.5 cm soil, with increased soil moisture content from 8.1 to 15.7%, the time of emergence decreased from 5 to 3 days, however, for moisture variation of 10.41 to 13.53%, there was no difference in time of emergence. Similarly, for moisture variation of 15.7 and 8.1% the time of emergence ranged as 4-7, 6-9 and 9-12 days for all three (5, 7.5 and 10 cm) of depth, however, the time of emergence was observed the same for soil moisture of 13.53 and 10.41%, respectively.

Table 4.7 Time of emergence of wheat at different soil moisture and varying seeding depth

S. No.	Soil moisture content, db %	Time of seedling emergence, days			
		Seeding depth, cm			
		2.5	**5**	**7.5**	**10**
1	15.7	3	4	6	9
2	13.53	4	5	8	10
3	10.41	4	5	8	11
4	8.1	5	7	9	12

In fact, the time of emergence was excessively long i.e. 9-12 days for sowing depth of 10 cm. it was also interesting to note that, a compromise between soil moisture and sowing depth can be reached as for same amount of time emergence. The time of emergence with initial soil moisture of 15.7% and seeding depth of 7.5 cm was same as that for initial soil moisture content of 8.1% and sowing depth 5 cm, Table 4.6 and Fig. 4.5 shows the time of emergence of wheat at different soil moisture and varying seeding depth. Based on the observation on time of emergence with different moisture level and soil depth, it is concluded that a soil moisture level above 10% and depth of 2.5-5.0 cm are favorable for seed germination. However, seeding depth beyond 7.5 cm must be avoided in any case, the seeding depth for wheat must be within the range of 2.5-5 cm. Same results were obtained by Dey et al. (2004).

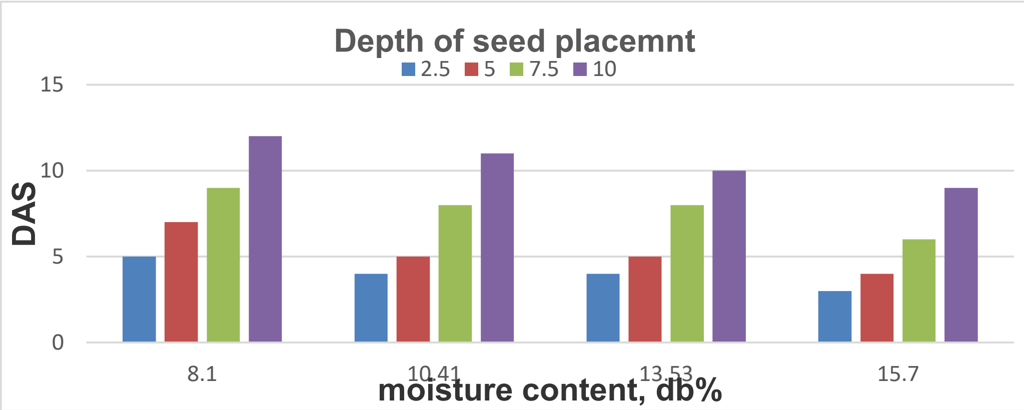


Fig. 4.5 Time of emergence of wheat with different moisture of soil

4.4 Design values of pressurized aqueous fertilizer metering system

Design implies intent or purpose; hence design of a pressurized fertilizer metering system implies that it is to be constructed to accomplish its intended job efficiently and safely. Success of design depends on degree to which the constructed device utilizes the ground condition to best attain the desired performance. Design of the metering mechanism also required certain methods and design parameters it should deliver metered amount of aqueous fertilizer uniformly without interruption. Dey et al. (2006) successfully developed a peristaltic pumping based aqueous fertilizer metering mechanism which works on the principle of suction. The present study on design development and evaluation of seed cum pressurized aqueous fertilizer drill was undertaken to develop an aqua fertilizer seeding system to facilitate precise seeding of plant with controlled application of aqua fertilizer. The main design variables of pressurized pumping system included pump rotational speeds, line pressures and nozzles sizes of aqueous fertilizer. The discharges from aqua fertilizer distributor for various levels of variables were recorded. Their effects on discharge pattern was studied and analyzed statistically also.

4.4.1 Discharge v/s pump rotational speed at various levels of nozzles at fully open valve

The influence of pump rotational speed on discharge rates was evaluated. The discharges from three levels of nozzle sizes i.e. 8, 10 and 12 mm were recorded for five levels of pump rotational speeds e.g. 666, 999, 1332, 1665 and 1998 by keeping when pressure and volume control valve was fully open. It was observed that the pump rotational speed directly influenced the discharge in linear manner for different levels of nozzle sizes, which is shown in the Figure 4.6-4.8. The trend was observed very similar when nozzle sizes increased from 8 to 12 mm. Generally the discharge from nine different nozzles was same because nozzle openings were uniformly spaced. Minor variation noticed due to possible minute variation in nozzle sizes while fabricating.

The discharge from nozzle diameter of 8, 10 and 12 mm openings increased linearly with increase in pump rotational speed from 666-1998 rpm, Figure 4.6. For 8 mm nozzle size, the range of discharge was 0.69 to 1.41 l/s for pump speeds range of 666 to 1998 rpm. For 10 mm nozzle size, the range of discharge was 0.74 to 1.53 l/s for pump speed range of 666 to 1998 rpm. For 12 nozzle size, the range of discharge was 0.72 to 1.48 l/s for pump speeds range of 666 to 1998 rpm. At 1665 rpm the three nozzles sizes gave discharge of 1.13, 1.21, and 1.17 l/s. The discharge increased by 63.77, 69.44 and 49.25%, for increased in rpm from 666 to 1665 for three nozzle sizes of 8, 10 and 12 mm, respectively.

Similarly, the observed increase in discharge due to speed changes from 1665 to 1998 rpm was 25.66, 28.57 and 45 % for three nozzle sizes of 8, 10 and 12 mm. The results indicated that nearly uniform variation in discharge was obtained over speed range of 666 to 1998 rpm. This variation in discharge was as per expectation. More the pump speed of a centrifugal pump, which is positive displacement pump, more will be discharge. Thus, the pumping system used for metering aqueous fertilizer was capable to give a discharge variation of to 0.13 to 1.21 l/s for different nozzle sizes. Appendix 4, 5 and 6 shows the pressure, speed and discharge for nozzle size 8, 10 and 12mm respectively.

Statistical analysis was done to know the relative performance of the pressurized aqua fertilizer metering system for discharge rates at various pump rotational speed for different nozzle size. The discharge obtained at pump rotational speed of 666, 999, 1332, 1665 and 1998 was significantly at 1% level which is shown in Table 4.7.

4.4.2 Discharge vs. nozzle sizes at pump rotational speed at fully open valve

The discharge rate for various levels of nozzle sizes at pump rotational speeds levels i.e. 666, 999, 1332, 1665 and 1998 rpm at fully opened valve was recorded. It was observed that discharge rate is similar for each nozzle size i.e. 8, 10 and 12 mm for various levels of pump rotational speeds, which is shown in Figure 4.6.

The experimental set up results showed that at 666 rpm the discharge from three nozzles i.e. 8, 10 and 12 mm were 0.69, 0.73 and 0.70 l/s respectively, which confirmed the principle of mass conservation in the pipe flow. At 1998 rpm, the three nozzle sizes of 8, 10 and 12 mm gave discharge of 1.42, 1.51 and 1.46 l/s. respectively, in the same order which showed relative higher value for 10 mm. As expected, the discharge from different nozzle sizes at same rotational speed of pump should almost be the same. The aqueous fertilizer was pumped by centrifugal pump and the latter being a positive displacement pump discharge should be same irrespective of nozzle sizes. However, minor variation in discharge may be witnessed due to deviation in nozzle size from design value caused while fabricating the same. At lower diameter, the line pressure will increase leading to variation in pump efficiency also. In addition, there could be possibility of slippage in belt pulley system of power transmission at lower size of nozzle due to development of higher line pressure. Having given scope for above variables, the discharge from different nozzle sizes at a given rpm should be same.

It was observed that velocity of discharge increased for smaller nozzle size i.e. 8 mm than 10 mm and 12 mm. This cause problem of seed as well as soil displacement. Hence, nozzle size of 8 mm was not used for fabrication of pressurized aqueous fertilizer metering system.

Fig. 4.6 shows the discharge at different nozzle sizes at various rotational speeds of pump at fully open valve.

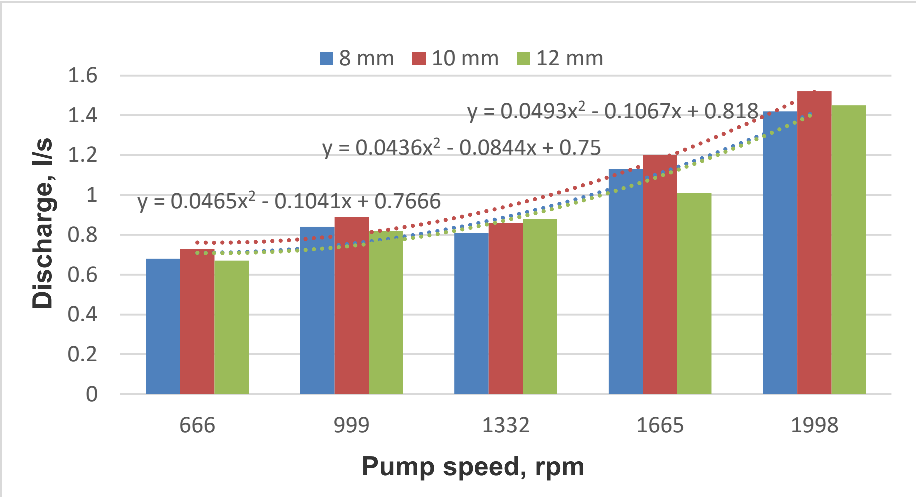


Fig 4.6 Discharge at different nozzle sizes at various rotational speeds of pump at fully open valve

4.4.3 Discharge vs. pump rotational speed for various levels of line pressure of aqueous fertilizer at different nozzle sizes

In pressurized aqueous fertilizer metering system, the rate of aqueous fertilizer could be controlled by varying the pressure levels. Here, four levels of pressures were used by providing control valve through partial opening. It could be an important variable for calibration of aqueous fertilizer. The discharge was recorded for varying pump rotational speed e.g. 666, 999, 1332, 1665 and 1998 rpm with calibrated line pressure levels of 0, 2, 4 and 6 kg /cm^2 and three levels of nozzle sizes e.g. 8, 10 and 12 mm. It was observed that discharge decreased with increase line pressure; however at given calibrated line pressure, discharge increased with increase in pump rotational speed in linear manner level of nozzle sizes i.e. 8, 10 and 12 mm, shown in Figure 4.6-4.8.

For 8 mm nozzle opening, the observed discharge range for increase in rotational speed from 666 to 1998 rpm was 0.68 to 1.42, 0.37 to 1.19, 0.31 to 0.90 and 0.12 to 0.82 l/sec at calibrated line pressure of 0, 2, 4 and 6 kg /cm^2, respectively, in the same order. For 10 mm nozzle opening, the observed discharge range for increase in rotational speed from 666 to 1998 rpm was 0.73 to 1.51, 0.39 to 1.26, 0.33 to 0.95, and 0.12 to 0.86 l/sec at calibrated line pressure of 0, 2, 4 and 6 kg /cm^2, respectively, in the same order. Similarly for 12 mm nozzle opening, the observed discharge range for increase in rotational speed from 666 to 1998 rpm was 0.67 to 1.45, 0.37 to 1.28, 0.28 to 1.20 and 0.0001 to 0.96 l/sec at calibrated line pressure of 0, 2, 4 and 6 kg /cm^2, respectively.

More the calibrated line pressure less was the discharge from nozzles. Approximately, 5.7 times reduction in discharge could be noticed (From 0.69 to 0.12 l/s) by increasing calibrated line pressure from 0 to 6 kg /cm^2 at a minimum rotational speed of 666 rpm. Similarly, at 1998 rpm, the reduction in observed due to pressure change from 0 to 6 kg /cm^2, was about 1.8 times. Same trend was found by Lande 2008. At high rotational speed, developed pump pressure could over power the line pressure and discharge gap was reduced. But at low rpm of the pump, the effect of line pressure was more pronounced. The same is exhibited by the patterns of results obtained.

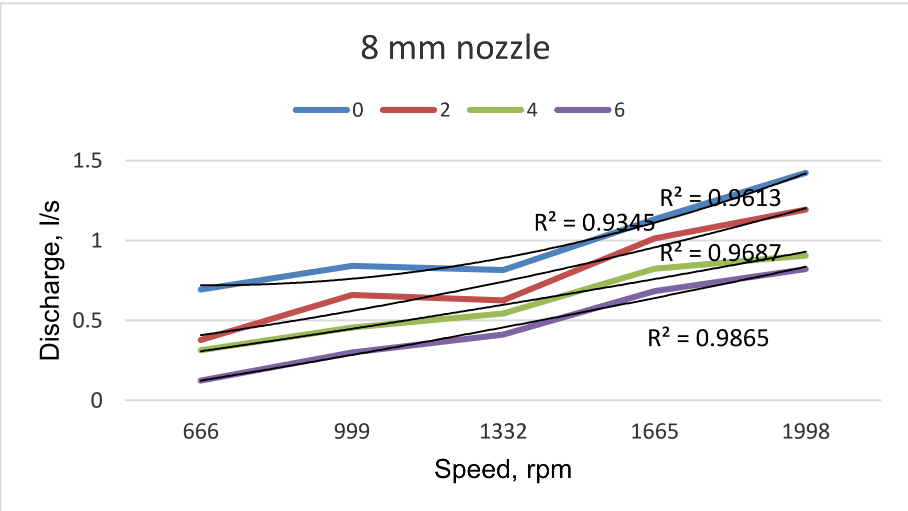


Fig 4.7 Discharge vs. rotational speed of pump for various levels of line pressure of aqueous fertilizer

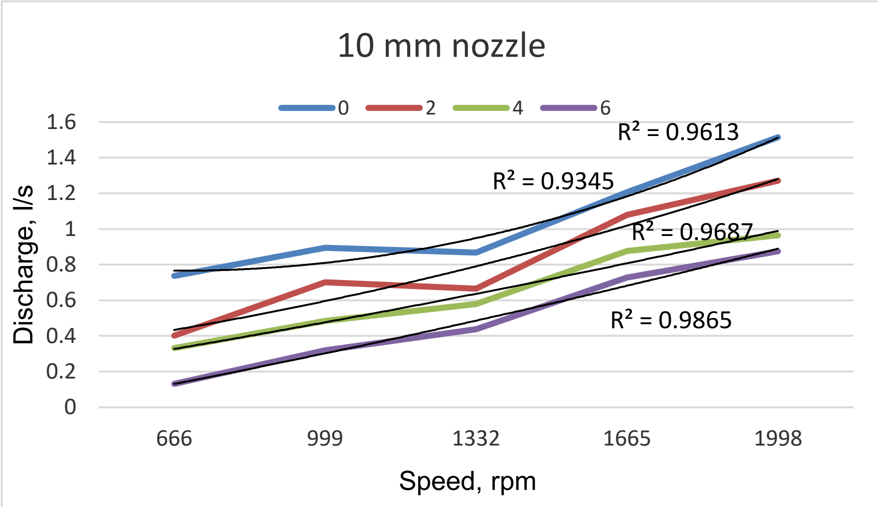


Fig 4.8 Discharge vs. rotational speed of pump for various levels of line pressure of aqueous fertilizer

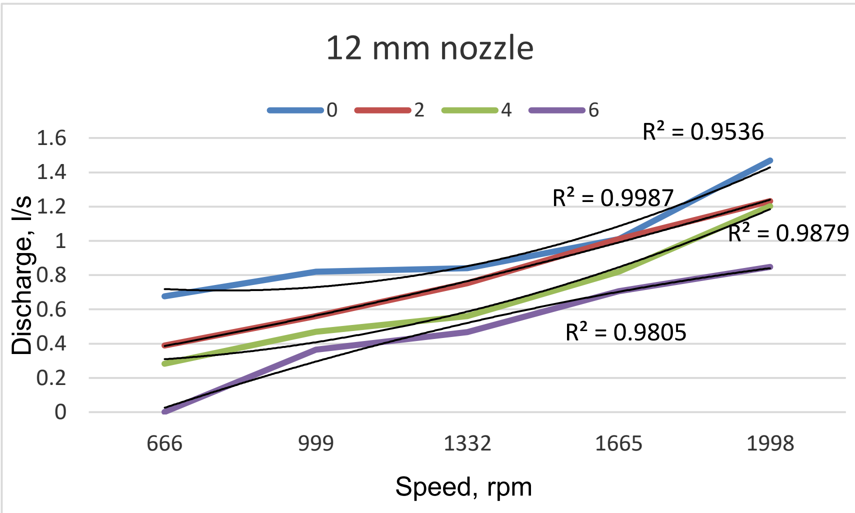


Fig 4.9 Discharge vs. rotational speed of pump for various levels of line pressure of aqueous fertilizer

Statistical analysis was done to know the relative performance of the pressurized aqua fertilizer metering system for discharge rates at various pump rotational speed for various levels of line pressure at different levels nozzle sizes, which is shown in Table 4.8. The discharge obtained at pump rotational speed of 666 to 1998 was significantly different for all levels of line pressure 0 to 6 kg /cm^2 and at all levels of nozzle sizes.

Table 4.8 Discharge, pump speed and pressure for various nozzle size

Speed	Pressure (kg/cm^2)	8mm Nozzle discharge (l/s)	10 mm Nozzle discharge (l/s)	12 mm Nozzle discharge (l/s)
S1 1998	0	1.42	1.51	1.47
	2	1.19	1.27	1.23
	4	0.91	0.96	0.94
	6	0.82	0.87	0.85
S2 1665	0	1.13	1.21	1.17
	2	1.01	1.08	1.05
	4	0.82	0.88	0.85
	6	0.68	0.73	0.71
S3 1332	0	0.81	0.87	0.84
	2	0.63	0.67	0.65
	4	0.54	0.58	0.56
	6	0.41	0.44	0.43
S4 999	0	0.84	0.89	0.87
	2	0.66	0.70	0.68
	4	0.45	0.48	0.47
	6	0.30	0.32	0.31
S5 666	0	0.69	0.74	0.72
	2	0.38	0.40	0.39
	4	0.31	0.33	0.32
	6	0.12	0.13	0.13

Table 4.9 Anova table for discharge, pump speed and pressure

Source	DF	SS	MSS	Fcal		Ftab 5%	Ftab 1%
S	4	12.582	3.145	55419.38	**	2.45	3.48
P	3	7.023	2.341	41245.02	**	2.68	3.95
SxP	12	0.342	0.029	502.17	**	1.83	2.34
D	2	0.062	0.031	545.02	**	3.07	4.79
SxD	8	0.008	0.001	17.86	**	2.02	2.66
PxD	6	0.005	0.001	13.29	**	2.18	2.96
SxPxD	24	0.000	0.000	0.16	ns	1.61	1.95
Error	120	0.007	0.000				
Total	179	20.028					

SE= 0.025 CV%= 3.413

Table 4.8 reveals about the ANOVA for aqueous fertilizer discharge (D), pump rotational speed (S) and in line pressure (P). It was found that the factor S, P and D as well as two factor interaction i.e. SxP, SxD and PxD was highly significant at 1% level. The three function interaction i.e. SxPxD was non-significant.

Interaction between the variables S and P, mean value of the first level of speed and pressure was highest from CD among all the levels of pump rotational speed and inline pressure. Interaction between the variables S and D, mean value of the first level of speed and 2nd level of nozzle size i.e. 10 mm was highest from CD among all the levels of pump rotational speed and discharge from various nozzle sizes. Interaction between the variables P and D, mean value of the first level of inline pressure and 2nd level of nozzle size i.e. 10 mm was highest from CD among all the levels of inline pressure and discharge from various nozzle sizes.

4.4.4 Selection of pump design values

The main objective of the study was to develop aqueous fertilizer metering system based on pressurized pumping system. The design values of the pump has to be from the selected study variables i.e. pump rotational speed and, nozzle size and line pressure. It would be appropriate to calibrate the pumping system by taking range of design variables to enable it to obtained a wide ranges of discharge by three different means i.e. by varying pump rotational speed, calibrated line pressure and nozzles size. In fact, the utility of nozzle size in design of pump was to select a suitable nozzle opening which should release aqueous fertilizer at a speed sufficient to target the area near seed, but should not disturb the soil in seed environment. The observations on discharges from three nozzles indicated that at high rpm at 8 mm; from different was at higher speed, which may disturb the soil. Whereas, at 12 mm it was tending to spread more. So, a nozzle size of 10 mm was selected. Moreover, this size gave little higher discharge. The rest two variables were used to calibrate the pumping system over their respective range to cover a wide range discharge. The line pressure of 6 kg /cm^2 was not accepted as it gave erratic and uneven discharge from different nine nozzles. Thus, only 0, 2 and 4 kg/cm^2 pressure levels were used in calibration. As the recommended rpm of pump is 1665, it was decided to avoid 1998 rpm as it may lead to damage to entire pressurized system because of enhanced friction and possibility of damage of centrifugal pump. So, rotational speed of 666, 999, 1332 and 1665 rpm were selected. Table 4.9 shows the design variables for pressurized pumping system.

Table 4.10 Selected design variables for pressurized pumping system

S. no.	Design variable	Design value
1	Pump rotational speed (rpm)	666, 999, 1332 and 1665
2	Nozzle size (mm)	10
3	Line pressure (kg/cm^2)	0, 2 and 4

4.4.5 Calibration of pressurized aqueous fertilizer metering system

The range of aqueous fertilizer requirement for selected soil texture i.e. sandy loam, loamy sand and loam were estimated as 0.15 to 0.92, 0.17-1.34 and 0.23-1.59 l/m. It was observed that the minimum requirement is 0.15 l/m and maximum requirement was 1.59 l/m. In pressurized aqueous fertilizer metering system, discharge rates decreased with increase in assumed forward speed for constant levels of pump rotational speed and line pressure. When forward speed increased from 1 to 4.5 kmph, it was observed that range of discharge rates were satisfied only by 10 mm nozzle size. Hence, nozzle size of 10 mm was selected. However, this was also befitting from standpoint aqueous fertilizer application in furrows without causing soil disturbance. The developed pressurized system is capable of delivering a maximum 3600 l/h and minimum of 369 l/h of aqueous fertilizer with refilling time of 6.66 to 65 minute, respectively if source of aqueous fertilizer is near to application field. Plate 4.1 shows the calibration of seed cum pressurized aqueous fertilizer drill.

Plate 4.1 Calibration of seed cum pressurized aqueous fertilizer drill

4.5 Development of tractor drawn aqua fertilizer seed drill

Aqueous fertilizer seed drill was developed using a 9-row seed cum fertilizer drill and developed pressurized aqua fertilizer pumping system. The existing nine row seed drill was modified to make scope for mounting design and fabricated aqueous fertilizer metering system based on pressurized pumping. The furrow opener was redesigned to enable it to adjust aqueous fertilizer tube alongside of the seed tube.

The seed cum pressurized aqueous fertilizer seed drill was planned to be operated by a 45 hp tractor. Different moving components of the machine were supplied power from the tractor. The centrifugal pump was powered by the PTO drive of the selected tractor with a speed of 540±10 rpm. A suitable power transmission system was designed and fabricated to accomplish this task. The power transmission system was designed taking universal fitted to PTO, two shafts of dia. 32 mm, four bearing (P-207), followed by pulley's through V-belt (B1973 Lp/B76 & B1415 Lp/B54). This power transmission system operated the centrifugal pump which supplied discharge to aqueous fertilizer distributor line, which supplies aqueous fertilizer to nine delivering tubes, Plate 4.2(a).

Arrangement was made to have a variable speed of pumping system. As two speeds e.g. 1665 and 1332 rpm were selected, this could be attained with the help of belt pulley system. The seed metering mechanism consists of fluted roller type and powered by ground wheel with the help of two sprockets of 15 teeth with one idler and one guider was provided and a chain of 1.59 cm pitch was used for the same.

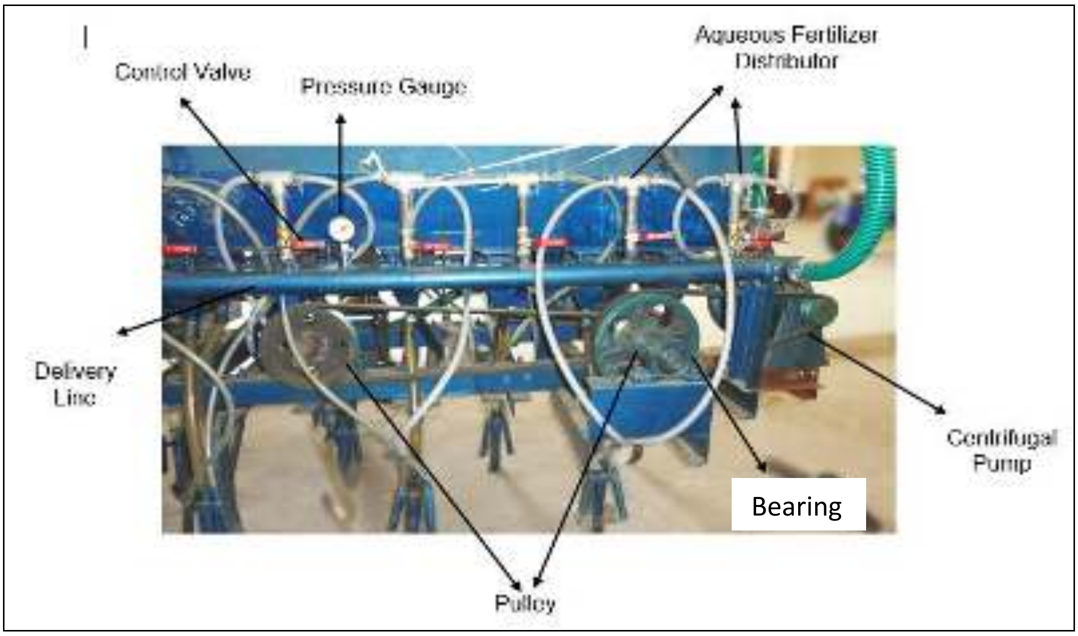


Plate 4.2(a) Developed seed cum pressurized aqueous fertilizer drill

Aqueous fertilizer distributor was mounted in a way to safely adjust it and making scope for distribution of aqueous fertilizer equally to dispense it through nine valves, which is shown in Plate 4.2(a).

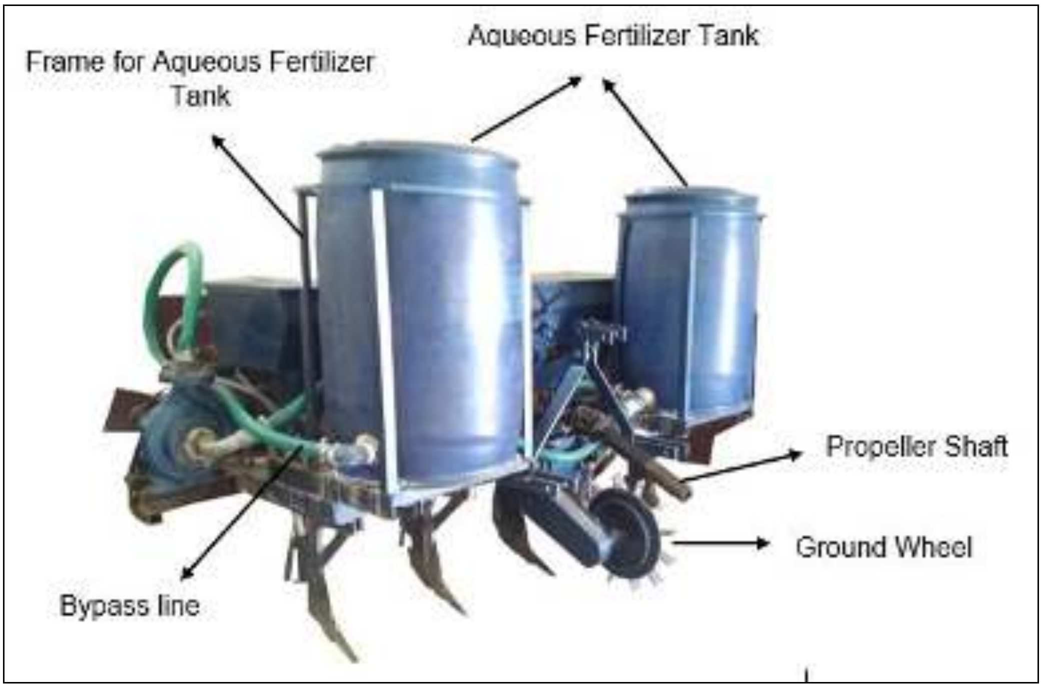


Plate 4.2(b) Developed seed cum pressurized aqueous fertilizer drill

A base frame for tank of capacity 400 liter was made up of 40 × 40 × 8 mm angle iron. The tank was tightly held with the help of arc-shape attachment. The design pumping system was mounted on mainframe of exiting seed drill. The developed seed cum pressurized aqueous fertilizer drill was fabricated with provision of varying pump speed and line pressure levels for required aqueous fertilizer dose, Plate 4.2(b).

4.6 Performance evaluation of seed cum pressurized aqueous fertilizer drill

Field evaluation of the developed seed cum pressurized aqua fertilizer drill was done in the experimental field of Horticulture, JNKVV, Jabalpur during the period Rabi, 2015-16 and 2016-17. For designing the experiment RBD was followed. During both the years six treatments (T_1, T_2, T_3, T_4, T_5, T_6) i.e. aqueous fertilizer application rate of 4500, 5500, 6500 l/ha, aqueous fertilizer seed drill with water only, zero till seed cum fertilizer drill and conventional seed cum fertilizer drill were done. Data on various crop germination and growth parameters like germination start, germination count, no of plant/m length, no of tillers per plant, no of ear head/m length, plant height, root length, root length density etc. were collected. Finally the influences of aqueous fertilizer rate on crop yield for all six treatments were evaluated.

4.6.1 Field capacity and field efficiency of the machines

An average field capacity of 0.35 ha/h was obtained for continuous operation of aqueous fertilizer drill at an average speed of 3 kmph. Appendix 10 shows the machine parameters of all the sowing machineries. A field efficiency of 65.5, 66.6 and 70.3% for seed cum pressurized aqueous fertilizer drill, zero till seed cum fertilizer drill and conventional seed cum fertilizer drill respectively was observed which was in the prescribed range of 60 to 80% for seed drill. The major loss in field efficiency was due to refilling of aqueous fertilizer tanks. No repairs, breakdown and adjustment of components during the operation were observed. The average depth of placement of seed of ten randomly selected observations was 5 cm thus, seeds were placed recommended range of seed depth of 3-5 cm. Fig. 4.10 & 4.11 shows the field efficiency and field capacity for different sowing machines.

The ANOVA table 4.10 reveals that the calculated value of F statistic

(29.73) at the time of test is greater than the corresponding F table value $F_{1\%}$ = 10.92, Hence, we conclude that treatments are found to be statistically highly significant i.e. all treatments under study are not equally effective, it indicates that all treatment parameters are pair wise statistically significant. In the study.

Table 4.11 Anova table of field capacity for different sowing machines

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	3	0.00	0.00	12.73	**	4.76	9.78
treatment	2	0.00	0.00	29.73	**	5.14	10.92
Error	6	0.00	0.00				
Total	11	0.00					

SEd= 0.004 SEm= 0.003 CD 5%= 0.010

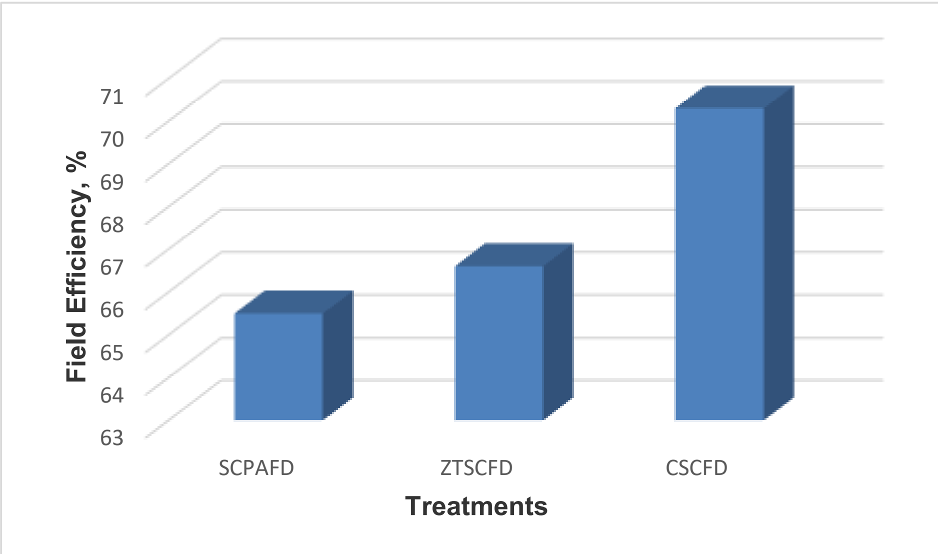


Fig 4.10 Field Efficiency of different treatments

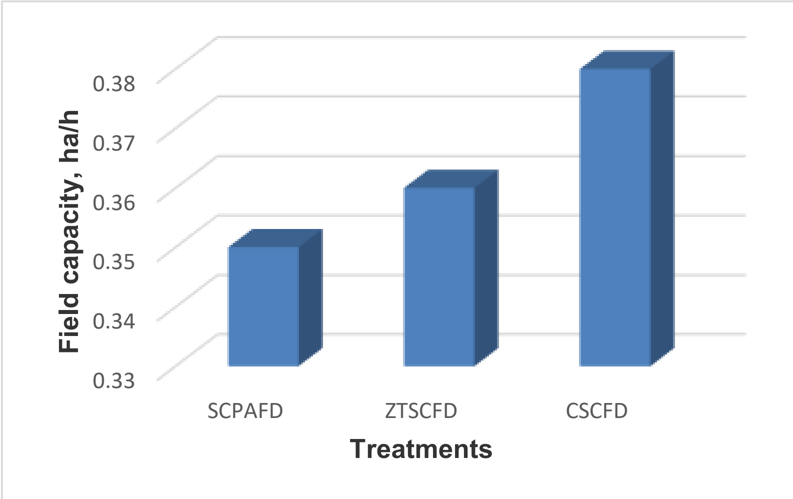


Fig 4.11 Field Capacity of different treatments

4.6.2 Fuel consumption of sowing systems

Fig. 4.12 shows fuel consumption of different sowing machines. In case of seed cum pressurized aqueous fertilizer drill, zero till seed cum fertilizer drill and conventional seed cum fertilizer drill, the fuel consumption was found to be 10.85, 9.97 and 8.42 lit/ha respectively. It is evident from figure that fuel consumption of zero till and conventional seed drill was less than seed cum pressurized aqueous fertilizer drill by 8.1 and 22.3%, because field capacity of ZTSCFD and CSCFD is more than SCPAFD.

Table 4.12 Anova table of fuel consumption for different sowing machines

Source	DF	SS	MSS	Fcal		F tab5%	F tab1%
Replication	3	0.12	0.04	11.77	**	4.76	9.78
treatment	2	0.62	0.31	91.18	**	5.14	10.92
Error	6	0.02	0.00				
Total	11	0.76					

SEd= 0.041 SEm= 0.029 CD 5%= 0.101

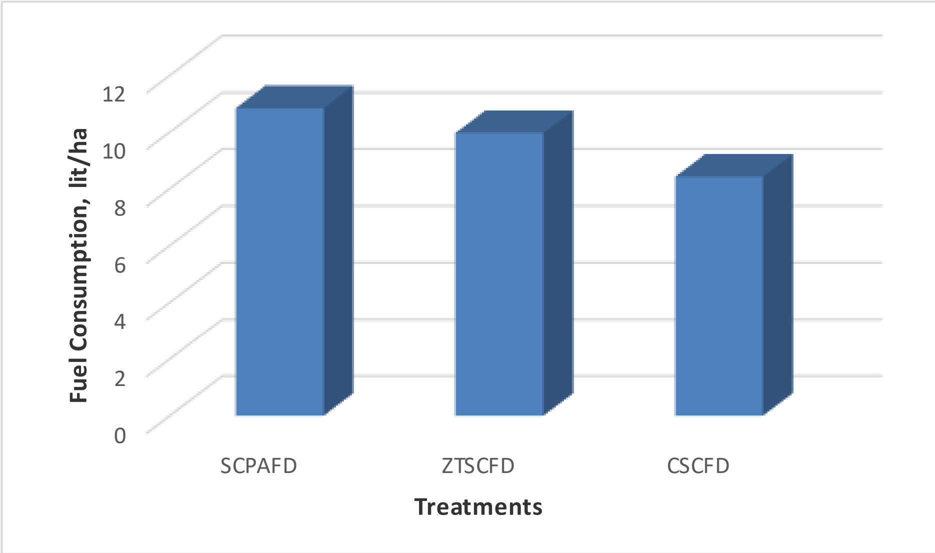


Fig. 4.12 Fuel consumption of sowing systems

The ANOVA table 4.11 reveals that the calculated value of F statistic (91.18) at the time of test is greater than the corresponding F table value $F_{1\ \%}$ = 10.92, Hence, we conclude that treatments are found to be statistically highly significant i.e. all treatments under study are not equally effective, it indicates that all treatment parameters are pair wise statistically significant. In the study.

4.6.3 Draft requirement of different tillage implement

The total draft required for different sowing systems are shown in Fig 4.13 The draft requirement for seed cum pressurized aqua fertilizer drill, zero till seed cum fertilizer drill and conventional seed cum fertilizer drill was 3.6, 3.0 and 2.31 KN respectively. In case of SCPAFD draft was 16.6 and 35.8% more than ZTSCFD and CSCFD respectively. This is due to the extra weight of two aqueous fertilizer tanks on the SCPAFD.

The ANOVA table 4.12 reveals that the calculated value of F statistic (184.57) at the time of test is greater than the corresponding F table value $F_{5\ \%}$ = 5.14, Hence, we conclude that treatments are found to be statistically highly significant i.e. all treatments under study are not equally effective, it indicates that all treatment parameters are pair wise statistically significant. In the study.

Table 4.13 Anova table of draft requirement for different sowing machines

Source	DF	SS	MSS	Fcal		F tab5%	F tab1%
Replication	3	0.10	0.03	3.87	ns	4.76	9.78
treatment	2	3.17	1.59	184.57	**	5.14	10.92
Error	6	0.05	0.01				
Total	11	3.33					

SEd= 0.066 SEm= 0.046 CD 5%= 0.160

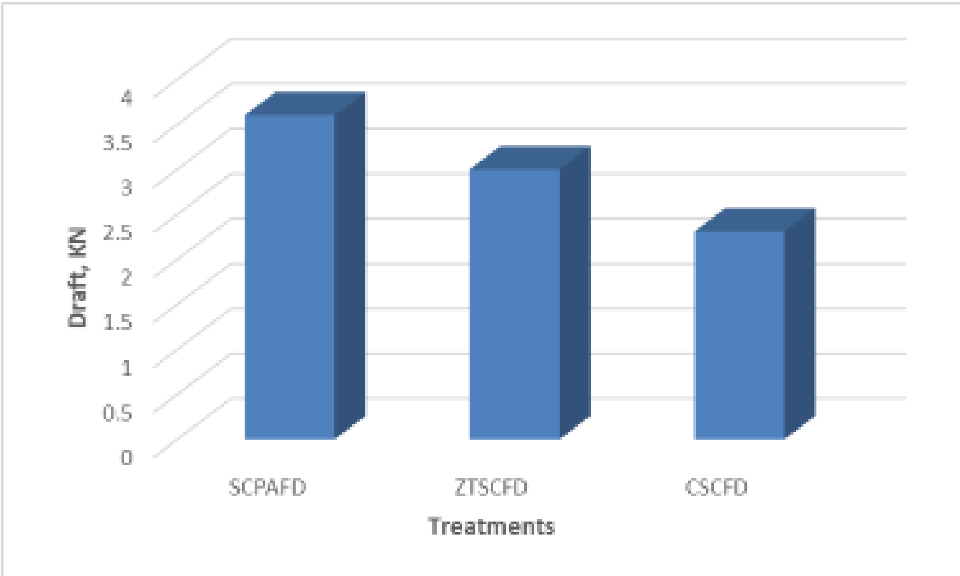


Fig 4.13 Draft requirement of different sowing systems

4.6.4 Bulk density of soil

Bulk density of soil measured before tillage and after sowing. It is evident from the observations that average bulk density of soil was same i.e. 1.51 g/cc in all treatments before any operation was performed.

In case of seed cum pressurized aqua fertilizer drill and conventional seed cum fertilizer drill, average soil bulk density was observed as 1.41 g/cc after sowing i.e. at 0 DAS. In case of zero till seed cum fertilizer drill, soil bulk density was observed 1.48 g/cc. Soil bulk density is less in case of SCPAFD and CSCFD due to the conventional tillage operation i.e. 1 × cultivator + 2 × disc harrow + 1 planker, whereas in case of ZTSCFD, no tillage operations were performed.

4.6.5 Cone Index of soil

The cone index of soil was measured by using cone penetrometer and was determined before and after in different treatments. The initial average cone index of soil before tillage was found 148.18, 218.19, 520.64, 735.67, 867.82 and 1023.26 kPa at depth of 25, 50, 75, 100, 125 and 150 mm respectively. After tillage, average values of cone index were 138.8, 192.9, 468.46, 652.28, 796.76 and 957.47 kPa at depth of 25, 50, 75, 100, 125 and 150 mm respectively. Fig. 4.14 shows the cone index of soil before and after tillage.

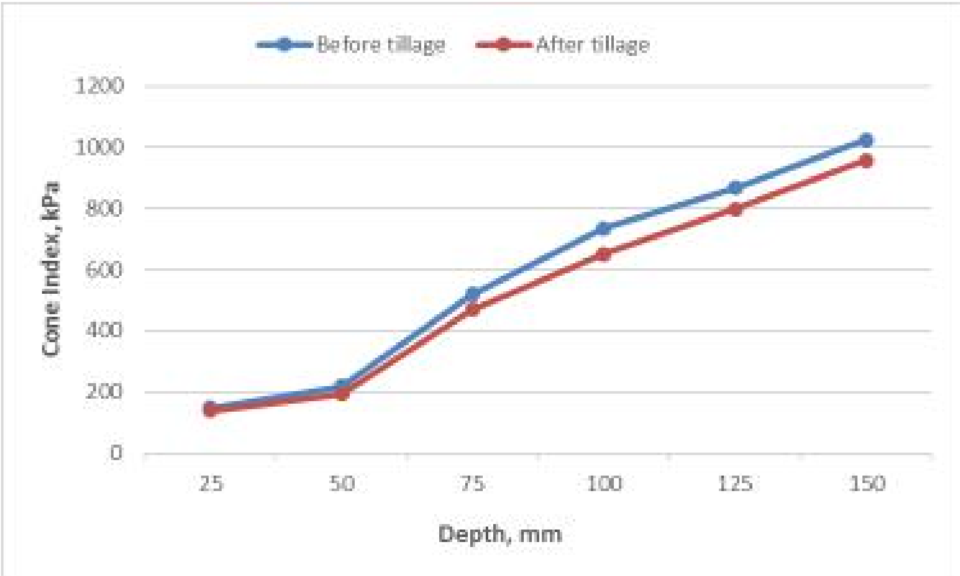


Fig. 4.14 Cone Index of soil

4.6.6 Influence of seed cum pressurized aqua fertilizer drill on soil moisture content for the year (2015-16)

Soil moisture variation with time at two depths i.e. 5 cm and 10 cm is presented in Table 4.9 & 4.10. The percentage increase in soil moisture due to aqua fertilizer application at the rate of 6500, 5500 and 4500 l/ha were 162, 136 and 124% just after sowing. The rate of 6500 l/ha maintained soil moisture levels of 28.7 and 24.6% at 3 DAS and 6 DAS, which was above germination limit as observed in section 4.1.3, Fig. 4.15. The application rate of 5500 l/ha were also able to maintain soil moisture above germination moisture content for three days. It could be concluded that for initial field moisture of above 12%, aqueous fertilizer rate of 6500 l/ha is sufficient to maintain germination moisture during the period of germination. The moisture content of 10 cm depth were in the range of germination moisture, however the application of aqueous fertilizer at the rate of 6500, 5500 and 4500 l/ha could increase soil moisture by 113, 107 and 92.1% after sowing, Fig 4.15. At higher depth moisture loss was expected to be slow. The results showed the expected trend. The moisture loss at 5 cm depth of 6500 l/ha aqueous fertilizer application rate was 12.5% after 3 days and 14.28% after 6 days while at 10 cm depth, the same were 10.1% and 11.37%. Similar trend were observed for other application rates of aqueous fertilizer. This pattern gives choice to farmer to select depth of sowing as per the moisture availability.

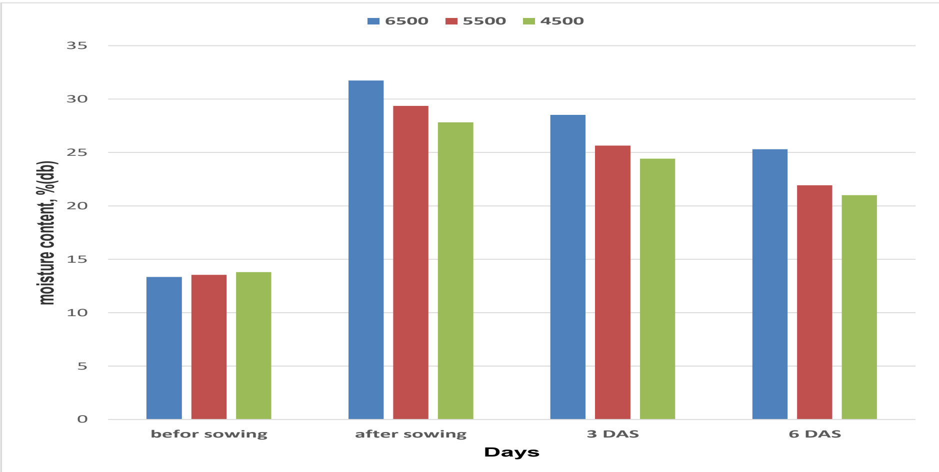


Fig 4.15 Pattern of moisture content after application of aqueous fertilizer at 5 cm depth

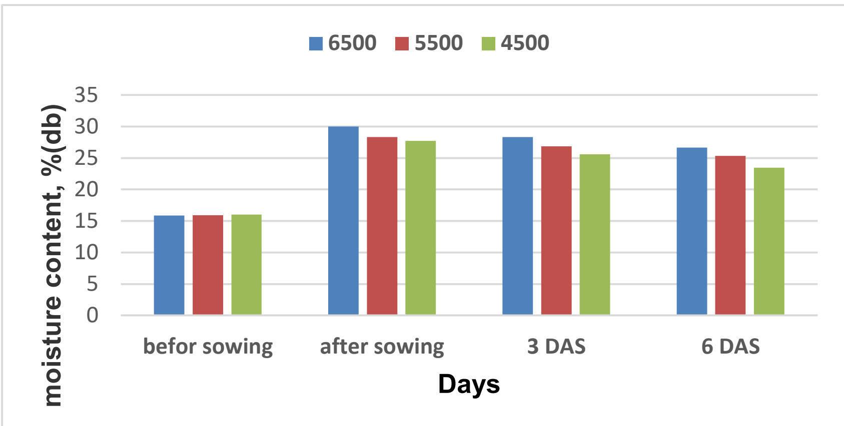


Fig 4.16 Pattern of moisture content after application of aqueous fertilizer at 10 cm depth

Table 4.14 Temporal changes in soil moisture after sowing with application of aqueous fertilizer (5 cm depth)

S. No.	Aqueous fertilizer application rate, l/ha	Soil moisture content (%db) before sowing	Soil moisture content (%db) after sowing	Soil moisture content (%db) at 3 DAS	Soil moisture content (%db) at 6 DAS
1	6500	12.50	32.80	28.70	24.60
2	5500	12.47	29.52	25.88	22.23
3	4500	12.10	27.15	24.28	21.41

Year, 2015

Table 4.15 Temporal changes in soil moisture after sowing with application of aqueous fertilizer (10 cm depth)

S. No.	Aqueous fertilizer application rate, l/ha	Soil moisture content (%db) before sowing	Soil moisture content (%db) after sowing	Soil moisture content (%db) at 3 DAS	Soil moisture content (%db) at 6 DAS
1	6500	14.37	30.64	27.52	24.39
2	5500	14.14	29.39	26.92	24.44
3	4500	14.18	27.25	25.32	23.39

Year, 2015

4.6.7 Influence of seed cum pressurized aqua fertilizer drill on soil moisture content for the year (2016-17)

Soil moisture variation with time at two depths i.e. 5 cm and 10 cm is presented in Table 4.11 & 4.12. The percentage increase in soil moisture due to aqua fertilizer application at the rate of 6500, 5500 and 4500 l/ha were 137, 116 and 101% just after sowing. The rate of 6500 l/ha maintained soil moisture levels of 28.52 and 25.30% at 3 DAS and 6 DAS, which was above germination limit as observed in section 4.1.3, Fig. 417-4.18. The application rate of 5500 l/ha were also able to maintain soil moisture above germination moisture content for three days. It could be concluded that for initial field moisture of above 13.35%, aqueous fertilizer rate of 6500 l/ha is sufficient to maintain germination moisture during the period of germination. The moisture content of 10 cm depth were in the range of germination moisture, however the application of aqueous fertilizer at the rate of 6500, 5500 and 4500 l/ha could increase soil moisture by 88.9, 78.3 and 73.31% after sowing, Fig 4.17-4.18. At higher depth moisture loss was expected to be slow. The results showed the expected trend. The moisture loss at 5 cm depth of 6500 l/ha aqueous fertilizer application rate was 10.14% after 3 days and 1.29% after 6 days while at 10 cm depth, the same were 5.57% and 5.89%. Similar trend were observed for other application rates of aqueous fertilizer. This pattern gives choice to farmer to select depth of sowing as per the moisture availability.

Generally for germination, wheat required 400 to 430 mm of water per growing season, based on conditions of soils. So, we can save large amount of water during germination stage and also due to precision application of aqueous fertilizer, we also reduced the amount of weeds at the time of germination.

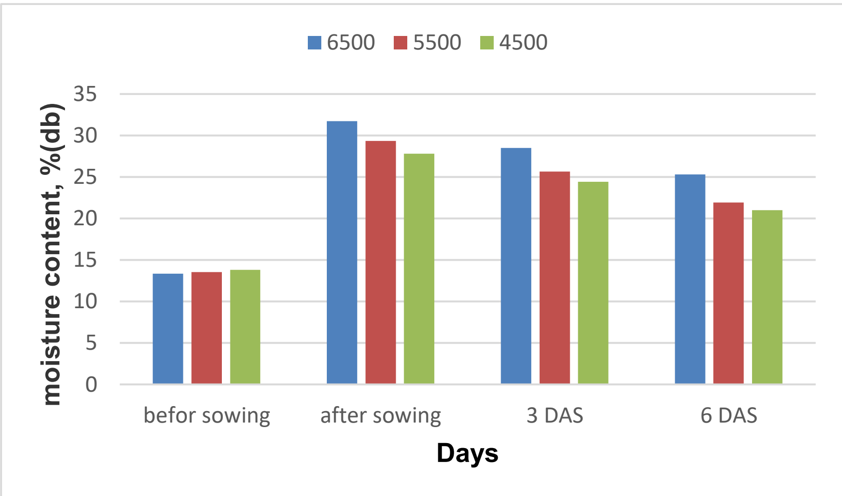


Fig 4.17 Pattern of moisture content after application of aqueous fertilizer at 5 cm depth

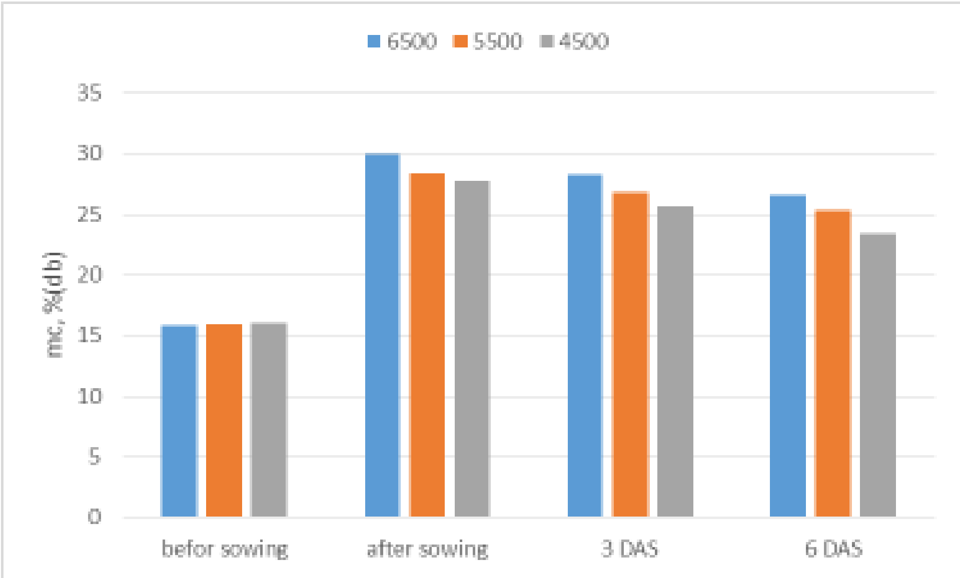


Fig 4.18 Pattern of moisture content after application of aqueous fertilizer at 10 cm depth

Table 4.16 Temporal changes in soil moisture after sowing with application of aqueous fertilizer (05 cm depth)

S. No.	Aqueous fertilizer application rate, l/ha	Soil moisture content (%db) before sowing	Soil moisture content (%db) after sowing	Soil moisture content (%db) at 3 DAS	Soil moisture content (%db) at 6 DAS
1	6500	13.35	31.74	28.52	25.30
2	5500	13.55	29.36	25.65	21.93
3	4500	13.80	27.83	24.42	21.00

Year, 2016

Table 4.17 Temporal changes in soil moisture after sowing with application of aqueous fertilizer (10 cm depth)

S. No.	Aqueous fertilizer application rate, l/ha	Soil moisture content (%db) before sowing	Soil moisture content (%db) after sowing	Soil moisture content (%db) at 3 DAS	Soil moisture content (%db) at 6 DAS
1	6500	15.87	29.98	28.31	26.64
2	5500	15.90	28.35	26.84	25.32
3	4500	16.00	27.73	25.60	23.47

Year, 2016

4.6.8 Crop response to aqueous fertilizer application (2015-16)

4.6.8.1 Germination start

Germination start was observed after sowing in aqueous fertilizer fields and control plots. It was found that the emergence of seed from soil took place at 4 days after sowing in aqueous fertilizer field and 7 days after sowing in other treatments (control field). In control plot germination start was not normal. The early emergence of seed in aqueous fertilizer treatment was due to adequate amount of moisture provided at the time of sowing. It means we can save minimum 3 days for next cultivation season.

4.6.8.2 Germination count per meter row

The data on germination count was taken at 11 days after sowing and 18 days after sowing, Table 4.17. Data shows that in all the aqua fertilizer plots, the germination was better as compared to control plots. This may be due to fact that proper placement of aqueous fertilizer, which increased the soil moisture at sowing depth led to better germination than in the case of without aqueous fertilizer. Amongst different plots with aqueous fertilizer, the initial plant population was almost same. Number of plant per meter row at 11 days after sowing were 74, 71, 66, 44, 42 and 51 in the plots with aqueous fertilizer rate of 6500, 5500, 4500 l/ha, ZTSCFD, CSCFD and SCPAFD (with water only) respectively, Fig 4.19 In general, higher the application rate of aqueous fertilizer, higher was the germination count. Thus, a maximum of 40% and 33% increase in germination count was observed due to application of aqueous fertilizer at the rate of 6500 and 4500 l/ha, respectively. The reference for comparison was control plots i.e. ZTSCFD, CSCFD and SCPAFD (water only) with no aqueous fertilizer application. The difference in germination count for the cases of 6500, 5500 and 4500 l/ha application rate of aqueous fertilizer were statistically significant at 1% level in comparison to germination count in no aqueous fertilizer plots.

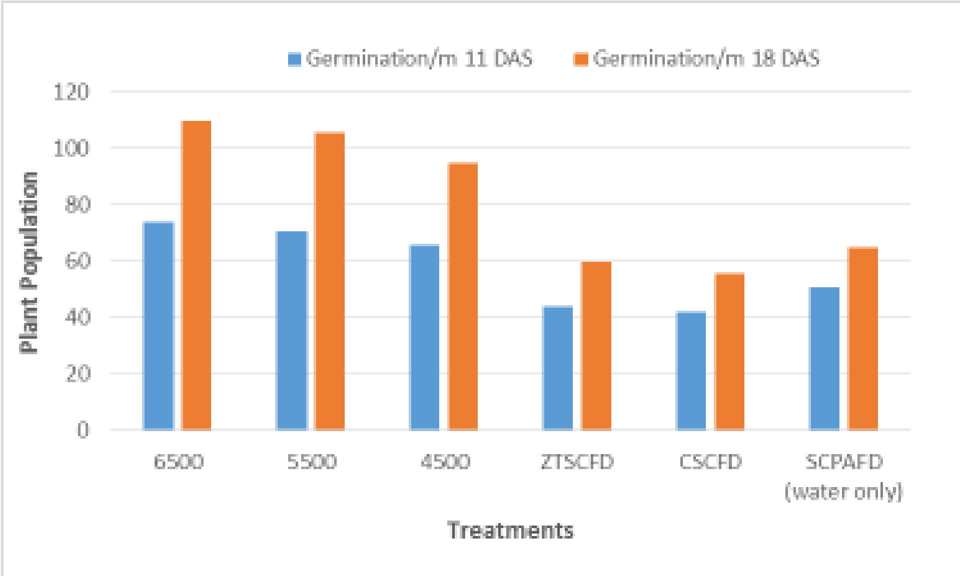


Fig. 4.19 Influence of aquous fertilizer rate on germination count (Year, 2015)

Similar trend was observed in case of germination count after 18 days after sowing. The number of plants per meter row after 18 days of sowing were 110, 106, 95, 60, 56, and 65 for aqueous fertilizer rates of 6500, 5500, 4500 l/ha, ZTSCFD, CSCFD and SCPAFD (with water only) respectively. Thus, aqueous fertilizer influenced germination of plants and generally, with higher dose of aqueous fertilizer application, the plant population at 18 days after sowing recorded appreciable increase. The statistical analysis shows that all the plots with aqueous fertilizer application gave significantly higher plant population than the one without aqueous fertilizer plots, Table 4.13. From above results, it is clear that the aqueous fertilizer did bring significant effect on germination of seed. Thus, if seed could be placed at proper depth where aqueous fertilizer could provide sufficient moisture, the seed will germinate successfully and faster.

Table 4.18 Influence of aqueous fertilizer application on crop germination

S.No.	Treatments	Germination/m length 11 DAS	Germination/m length 18 DAS
1	6500 l/ha	74.00	110.00
2	5500 l/ha	71.00	106.00
3	4500 l/ha	66.00	95.00
4	ZTSCFD	44.00	60.00
5	CSCFD	42.00	56.00
6	SCPAFD (water only)	51.00	65.00

Table 4.19 Anova for germination count 11 DAS

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	129.10	64.55	67.74	**	4.10	7.56
treatment	5	8934.00	1786.80	1875.00	**	3.33	5.64
Error	10	9.53	0.95				
Total	17	9072.63					

Table 4.20 Anova for germination count 18 DAS

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	289.69	144.85	206.42	**	4.10	7.56
treatment	5	6578.50	1315.70	1875.00	**	3.33	5.64
Error	10	7.02	0.70				
Total	17	6875.21					

The ANOVA table 4.18 & 4.19 reveals that the calculated value of F statistic (1786) at the time of 11 DAS and 1315 at 18 DAS is greater than the corresponding F table value $F_{5\,\%}$ = 3.33, Hence, we conclude that treatments are found to be statistically highly significant i.e. all treatments under study are not equally effective, it indicates that all treatment parameters are pair wise statistically significant in the study.

4.6.8.3 Number of plant per meter row

The number of plant was counted at 90 days after sowing. Data showed that the number of plants per meter was 150, 146, 124, 105, 102 and 110 with discharge of rate of 6500, 5500, 4500 l/ha and control treatments i.e. CSCFD, ZTSCFD and SCPAFD (with water only) respectively, Table 4.16. A maximum of 32% and minimum of 17.7% increase in number of plant per meter was observed due to application of aqueous fertilizer at the rate of 6500, 4500 l/ha, respectively. The plant population was 102 per meter in case of ZTSCFD which was appreciably low in comparison to aqueous fertilizer application at 6500 l/ha. The plant population (number of tiller) after 90 DAS for wheat crop in the same soil under normal irrigation condition has been reported as 450/m^2, (Anonymous, 2006). Statistical analysis shows that there were significant differences among the aqueous fertilizer field in comparison to control plots, Table 4.16. This is because all the seeds got germinated and there was good growth of the crop in the plots with aqueous fertilizer by 90 days after sowing. Fig. 4.20

Table 4.21 Anova for number of plant per meter length

Source	DF	SS	MSS	Fcal		F tab5%	F tab1%
Replication	2	289.69	144.85	206.42	**	4.10	7.56
treatment	5	6578.50	1315.70	1875.00	**	3.33	5.64
Error	10	7.02	0.70				
Total	17	6875.21					

SEd= 0.684 SEm= 0.484 CD 5%= 1.524

The ANOVA table 4.20 reveals that the calculated value of F statistic (1875.00) at the time of test is greater than the corresponding F table value $F_{1\%}$ = 5.64, Hence, we conclude that treatments are found to be statistically highly significant i.e. all treatments under study are not equally effective, it indicates that all treatment parameters are pair wise statistically significant. In the study.

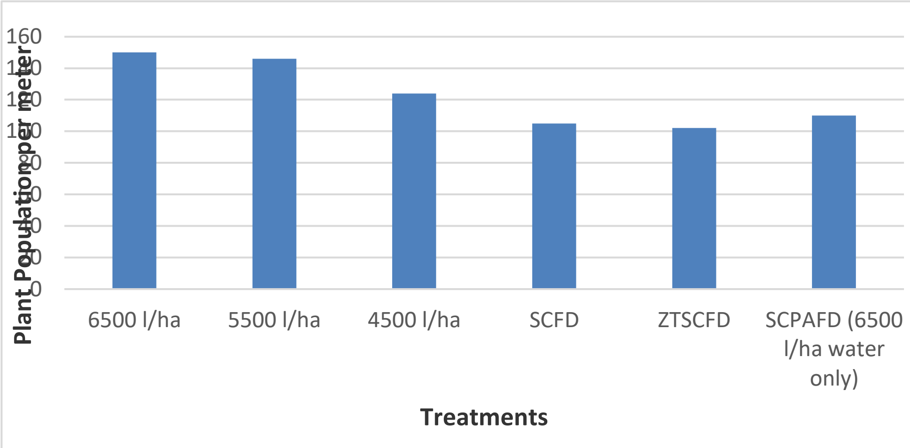


Fig 4.20 Number of plant per meter row of different treatments

4.6.8.4 Number of tiller per plant

The total number of tillers per plant was measured at 90 days after sowing. Data shows that the number of tiller per plant were 4, 4, 3, and 2.5, 2.5, 2.5 in the plots with aqueous fertilizer application 6500, 5500, 4500 l/ha and controlled plots i.e. CSCFD, ZTSCFD, SCPAFD (with water), respectively. Number of tiller per plant also followed similar trend and in general, with increase in aqueous fertilizer application, number of tiller per meter increased. When compared with shoot per plant in control plot, a maximum of 37.5% increase in tiller count was observed due to application of aqueous fertilizer at the rate of 6500 l/ha. Statistical analysis shows that number of tiller per plant was significantly higher in all aqueous fertilizer fields with comparison to controlled plots, Table 4.21. This was due to precise application of aqueous fertilizer & availability at the time of sowing which enhanced sprouting of germinated wheat plant. Same trend was obtained by kamal kant et al. (2008).

Table 4.22 Anova for number of tiller per plant

Source	DF	SS	MSS	Fcal		F tab5%	F tab1%
Replication	2	0.18	0.09	105.31	**	4.10	7.56
treatment	5	8.13	1.63	1875.00	**	3.33	5.64
Error	10	0.01	0.00				
Total	17	8.32					

The ANOVA table 4.21 reveals that the calculated value of F statistic (1875.00) at the time of test is greater than the corresponding F table value $F_{5\%}$ = 3.33, Hence, we conclude that treatments are found to be statistically highly significant i.e. all treatments under study are not equally effective, it indicates that all treatment parameters are pair wise statistically significant. In the study.

4.6.8.5 Number of ear head per meter row

Number of ear head per meter row length was more in 110 in plot with aqueous fertilizer application rate of 6500 l/ha followed by 107 in case of plot with 5500 l/ha, 102 for 4500 l/ha. In controlled plots the number of ear head per meter row was 84 for CSCFD, 80 for ZTSCFD and 82 for SCPAFD (with water only). Number of ear head per plant also followed similar trend and in general, with increase in aqueous fertilizer application, number of ear head per plant increased. When compared with ear head per plant in control plot, a maximum of 27.27% and minimum of 21.5% increase in ear head per plant was observed due to application of aqueous fertilizer at the rate of 6500 l/ha. and 4500 l/ha, respectively. Statistical analysis shows that number of ear head per plant was significantly higher in all aqueous fertilizer fields with comparison to controlled plots, Table 4.22. This was again due to aqueous fertilizer which enhanced the early germination of seed after sowing. This increase ultimately led to higher crop yield. Same trend found by Dey AK. (2004).

Table 4.23 Anova for number of ear head per meter

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	170.25	85.13	286.40	**	4.10	7.56
treatment	5	2786.50	557.30	1875.00	**	3.33	5.64
Error	10	2.97	0.30				
Total	17	2959.73					

4.6.8.6 Plant height

Plant height was recorded after 30, 60 and 90 days of sowing. The analysis of data revealed that the height of plant were significantly varied in various treatments up to 90 DAS but after these period no significant variation was observed in plant height in various treatments. It is evident from the fig. 4.21 that height of plants for plots of aqueous fertilizer dose for 30, 60 and 90 DAS was 35, 54.6 and 92 cm with application rate of 6500 l/ha respectively. The minimum plant height of 20, 46.3 and 74 cm for 30, 60 and 90 DAS for controlled plot (ZTSCFD). Like other plant growth parameters, in general, plant height increased with increase in aqueous fertilizer application. A maximum of 19.5% and minimum of 14.2% increase in plant height was observed due to application of aqueous fertilizer at the rate of 6500 and 4500 l/ha, respectively, Table 4.23. Same trend was found by Devram LS. (2008).

Table 4.24 Mean height of plant of wheat crop

Treatment	Plant height (cm)		
	30 DAS	60 DAS	90 DAS
6500 l/ha	35.00	54.60	92.00
5500 l/ha	34.30	53.30	90.00
4500 l/ha	33.70	51.20	86.00
CSCFD	24.00	48.60	76.00
ZTSCFD	20.00	46.30	74.00
SCPAFD (water only)	26.00	45.00	74.70

The comparison were made with plant height in control plot. Analysis of various shows that the height of plant in all aqueous fertilizer fields in significantly more than that of non-aqueous fertilizer field, Table 4.20. The treatment of 6500 l/ha discharge gave maximum height due to adequate amount of aqueous fertilizer was given at the time of sowing which enhanced the growth of crop.

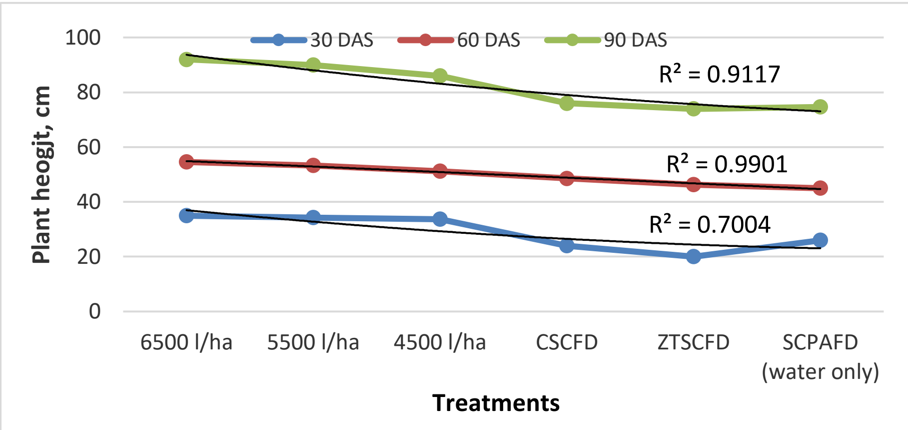


Fig 4.21 Plant height under different treatments

Table 4.25 Anova for plant height 30 DAS

Source	DF	SS	MSS	Fcal		F tab5%	F tab1%
Replication	2	15.96	7.98	124.08	**	4.10	7.56
treatment	5	603.04	120.61	1875.00	**	3.33	5.64
Error	10	0.64	0.06				
Total	17	619.65					

Table 4.26 Anova for plant height 60 DAS

Source	DF	SS	MSS	Fcal		F tab5%	F tab1%
Replication	2	47.68	23.84	1007.13	**	4.10	7.56
treatment	5	221.92	44.38	1875.00	**	3.33	5.64
Error	10	0.24	0.02				
Total	17	269.84					

Table 4.27 Anova for plant height 90 DAS

Source	DF	SS	MSS	Fcal		F tab5%	F tab1%
Replication	2	129.47	64.73	607.11	**	4.10	7.56
treatment	5	999.63	199.93	1875.00	**	3.33	5.64
Error	10	1.07	0.11				
Total	17	1130.16					

The ANOVA table 4.24-4.26 reveals that the calculated value of F statistic 1875 at the 30, 60 and 90 DAS is greater than the corresponding F table value $F_{5\,\%}$ = 3.33, Hence, we conclude that treatments are found to be statistically highly significant i.e. all treatments under study are not equally effective, it indicates that all treatment parameters are pair wise statistically significant. In the study.

4.6.8.7 Root length

Root length at 30, 60 and 90 DAS for various treatment is shown in Table 4.24. Root length at 30 days for different aqueous fertilizer rates was found to be significant. Root length for 30 DAS was 90.6, 87 and 80.2 mm for aqueous fertilizer rate 6500, 5500 and 4500 l/ha respectively. Whereas non aqueous fertilizer treatments had root length after 30 days was found to be 76.14, 70.91 and 75.20 for CSCFD, ZTSCFD and SCPAFD (water only) respectively. Root length was observed maximum 21.7% and minimum 11.5% with aqueous fertilizer rate 6500 and 4500 l/ha compared with least root length of non-aqueous fertilizer treatment i.e. ZTSCFD. Fig.4.22

Table 4.28 Anova for root length after 30 days

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	122.91	61.45	681.07	**	4.10	7.56
treatment	5	845.90	169.18	1875.00	**	3.33	5.64
Error	10	0.90	0.09				
Total	17	969.71					

Table 4.29 Root length (mm) for different treatments

Treatment	Root length (mm)		
	30 DAS	60 DAS	90 DAS
6500 l/ha	90.60	120.80	256.40
5500 l/ha	87.00	114.40	248.20
4500 l/ha	80.20	110.20	234.70
CSCFD	76.14	101.70	209.10
ZTSCFD	70.91	95.66	188.20
SCPAFD (6500 l/ha water only)	75.20	102.40	211.50

Root length for 60 DAS was 120.8, 114.4 and 110.2 mm for aqueous fertilizer rate 6500, 5500 and 4500 l/ha respectively. Whereas non aqueous fertilizer treatments had root length after 60 days was found to be 101.7, 95.66 and 102.4 mm for CSCFD, ZTSCFD and SCPAFD (water only) respectively. Root length was observed maximum 20.8% and minimum 13.19% with aqueous fertilizer rate 6500 and 4500 l/ha compared with least root length of non-aqueous fertilizer treatment i.e. ZTSCFD.

Table 4.30 Anova for root length after 60 days

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	221.99	111.00	803.62	**	4.10	7.56
treatment	5	1294.86	258.97	1875.00	**	3.33	5.64
Error	10	1.38	0.14				
Total	17	1518.24					

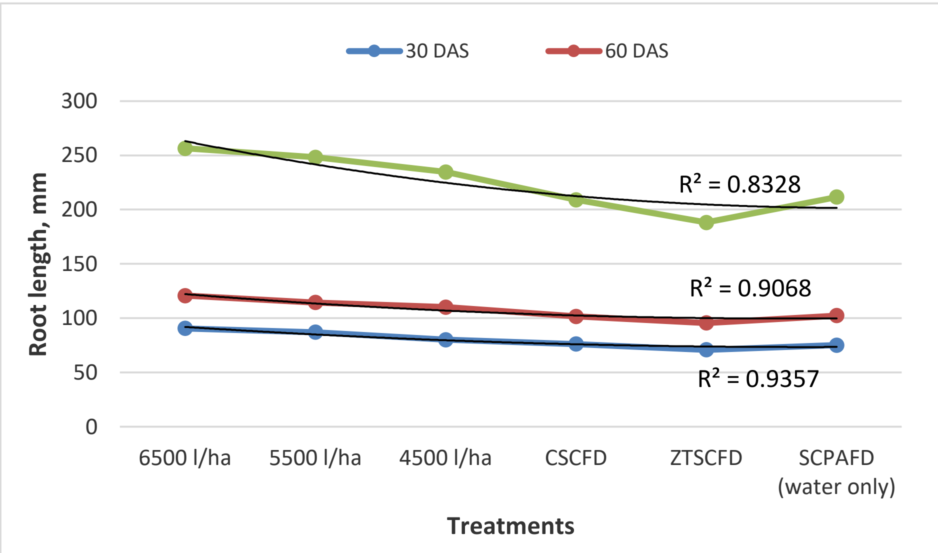


Fig. 4.22 Root length for different treatments after 30, 60 and 90 DAS

Root length for 90 DAS was 256.4, 248.2 and 234.7 mm for aqueous fertilizer rate 6500, 5500 and 4500 l/ha respectively. Whereas non aqueous fertilizer treatments had root length after 90 days was found to be 209.1, 188.2 and 211.5 mm for CSCFD, ZTSCFD and SCPAFD (water only) respectively. Root length was observed maximum 26.59% and minimum 19.81% with aqueous fertilizer rate 6500 and 4500 l/ha compared with least root length of non-aqueous fertilizer treatment i.e. ZTSCFD.

Table 4.31 Anova for root length after 90 days

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	969.27	484.63	444.52	**	4.10	7.56
treatment	5	10220.97	2044.19	1875.00	**	3.33	5.64
Error	10	10.90	1.09				
Total	17	11201.13					

4.6.8.8 Dry root weight

Dry rot weight per plant at 40 and 90 DAS for various treatment is presented in Table 4.27. At these DAS, effect of different aqueous fertilizer treatments on dry root weight was significant at 1% level of significant. Maximum and minimum dry root weight was found 0.79 and 0.68 g for aqueous fertilizer rate 6500 l/ha and 4500 l/ha for 30 DAS. Whereas for non-aqueous fertilizer treatments dry root weight was found to be 0.63, 0.55 and 0.65 g for CSCFD, ZTSCFD and SCPAFD (water only) respectively after 30 days sowing. Fig.4.23

Table 4.32 Dry root weight of wheat for different treatments

Treatment	Dry Root Weight (g)	
	30 DAS	90 DAS
6500 l/ha	0.79	5.89
5500 l/ha	0.73	5.48
4500 l/ha	0.68	5.00
CSCFD	0.63	4.43
ZTSCFD	0.55	3.68
SCPAFD (water only)	0.65	3.99

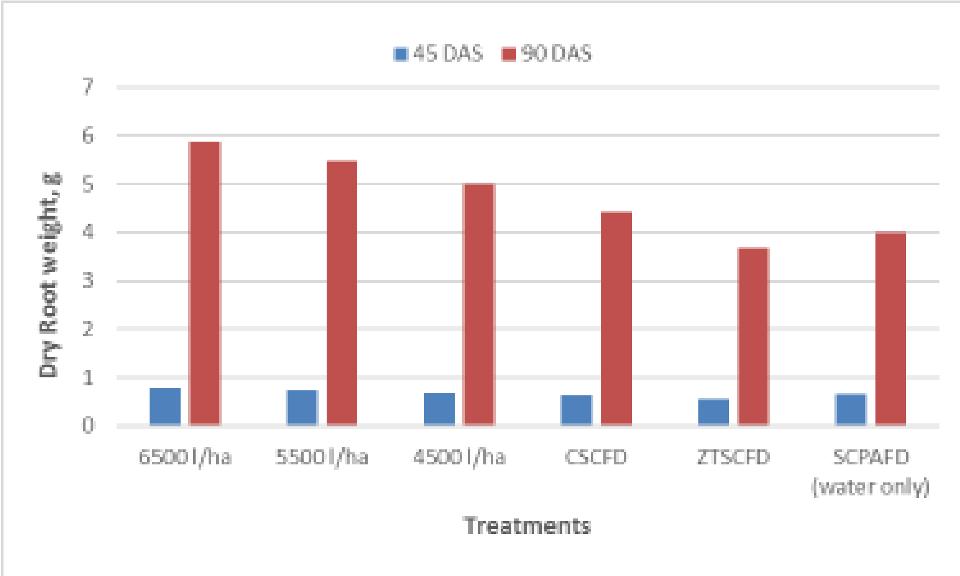


Fig. 4.23 Dry root weight for different treatments

Dry root weight after 90 of sowing was found 5.89, 5.48 and 5.0 g for aqueous fertilizer rate 6500, 5500 and 4500 l/ha. Whereas for non-aqueous fertilizer treatments dry root weight was found to be 4.43, 3.68 and 3.99 g for CSCFD, ZTSCFD and SCPAFD (water only) respectively. Dry root weight for aqueous fertilizer was maximum 37.5% and minimum 26.4% higher than non-aqueous fertilizer treatments.

Table 4.33 Anova of Dry root weight 45 DAS

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	0.01	0.00	392.48	**	4.10	7.56
treatment	5	0.10	0.02	1875.00	**	3.33	5.64
Error	10	0.00	0.00				
Total	17	0.11					

Table 4.34 Anova of Dry root weight 45 DAS

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	0.43	0.22	181.58	**	4.10	7.56
treatment	5	11.16	2.23	1875.00	**	3.33	5.64
Error	10	0.01	0.00				
Total	17	11.60					

4.6.8.9 Length of ear head

Length of ear head was measured after 60 and 90 days after sowing. Data showed that the length of ear head was almost same 6.6 mm and 14 mm for 60 and 90 DAS respectively, for all the three aqueous fertilize treatments and slightly higher than the plots without aqueous fertilizer fields i.e. 5.2, 5 and 5.4 mm (60 DAS) and 11.4, 10.6 and 10.4 mm (90 DAS) for CSCFD, ZTSCFD and SCPAFD (with water only) respectively, in later stage of plant growth, effect of aqueous fertilizer application got stabilized, Table 4.30. Such aberration in the observations are possible as in January to March. It is noteworthy that main intention behind aqueous fertilizer application is to help the crop for its germination and initial growth, Fig. 4.24. Statistically, there were significant differences amongst the treatments. Plate 4.3

Plate 4.3 Length of ear head of different treatments

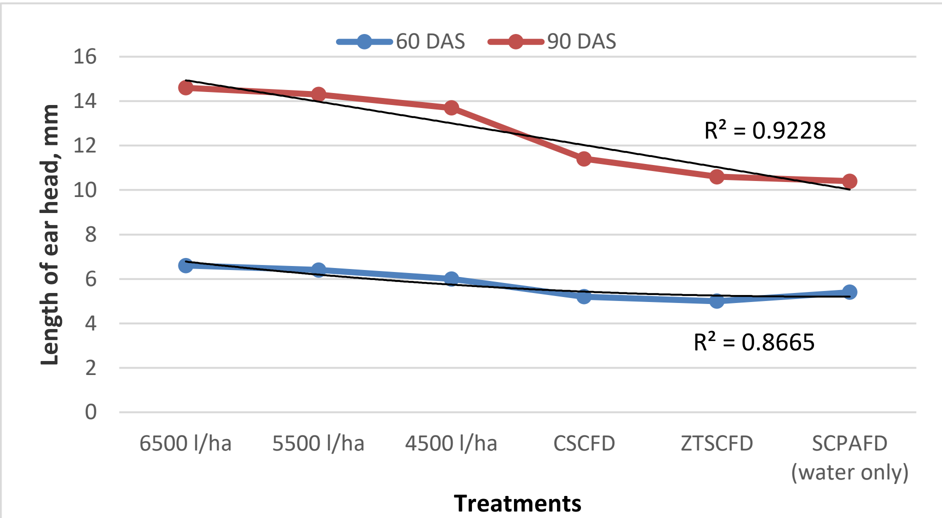


Fig. 4.24 Length of ear heads of different treatments

Table 4.35 Anova for length of ear head 60 DAS

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	0.64	0.32	454.85	**	4.10	7.56
treatment	5	6.58	1.32	1875.00	**	3.33	5.64
Error	10	0.01	0.00				
Total	17	7.23					

Table 4.36 Anova for length of ear head 90 DAS

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	3.00	1.50	255.87	**	4.10	7.56
treatment	5	54.96	10.99	1875.00	**	3.33	5.64
Error	10	0.06	0.01				
Total	17	58.02					

4.6.8.10 Grain yield

The grain yield data was recorded after harvesting the crop by taking samples from per meter square area. The grain yield was maximum 5230 kg/ha with 6500 l/ha followed by 5180 and 5010 kg/ha with 5500 l/ha and 4500 l/ha. with non-aqueous fertilizer treatments the yield was 4200, 4070 and 3907 kg/ha for CSCFD, ZTSCFD and SCPAFD (with water only) respectively, table 4.32 . Thus, a maximum of 25.29% and minimum of 22% increase in grain yield was observed due to application of aqueous fertilizer at the rate of 6500 and 4500 l/ha, respectively, Fig 4.25. The yield of same wheat crop in irrigated fields in experimental area at JNKVV has been reported 4200 kg/ha. (Chouhan, 2015), which is comparable to the yield from plots with aqueous fertilizer application of 6500 l/ha. As discussed earlier, the influence of differential application rates of aqueous fertilizer was expected to be reduced with growth stages. Field and environmental conditions helped in this regard. Analysis of variance shows that there was significant effect of treatments amongst aqueous fertilizer plot w.r.t. grain yield and significantly higher when compared with control plots table 4.37. Better yield with 6500 l/ha was due to higher application rate of aqueous fertilizer, better germination, more number of ear head, better plant height and spike development in comparison to other treatments.

Table 4.37 Influence of aqueous fertilizer application on crop yield

S.No.	Treatments	Grain yield, kg/ha	Straw grain ratio	1000 grain weight
1.	6500 l/ha	5230.00	1.58	47.00
2.	5500 l/ha	5180.00	1.50	43.60
3.	4500 l/ha	5010.00	1.49	41.80
4.	CSCFD	4200.00	1.35	36.00
5.	ZTSCFD	4070.00	1.32	33.70
6.	SCPAFD (6500 l/ha water only)	3907.00	1.29	30.90

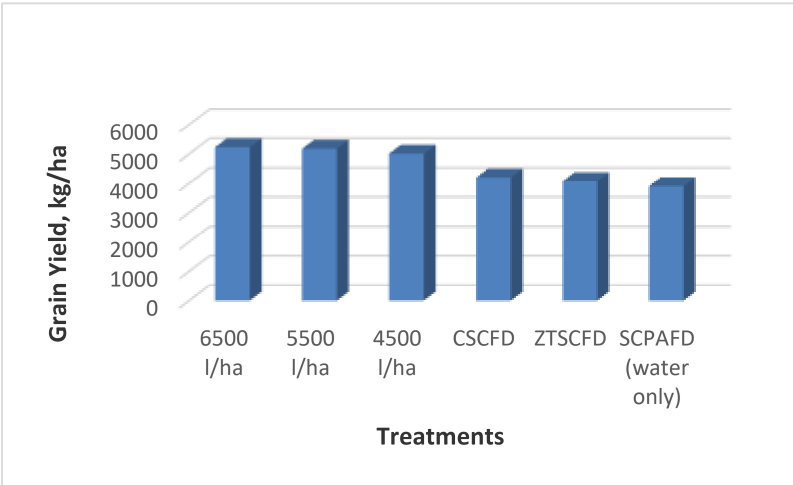


Fig. 4.25 Grain yield of different treatments

Table 4.38 Anova for grain yield

Source	DF	SS	MSS	Fcal		F tab5%	F tab1%
Replication	2	406183.68	203091.84	348.23	**	4.10	7.56
treatment	5	5467642.50	5467642.50	1875.00	**	3.33	5.64
Error	10	5832.15	583.22				
Total	17	5879658.34					

4.6.8.11 Straw grain ratio

Straw grain ration was recorded after harvesting the crop by taking samples from per meter square area. Data showed that the straw grain ratio recorded similar trend as grain yield due to supplication of aqueous fertilizer at different rates. The maximum straw yield was found in aqueous fertilizer rate of 6500 l/ha (1.58) followed by 5500 l/ha (1.50) and without aqueous fertilizer straw grain ratio was 1.35, 1.32 and 1.29 for CSCFD, ZTSCFD and SCPAFD (with water only) respectively, Table 4.34 Thus, a maximum of 15.1% and minimum 12.8% increase in straw grain ratio was observed due to application aqueous fertilizer at the rate of 6500 and 4500 l/ha. All the comparisons were with non-aqueous fertilizer treatments. Analysis of variance shows that the straw grain ratio of all aqueous fertilizer fields is significantly higher than that from non-aqueous fertilizer plots, Table 4.38 Reason for above trend were better plant height and plant stand in respective treatments as compared to control one.

Table 4.39 Anova for straw grain ratio

Source	DF	SS	MSS	Fcal		F tab5%	F tab1%
Replication	2	0.04	0.02	882.81	**	4.10	7.56
treatment	5	0.21	0.04	1875.00	**	3.33	5.64
Error	10	0.00	0.00				
Total	17	0.25					

4.6.9 Crop response to aqueous fertilizer application (2016-17)

4. 6.9.1 Germination start

Germination start was observed after sowing in aqueous fertilizer fields and control plots. It was found that the emergence of seed from soil took place at 4 days after sowing in aqueous fertilizer field and 7 days after sowing in other treatments (control field). In control plot germination start was not normal. The early emergence of seed in aqueous fertilizer treatment was due to adequate amount of moisture provided at the time of sowing.

4.6.9.2 Germination count per meter row

The data on germination count was taken at 11 days after sowing and 18 days after sowing, Table 4.39. Data shows that in all the aqua fertilizer plots, the germination was better as compared to control plots. This may be due to fact that proper placement of aqueous fertilizer, which increased the soil moisture at sowing depth led to better germination than in the case of without aqueous fertilizer. Amongst different plots with aqueous fertilizer, the initial plant population was almost same. Number of plant per meter row at 11 days after sowing were 71, 68, 64, 41, 39 and 47 in the plots with aqueous fertilizer rate of 6500, 5500, 4500 l/ha, ZTSCFD, CSCFD and SCPAFD (with water only) respectively, Fig 4.26. In general, higher the application rate of aqueous fertilizer, higher was the germination count. Thus, a maximum of 45% and 39% increase in germination count was observed due to application of aqueous fertilizer at the rate of 6500 and 4500 l/ha, respectively. The reference for comparison was control plots i.e. ZTSCFD, CSCFD and SCPAFD (water only) with no aqueous fertilizer application. The difference in germination count for the cases of 6500, 5500 and 4500 l/ha application rate of aqueous fertilizer were statistically significant in comparison to germination count in no aqueous fertilizer plots.

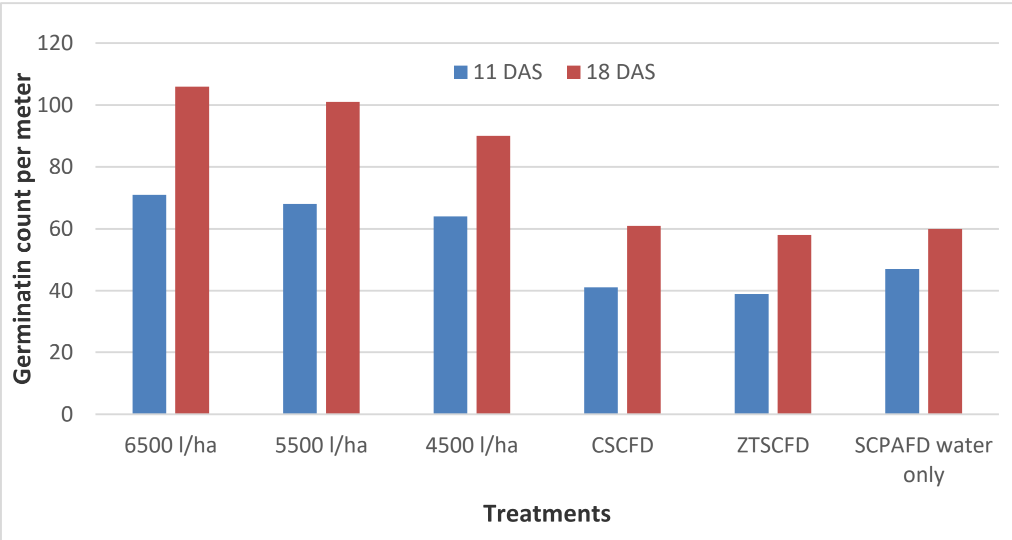


Fig. 4.26 Influence of aquous fertilizer rate on germination count (Year, 2016)

Similar trend was observed in case of germination count after 18 days after sowing. The number of plants per meter row after 18 days of sowing were 106, 101, 90, 58, 61 and 60 for aqueous fertilizer rates of 6500, 5500, 4500 l/ha, ZTSCFD, CSCFD and SCPAFD (with water only) respectively. Thus, aqueous fertilizer influenced germination of plants and generally, with higher dose of aqueous fertilizer application, the plant population at 18 days after sowing recorded appreciable increase. The statistical analysis shows that all the plots with aqueous fertilizer application gave significantly higher plant population than the one without aqueous fertilizer plots, Table 4.35. From above results, it is clear that the aqueous fertilizer did bring significant effect on germination of seed. Thus, if seed could be placed at proper depth where aqueous fertilizer could provide sufficient moisture, the seed will germinate successfully and faster.

Table 4.40 Influence of aqueous fertilizer application on crop germination

S.No.	Treatments	Germination/m length 11 DAS	Germination/m length 18 DAS
1	6500 l/ha	71.00	106.00
2	5500 l/ha	68.00	101.00
3	4500 l/ha	64.00	90.00
4	ZTSCFD	41.00	61.00
5	CSCFD	39.00	58.00
6	SCPAFD (water only)	47.00	60.00

Table 4.41 Anova for germination count 11 DAS

Source	DF	SS	MSS	Fcal		F tab5%	F tab1%
Replication	2	58.08	29.04	88.80	**	4.10	7.56
treatment	5	3066.00	613.20	1875.00	**	3.33	5.64
Error	10	3.27	0.33				
Total	17	3127.35					

Table 4.42 Anova for germination count 18 DAS

Source	DF	SS	MSS	Fcal		F tab5%	F tab1%
Replication	2	120.84	60.42	76.77	**	4.10	7.56
treatment	5	7378.00	1475.60	1875.00	**	3.33	5.64
Error	10	7.87	0.79				
Total	17	7506.71					

Plate 4.4(a) Crop view after 30 days for treatment 6500 l/ha

Plate 4.4(b) Crop view after 30 days for treatment 5500 l/ha

Plate 4.4(c) Crop view after 30 days for treatment 4500 l/ha

Plate 4.4(d) Crop view after 30 days for treatment ZTSCFD

Plate 4.4(e) Crop view after 30 days for treatment CSCFD

Plate 4.4(f) Crop view after 30 days for treatment SCPAFD (6500 l/ha water only)

Plate 4.5(a) Crop view after 90 days for treatment 6500 l/ha

Plate 4.5(b) Crop view after 90 days for treatment 5500 l/ha

Plate 4.5(c) Crop view after 90 days for treatment 4500 l/ha

Plate 4.5(e) Crop view after 90 days for treatment CSCFD

Plate 4.5(d) Crop view after 90 days for treatment ZTSCFD

Plate 4.5(f) Crop view after 90 days for treatment SCPAFD (6500 l/ha water only)

4.6.9.3 Number of plant per meter row

The number of plant was counted at 90 days after sowing. Data showed that the number of plants per meter was 145, 142, 122, 101, 103 and 100 with discharge of rate of 6500, 5500, 4500 l/ha and control treatments i.e. CSCFD, ZTSCFD and SCPAFD (with water only) respectively. A maximum of 31% and minimum of 18.03% increase in number of plant per meter was observed due to application of aqueous fertilizer at the rate of 6500, 4500 l/ha, respectively. The plant population was 101 per meter in case of CSCFD which was appreciably low in comparison to aqueous fertilizer application at 6500 l/ha. The plant population (number of tiller) after 90 DAS for wheat crop in the same soil under normal irrigation condition has been reported as 450/m^2, (Anonymous, 2006). Statistical analysis shows that there were significant differences among the aqueous fertilizer field in comparison to control plots, Table 4.38. This is because all the seeds got germinated and there was good growth of the crop in the plots with aqueous fertilizer by 90 days after sowing. Fig. 4.27

Table 4.43 Anova for number of plant per meter length

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	271.13	135.57	196.60	**	4.10	7.56
treatment	5	6464.50	1292.90	1875.00	**	3.33	5.64
Error	10	6.90	0.69				
Total	17	6742.53					

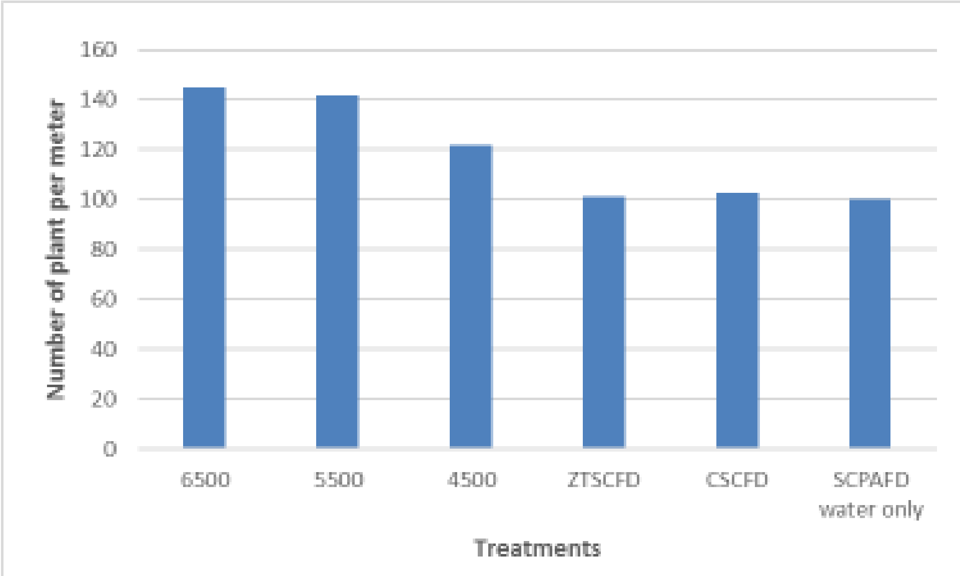


Fig 4.27 Number of plant per meter row of different treatments

4.6.9.4 Number of tiller per plant

The total number of tillers per plant was measured at 90days after sowing. Data shows that the number of tiller per plant were 4, 4, 3, and 2.5, 2.5, 2.5 in the plots with aqueous fertilizer application 6500, 5500, 4500 l/ha and controlled plots i.e. CSCFD, ZTSCFD, SCPAFD (with water), respectively, Table 4.39. Number of tiller per plant also followed similar trend and in general, with increase in aqueous fertilizer application, number of tiller per meter increased. When compared with shoot per plant in control plot, a maximum of 37.5% increase in tiller count was observed due to application of aqueous fertilizer at the rate of 6500 l/ha. Statistical analysis shows that number of tiller per plant was significantly higher in all aqueous fertilizer fields with comparison to controlled plots, Table 4.39. This was due to aqueous fertilizer availability at the time of sowing which enhanced sprouting of germinated wheat plant.

Table 4.44 Anova for number of tiller per plant

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	0.18	0.09	105.31	**	4.10	7.56
treatment	5	8.13	1.63	1875.00	**	3.33	5.64
Error	10	0.01	0.00				
Total	17	8.32					

4.6.9.5 Number of ear head per meter row

Number of ear head per meter row length was more in 107 in plot with aqueous fertilizer application rate of 6500 l/ha followed by 104 in case of plot with 5500 l/ha, 99 for 4500 l/ha. In controlled plots the number of ear head per meter row was 85 for CSCFD, 83 for ZTSCFD and 88 for SCPAFD (with water only). Number of ear head per plant also followed similar trend and in general, with increase in aqueous fertilizer application, number of ear head per plant increased. When compared with ear head per plant in control plot, a maximum of 22.42% and minimum of 16.16% increase in ear head per plant was observed due to application of aqueous fertilizer at the rate of 6500 l/ha. and 4500 l/ha, respectively. Statistical analysis shows that number of ear head per plant was significantly higher in all aqueous fertilizer fields with comparison to controlled plots, Table 4.0. This was again due to aqueous fertilizer which enhanced the early germination of seed after sowing. This increase ultimately led to higher crop yield.

Table 4.45 Anova for number of ear head per meter

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	170.86	85.43	502.44	**	4.10	7.56
treatment	5	1594.00	318.80	1875.00	**	3.33	5.64
Error	10	1.70	0.17				
Total	17	1766.56					

4.6.9.6 Plant height

Plant height was recorded after 30, 60 and 90 days of sowing. The analysis of data revealed that the height of plant were significantly varied in various treatments up to 90 DAS but after these period no significant variation was observed in plant height in various treatments. Height of plants for plots of aqueous fertilizer dose for 30, 60 and 90 DAS was 32, 53.7 and 91 cm with application rate of 6500 l/ha respectively. The minimum plant height of 21, 42 and 70 cm for 30, 60 and 90 DAS for controlled plots. Like other plant growth parameters, in general, plant height increased with increase in aqueous fertilizer application. A maximum of 23% and minimum of 19.5% increase in plant height was observed due to application of aqueous fertilizer at the rate of 6500 and 4500 l/ha, respectively, Table 4.41 & Fig.4.28.

Table 4.46 Mean height of plant of wheat crop

Treatment	Plant height (cm)		
	30 DAS	60 DAS	90 DAS
6500 l/ha	32.00	53.70	91.00
5500 l/ha	33.00	54.30	88.00
4500 l/ha	30.00	50.00	87.00
CSCFD	25.00	44.00	72.00
ZTSCFD	22.00	46.00	70.00
SCPAFD (water only)	21.00	42.00	71.00

The comparison were made with plant height in control plot. Analysis of various shows that the height of plant in all aqueous fertilizer fields in significantly more than that of non-aqueous fertilizer field, Table 4.42. The treatment of 6500 l/ha discharge gave maximum height due to adequate amount of aqueous fertilizer was given at the time of sowing which enhanced the growth of crop.

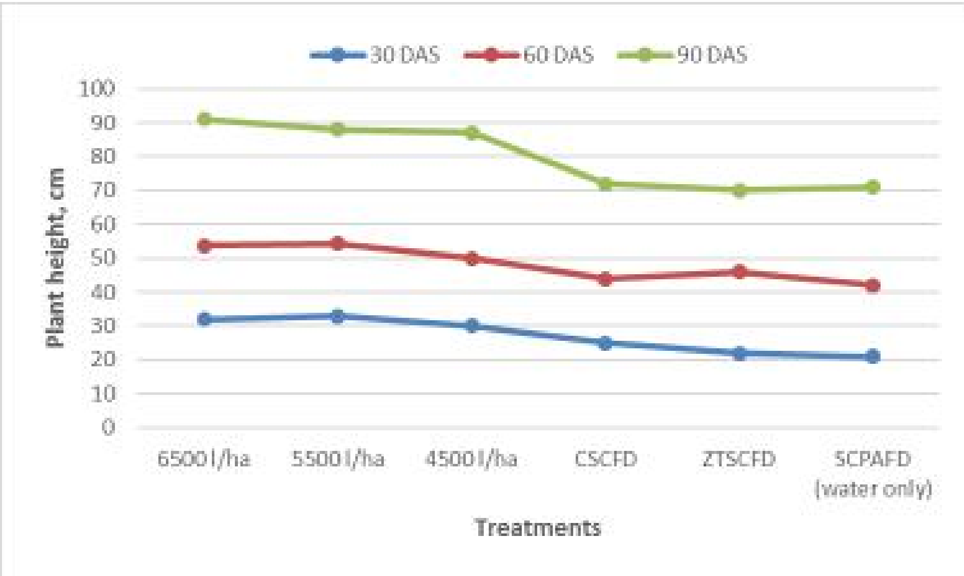


Fig 4.28 Plant height under different treatments

Table 4.47 Anova for plant height 30 DAS

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	14.17	7.09	164.21	**	4.10	7.56
treatment	5	404.50	80.90	1875.00	**	3.33	5.64
Error	10	0.43	0.04				
Total	17	419.10					

Table 4.48 Anova for plant height 60 DAS

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	44.85	22.43	532.90	**	4.10	7.56
treatment	5	394.54	78.91	1875.00	**	3.33	5.64
Error	10	0.42	0.04				
Total	17	439.81					

Table 4.49 Anova for plant height 90 DAS

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	122.37	61.18	399.31	**	4.10	7.56
treatment	5	1436.50	287.30	1875.00	**	3.33	5.64
Error	10	1.53	0.15				
Total	17	1560.40					

4.6.9.7 Root length

Root length at 30, 60 and 90 DAS for various treatment is shown in Table 4.46. Root length at 30 days for different aqueous fertilizer rates was found to be significant. Root length for 30 DAS was 91.6, 88 and 81.2 mm for aqueous fertilizer rate 6500, 5500 and 4500 l/ha respectively. Whereas non-aqueous fertilizer treatments had root length after 30 days was found to be 77.14, 71.91 and 76.20 for CSCFD, ZTSCFD and SCPAFD (water only) respectively. Root length was observed maximum 21.7% and minimum 11.5% with aqueous fertilizer rate 6500 and 4500 l/ha compared with least root length of non-aqueous fertilizer treatment i.e. ZTSCFD, Fig.4.29.

Table 4.50 Anova for root length after 30 days

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	126.00	63.00	698.20	**	4.10	7.56
treatment	5	845.90	169.18	1875.00	**	3.33	5.64
Error	10	0.90	0.09				
Total	17	972.80					

Table 4.51 Root length (mm) for different treatments

Treatment	Root length (mm)		
	30 DAS	60 DAS	90 DAS
6500 l/ha	91.60	121.80	257.40
5500 l/ha	88.00	115.40	249.20
4500 l/ha	81.20	111.20	235.70
CSCFD	77.14	102.70	210.10
ZTSCFD	71.91	96.66	189.20
SCPAFD (water only)	76.20	103.40	212.50

Root length for 60 DAS was 121.8, 115.4 and 111.2 mm for aqueous fertilizer rate 6500, 5500 and 4500 l/ha respectively. Whereas non aqueous fertilizer treatments had root length after 60 days was found to be 102.7, 96.66 and 103.4 mm for CSCFD, ZTSCFD and SCPAFD (water only) respectively. Root length was observed maximum 20.8% and minimum 13.19% with aqueous fertilizer rate 6500 and 4500 l/ha compared with least root length of non-aqueous fertilizer treatment i.e. ZTSCFD.

Table 4.52 Anova for root length after 60 days

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	226.14	113.07	818.64	**	4.10	7.56
treatment	5	1294.86	258.97	1875.00	**	3.33	5.64
Error	10	1.38	0.14				
Total	17	1522.38					

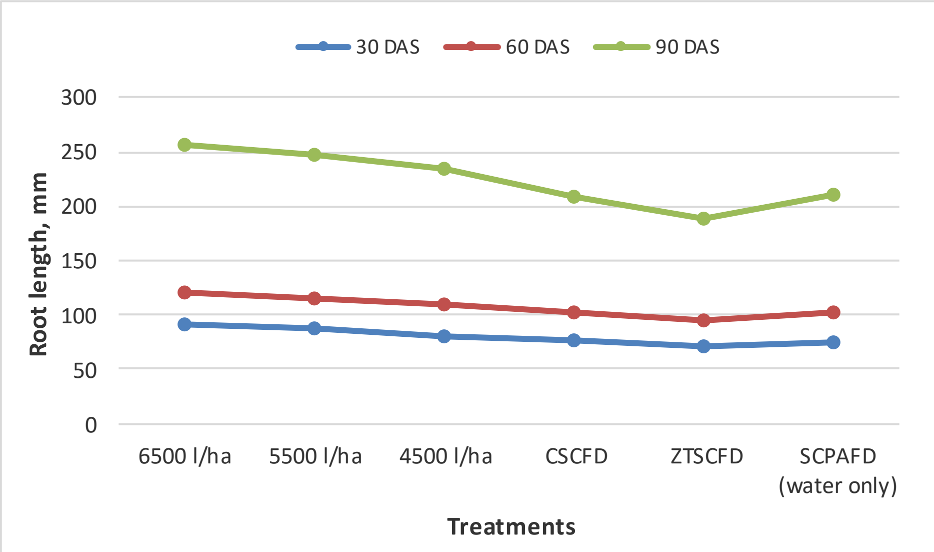


Fig. 4.29 Root length for different treatments after 30, 60 and 90 DAS

Root length for 90 DAS was 257.4, 249.2 and 235.7 mm for aqueous fertilizer rate 6500, 5500 and 4500 l/ha respectively. Whereas non aqueous fertilizer treatments had root length after 90 days was found to be 210.1, 189.2 and 212.5 mm for CSCFD, ZTSCFD and SCPAFD (water only) respectively. Root length was observed maximum 26.59% and minimum 19.81% with aqueous fertilizer rate 6500 and 4500 l/ha compared with least root length of non-aqueous fertilizer treatment i.e. ZTSCFD.

Table 4.53 Anova for root length after 90 days

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	977.91	488.96	448.49	**	4.10	7.56
treatment	5	10220.97	2044.19	1875.00	**	3.33	5.64
Error	10	10.90	1.09				
Total	17	11209.78					

4.6.9.8 Dry root weight

Dry rot weight per plant at 40 and 90 DAS for various treatment is presented in Table 4.49. At these DAS, effect of different aqueous fertilizer treatments on dry root weight was significant at 1% level of significant. Maximum and minimum dry root weight was found 0.76 and 0.65 g for aqueous fertilizer rate 6500 l/ha and 4500 l/ha for 30 DAS. Whereas for non-aqueous fertilizer treatments dry root weight was found to be 0.62, 0.53 and

0.60 g for CSCFD, ZTSCFD and SCPAFD (water only) respectively after 30 days sowing. Fig.4.30

Table 4.54 Dry root weight of wheat for different treatments

Treatment	Dry Root Weight (g)	
	30 DAS	90 DAS
6500 l/ha	0.76	6.89
5500 l/ha	0.75	6.48
4500 l/ha	0.65	6.00
CSCFD	0.62	5.43
ZTSCFD	0.53	4.68
SCPAFD (water only)	0.60	4.99

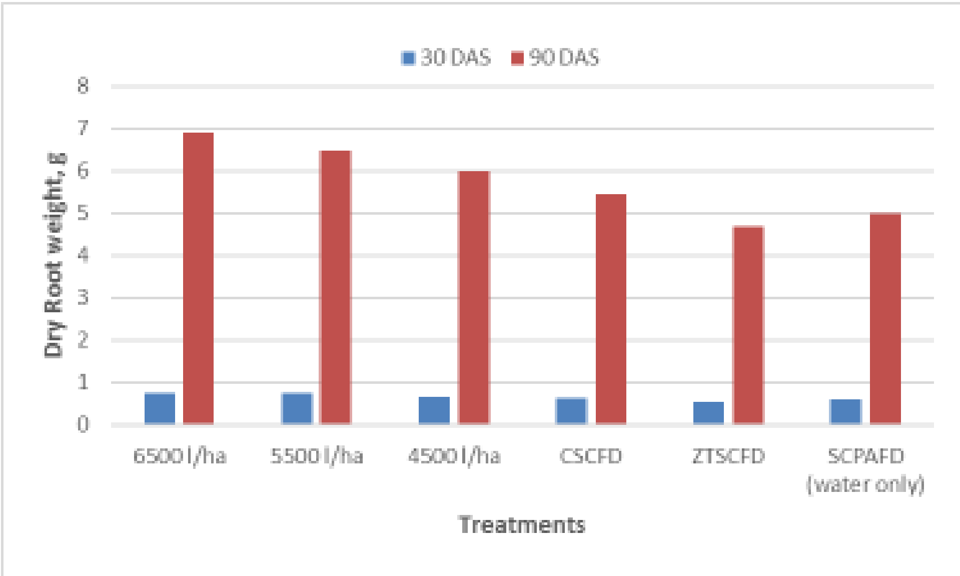


Fig. 4.30 Dry root weight for different treatments

Dry root weight after 90 of sowing was found 6.89, 6.48 and 6.1 g for aqueous fertilizer rate 6500, 5500 and 4500 l/ha. Whereas for non-aqueous fertilizer treatments dry root weight was found to be 5.43, 4.68 and 4.99 g for CSCFD, ZTSCFD and SCPAFD (water only) respectively. Dry root weight for aqueous fertilizer was maximum 37.5% and minimum 26.4% higher than non-aqueous fertilizer treatments.

Table 4.55 Anova of Dry root weight 45 DAS

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	0.01	0.00	319.43	**	4.10	7.56
treatment	5	0.12	0.02	1875.00	**	3.33	5.64
Error	10	0.00	0.00				
Total	17	0.13					

Table 4.56 Anova of Dry root weight 45 DAS

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	0.63	0.32	266.19	**	4.10	7.56
treatment	5	11.16	2.23	1875.00	**	3.33	5.64
Error	10	0.01	0.00				
Total	17	11.80					

4.6.9.9 Length of ear head

Length of ear head was measured after 60 and 90 days after sowing. Data showed that the length of ear head was almost same 5.9 mm and 13.8 mm for 60 and 90 DAS respectively, for all the three aqueous fertilize treatments and slightly higher than the plots without aqueous fertilizer fields i.e. 4.8, 4.6 and 4.8 mm (60 DAS) and 11.3, 9.2 and 8.9 mm (90 DAS) for CSCFD, ZTSCFD and SCPAFD (with water only) respectively, in later stage of plant growth, effect of aqueous fertilizer application got stabilized, Table 4.52. Such aberration in the observations are possible as in January to March. It is noteworthy that main intention behind aqueous fertilizer application is to help the crop for its germination and initial growth. Statistically, there were significant differences amongst the treatments. Fig.4.31

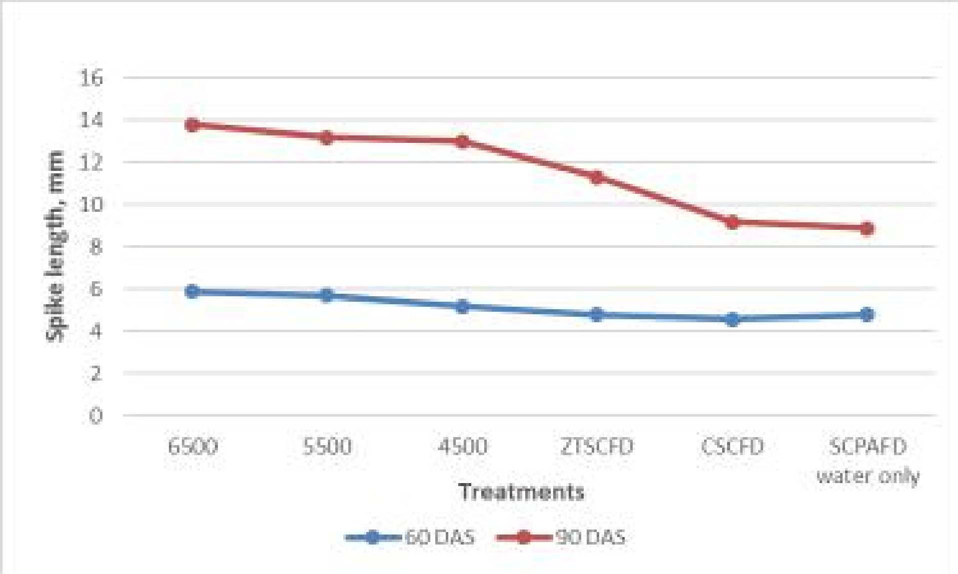


Fig. 4.31 Length of ear heads of different treatments

Table 4.57 Anova for length of ear head 60 DAS

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	0.51	0.26	566.63	**	4.10	7.56
treatment	5	4.24	0.85	1875.00	**	3.33	5.64
Error	10	0.00	0.00				
Total	17	4.76					

Table 4.58 Anova for length of ear head 90 DAS

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	2.57	1.28	178.44	**	4.10	7.56
treatment	5	67.48	13.50	1875.00	**	3.33	5.64
Error	10	0.07	0.01				
Total	17	70.12					

4.6.9.10 Grain yield

The grain yield data was recorded after harvesting the crop by taking samples from per meter square area. The grain yield was maximum 5062 kg/ha with 6500 l/ha followed by 4950 and 4720 kg/ha with 5500 l/ha and 4500 l/ha. with non-aqueous fertilizer treatments the yield was 4170, 4035 and 3780 kg/ha for CSCFD, ZTSCFD and SCPAFD (with water only) respectively, table 4.54. Thus, a maximum of 25.3% and minimum of 19.9% increase in grain yield was observed due to application of aqueous fertilizer at the rate of 6500 and 4500 l/ha, respectively, Fig 4.32. The yield of same wheat crop in irrigated fields in experimental area at JNKVV has been reported 4200 kg/ha. (Chouhan, 2015), which is comparable to the yield from plots with aqueous fertilizer application of 6500 l/ha. As discussed earlier, the influence of differential application rates of aqueous fertilizer was expected to be reduced with growth stages. Field and environmental conditions helped in this regard. Analysis of variance shows that there was significant effect of treatments amongst aqueous fertilizer plot w.r.t. grain yield and significantly higher when compared with control plots table 4.58. Better yield with 6500 l/ha was due to precise application of pressurized aqueous fertilizer, better germination, more number of ear head, better plant height and spike development in comparison to other treatments.

Table 4.59 Influence of aqueous fertilizer application on crop yield

S.No.	Treatments	Grain yield, kg/ha	Straw grain ratio	1000 grain weight
1.	6500 l/ha	5062.00	1.53	43.50
2.	5500 l/ha	4950.00	1.51	42.60
3.	4500 l/ha	4720.00	1.48	40.80
4.	CSCFD	4170.00	1.32	34.30
5.	ZTSCFD	4035.00	1.29	36.70
6.	SCPAFD (water only)	3780.00	1.23	32.10

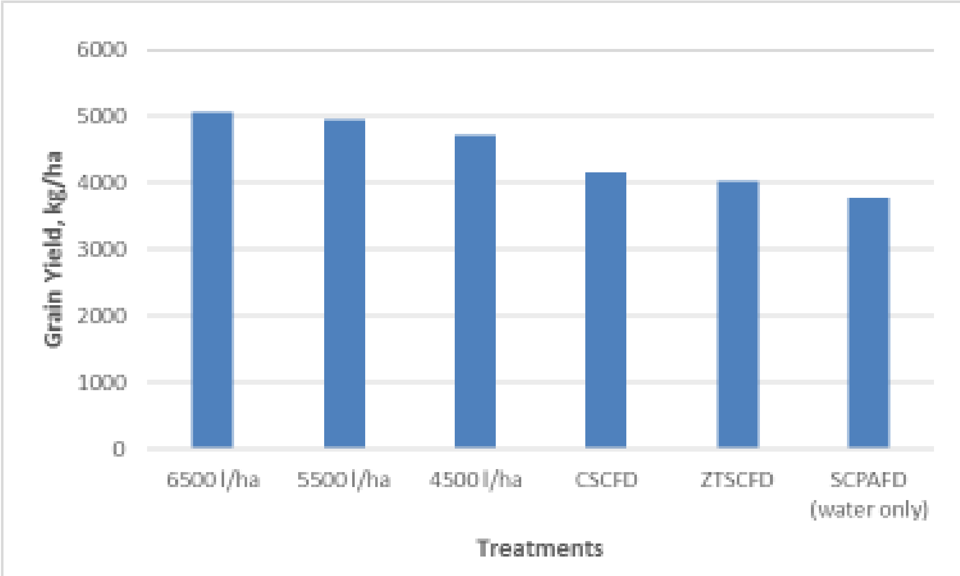


Fig. 4.32 Grain yield of different treatments

Table 4.60 Anova for grain yield

Source	**DF**	**SS**	**MSS**	**F cal.**		**F tab5%**	**F tab1%**
Replication	2	380692.31	190346.16	425.82	**	4.10	7.56
treatment	5	4190762.50	838152.50	1875.00	**	3.33	5.64
Error	10	4470.15	447.01				
Total	17	4575924.96					

4.6.9.11 Straw grain ratio

Straw grain ration was recorded after harvesting the crop by taking samples from per meter square area. Data showed that the straw grain ratio recorded similar trend as grain yield due to supplication of aqueous fertilizer at different rates. The maximum straw yield was found in aqueous fertilizer rate of 6500 l/ha (1.53) followed by 5500 l/ha (1.51) and without aqueous fertilizer straw grain ratio was 1.32, 1.29 and 1.23 for CSCFD, ZTSCFD and SCPAFD (with water only) respectively. Thus, a maximum of 19.6% and minimum 16.8% increase in straw grain ratio was observed due to application aqueous fertilizer at the rate of 6500 and 4500 l/ha. All the comparisons were with non-aqueous fertilizer treatments. Analysis of variance shows that the straw grain ratio of all aqueous fertilizer fields is significantly higher than that from non-aqueous fertilizer plots, Table 4.56. Reason for above trend were better application of pressurized aqueous fertilizer which causes better plant height and plant stand in respective treatments as compared to control one.

Table 4.61 Anova for straw grain ratio

Source	DF	SS	MSS	F cal.		F tab5%	F tab1%
Replication	2	0.04	0.02	705.67	**	4.10	7.56
treatment	5	0.25	0.05	1875.00	**	3.33	5.64
Error	10	0.00	0.00				
Total	17	0.29					

4.6.9.12 Economic analysis of use of the machine

Seed cum pressurized aqua fertilizer drill is meant for making possible the wheat crop in the areas where it is not possible due to absence of soil moisture. So, in one way it would be economical as it is going to make crop sowing possible in the areas where it is not possible, on the other hand its economy can be compared on the basis of all machine parameters such as field efficiency, field capacity, draft requirement, fuel consumption and also biometrics of crop. The comparison can also be made with the help of cost incurred on wheat sowing in moisture deficit areas by pressurized aqua fertilizer drill and gain in yield via normal sowing machines and yield loss. The parameters of economics of use of the machine are given in and Fig.4.33 same trend was found by kamal kant et al. (2008).

The final cost of prototype was worked out to be Rs. 37365, Appendix 11 and hourly cost of operation was computed to be Rs. 623.15, Appendix 14. The hourly cost of operation by Tractor was Rs. 519.5.

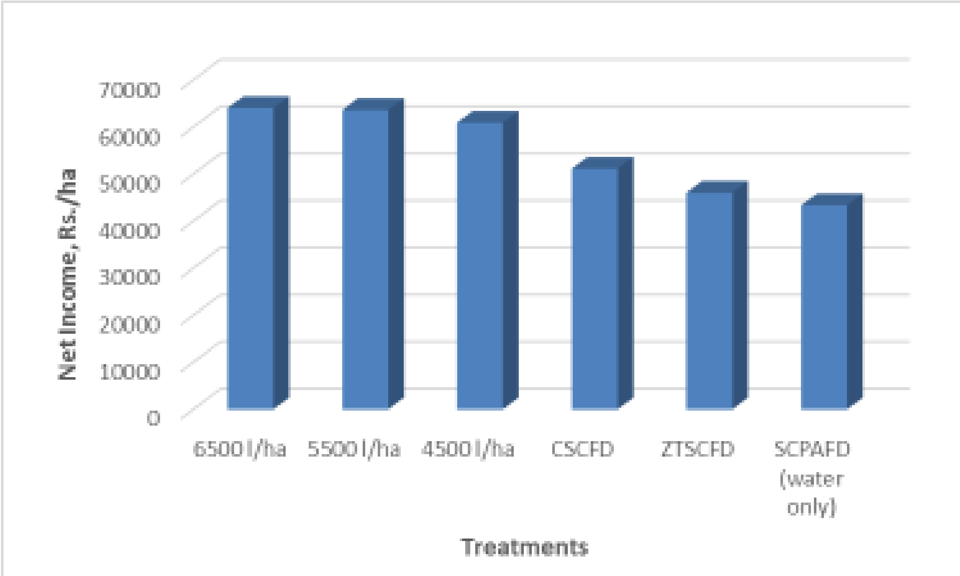


Fig. 4.33 Net income of different treatments

The maximum net income from seed cum pressurized aqua fertilizer drill found Rs. 64046 / ha. with aqueous fertilizer rate of 6500 l/ha, followed by Rs. 63645.34/ha with aqueous fertilizer rate of 5500 l/ha and Rs. 60948.96/ha with aqueous fertilizer rate of 4500 l/ha. With non-aqueous fertilizer net income was obtained Rs. 51151.04, 46053.52 and 43390.27 /ha for ZTSCFD, CSCFD and SCPAFD (water only), respectively. The net income was maximum 32.25% more than the controlled treatments with aqueous fertilizer rate 6500 l/ha and minimum 28.8% with aqueous fertilizer rate of 4500 l/ha.

4.6.10 Energy requirements for different treatments

4.6.10.1 Source wise energy (MJ/ha) consumption for different treatments

The source wise energy consumption for different treatments is shown in Fig. 4.34 to 4.39. The energy consumed in man, diesel, electricity, seed, fertilizer, tractor and machines given in Appendix 15.

4.6.10.1.1 Human energy consumed under different treatments

The energy consumed of human in SCPAFD, ZTSCFD and CSCFD was found to be 455.41, 511.59 and 472.71 MJ/ha respectively. In ZTSCFD energy consumed of human was 10.98 and 7.59% more than SCPAFD and CSCFD respectively. Because in ZTSCFD sowing was done by zero till seed cum fertilizer drill so more energy consumed in interculture operation. So, more human energy consumed in weeding operations. The similar results were also reported by other researchers namely Mittal *et al. (*1985) and Khandelwal *et al.* (1993). .The obtained energy consumed of human for different treatments are given in appendix no. 15.

4.6.10.1.2 Diesel energy consumed under different treatments

The energy consumed of Diesel in SCPAFD, ZTSCFD and CSCFD was found to be 2649.92, 1524.29 and 2010.35 MJ/ha respectively. In SCPAFD energy consumed of human was 42.4 and 24.13% more than ZTSCFD and CSCFD respectively. Because in ZTSCFD sowing was done by zero till seed cum fertilizer drill so no energy consumed in field preparation. Therefore, more diesel energy consumed in tillage operations with SCPAFD and CSCFD. The similar results were also reported by other researchers namely Mittal *et al. (*1985) and Khandelwal *et al.* (1993). .The obtained energy consumed of human for different treatments are given in appendix no. 15.

4.6.10.1.3 Energy consumed of seed for different treatments

The energy consumed of seed was found to be same 1176 MJ/ha in all treatments because seed rate was uniform under all treatments. The similar results were also reported by other researchers name as Mittal *et al. (*1985) and Singh *et al.* (2003).The obtained energy consumed of seed for different treatments are given in appendix no. 15.

4.6.10.1.4 Energy consumed of fertilizer for different treatments

The energy consumed of fertilizer was same in all treatments which are 2000 MJ/ha. Because recommended dose of fertilizer application was same in all treatments. The obtained energy consumed of fertilizer is given in appendix no. 15.

4.6.10.1.5 Energy consumed of tractor for different treatments

The energy consumed of tractor in SCPAFD, ZTSCFD and CSCFD was found to be 110.35, 76.05 and 136.65 MJ/ha respectively. In CSCFD energy consumed of tractor was 19.24 and 44.3% more than SCPAFD and ZTSCFD respectively. Because in ZTSCFD sowing was done by zero till seed cum fertilizer drill so no energy consumed in field preparation. Therefore, more tractor energy consumed in tillage operations with SCPAFD and CSCFD. The similar results were also reported by other researchers namely

Jadhao *et al.* (2004) and Hatirlia *et al.* (2005).The obtained energy consumed of tractor for different treatments are given in appendix no. 15.

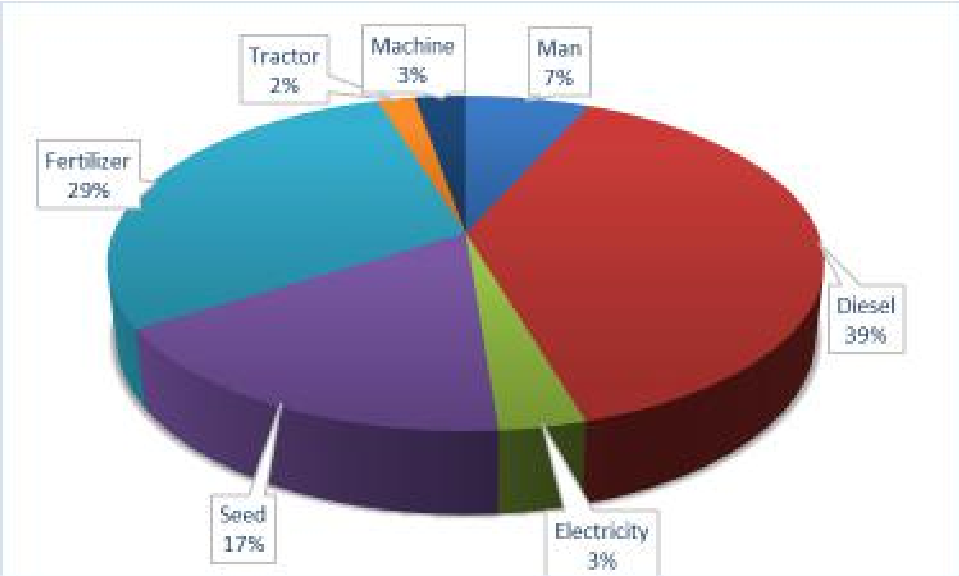


Fig. 4.34 Source wise energy (MJ/ha) consumption for aqueous fertilizer rate 6500 l/ha

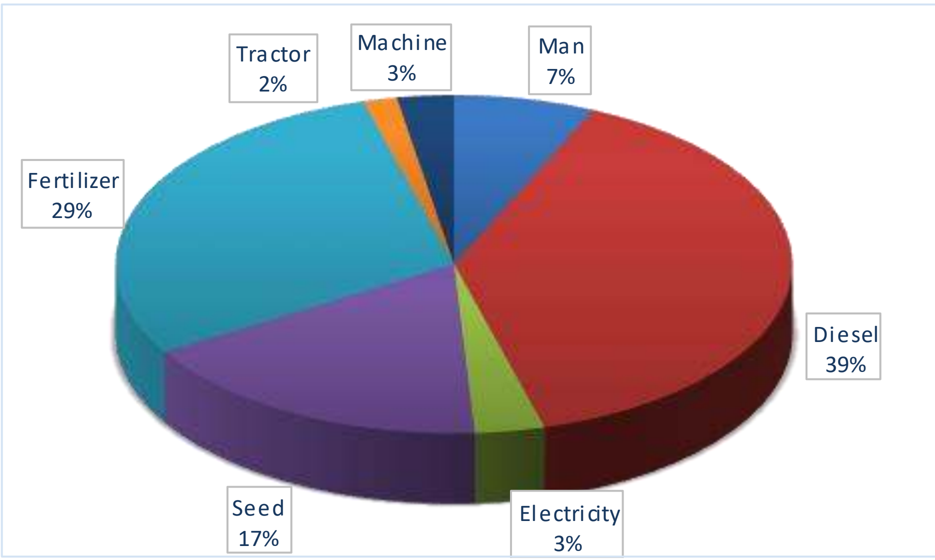


Fig. 4.35 Source wise energy (MJ/ha) consumption for aqueous fertilizer rate 5500 l/ha

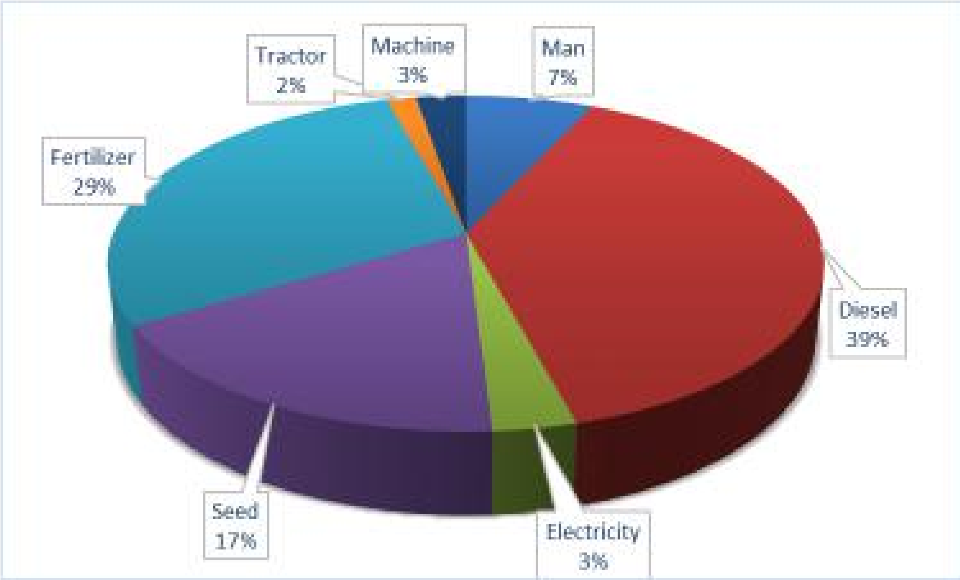


Fig. 4.36 Source wise energy (MJ/ha) consumption for aqueous fertilizer rate 4500 l/ha

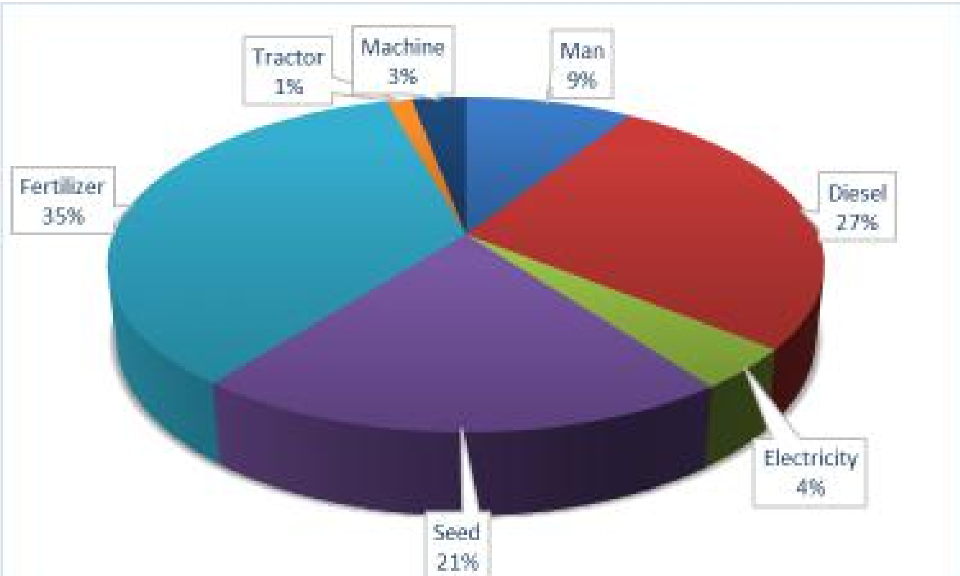


Fig. 4.37 Source wise energy (MJ/ha) consumption for ZTSCFD

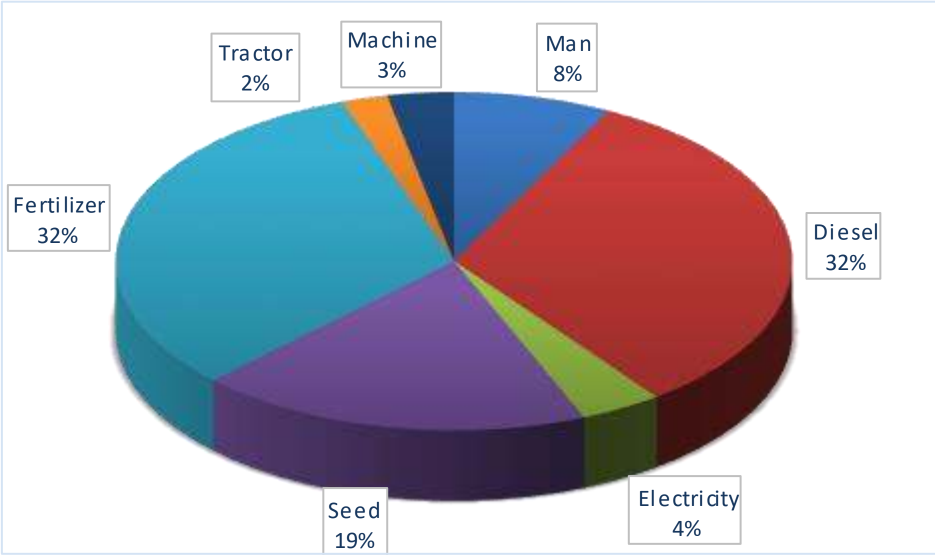


Fig. 4.38 Source wise energy (MJ/ha) consumption for CSCFD

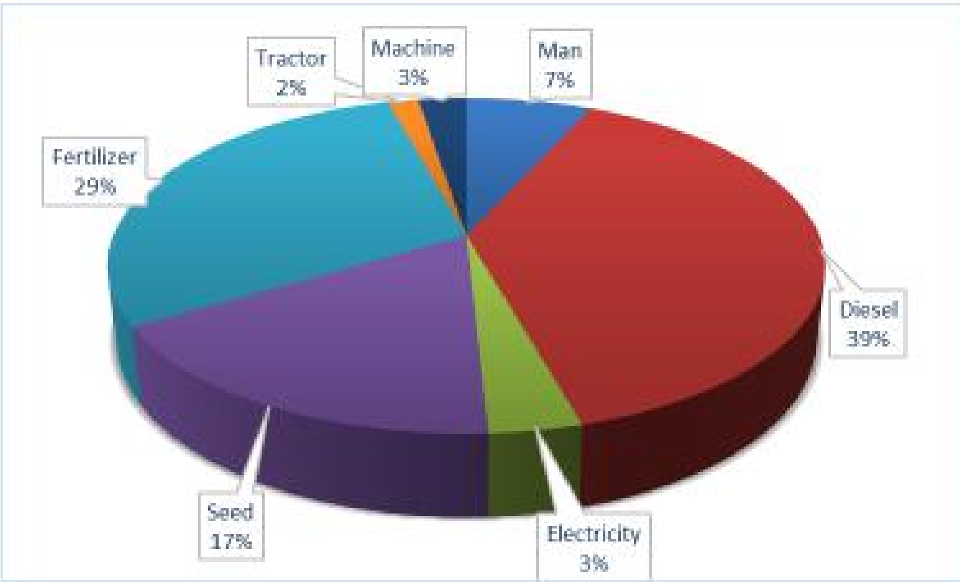


Fig. 4.39 Source wise energy (MJ/ha) consumption for SCPAFD (with water only)

4.6.10.2 Operation wise energy (MJ/ha) consumption for different treatments

The energy consumption in different operations for different treatments are shown in fig. 4.40 to 4.45. Total maximum energy consumption were obtained 4324.74 MJ/ha with SCPAFD (with water only) followed by 4298.6 with aqueous fertilizer rate 6500 l/ha. and minimum energy requirement were obtained 3222.83 MJ/ha for ZTSCFD. This trend obtained because ZTSCFD required no tillage, hence the energy consumed in is less than the other treatments with ZTSCFD. Appendix 16.

4.6.10.2.1 Energy consumption in different tillage operations

In all the treatments except zero tillage, energy consumed in tillage operation was found to be 1713.92 and zero (0) MJ/ha. The energy consumed in tillage operation in case of ZTSCFD treatment was zero (0) because, field preparation was not done and sowing was done directly by using zero till seed cum fertilizer drill. The similar opinion were also reported by other researchers namely Khandelwal *et al.* (1993) and Hashem *et al. (*2011).The obtained energy consumed of man for different treatments are given in appendix no. 16.

4.6.10.2.2 Energy consumption in different interculture operation

The energy consumed of interculture in SCPAFD, ZTSCFD and CSCFD was found to be 254.45, 336.45 and 261.8 MJ/ha respectively. In ZTSCFD energy consumed of interculture was 24.3 and 22.18% more than SCPAFD and CSCFD respectively. Because in ZTSCFD sowing was done by zero till seed cum fertilizer drill so more energy consumed in interculture operation. So, more human energy consumed in weeding operations. The similar results were also reported by other researcher namely Mittal *et al. (*1985). The obtained energy consumed of human for different treatments are given in appendix no. 16.

4.6.10.2.3 Energy consumption in different harvesting operations

The energy consumed of harvesting in SCPAFD, ZTSCFD and CSCFD was found to be 146.53, 133.6 and 147.17 MJ/ha respectively. In ZTSCFD energy consumed of harvesting was 8.83 and 9.22% less than SCPAFD and CSCFD respectively. Because in ZTSCFD sowing was done by zero till seed cum fertilizer drill and it has comparatively less grain yield per hectare, so less energy consumed in harvesting operation. The similar results were also reported by other researcher namely Mittal *et al. (*1985). The obtained energy consumed of human for different treatments are given in appendix no. 16.

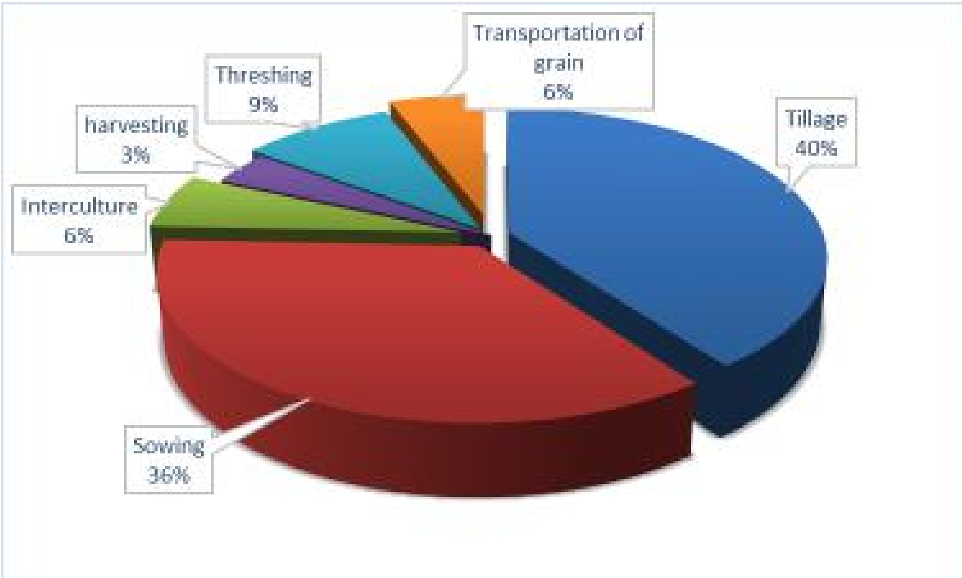


Fig 4.40 Operation wise energy (MJ/ha) consumption for treatment 6500 l/ha

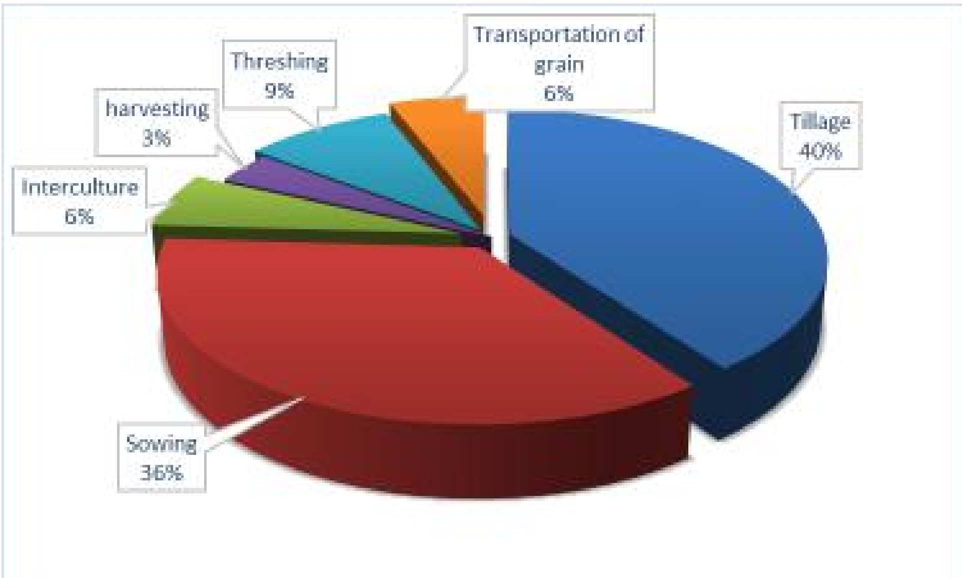


Fig 4.41 Operation wise energy (MJ/ha) consumption for treatment 5500 l/ha

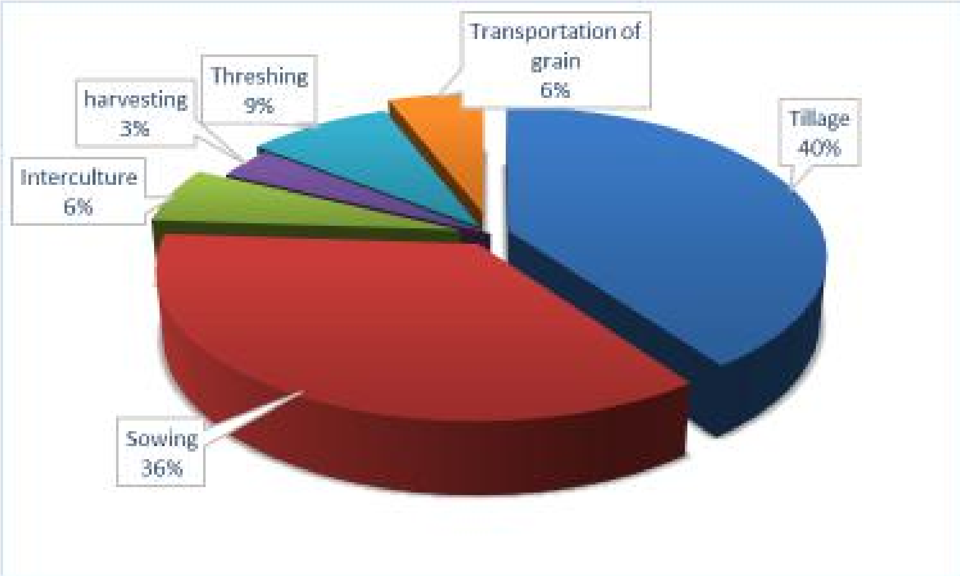


Fig 4.42 Operation wise energy (MJ/ha) consumption for treatment 4500 l/ha

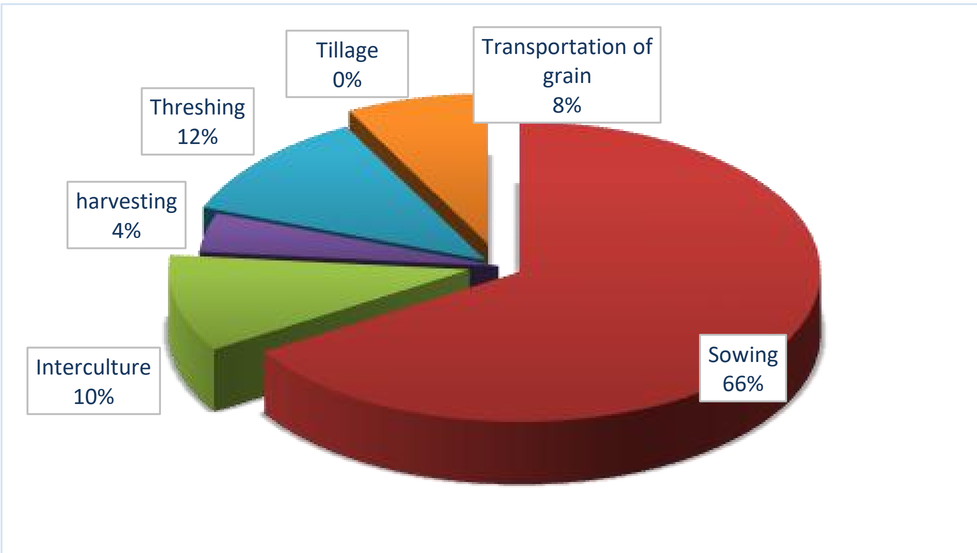


Fig 4.43 Operation wise energy (MJ/ha) consumption for treatment ZTSCFD

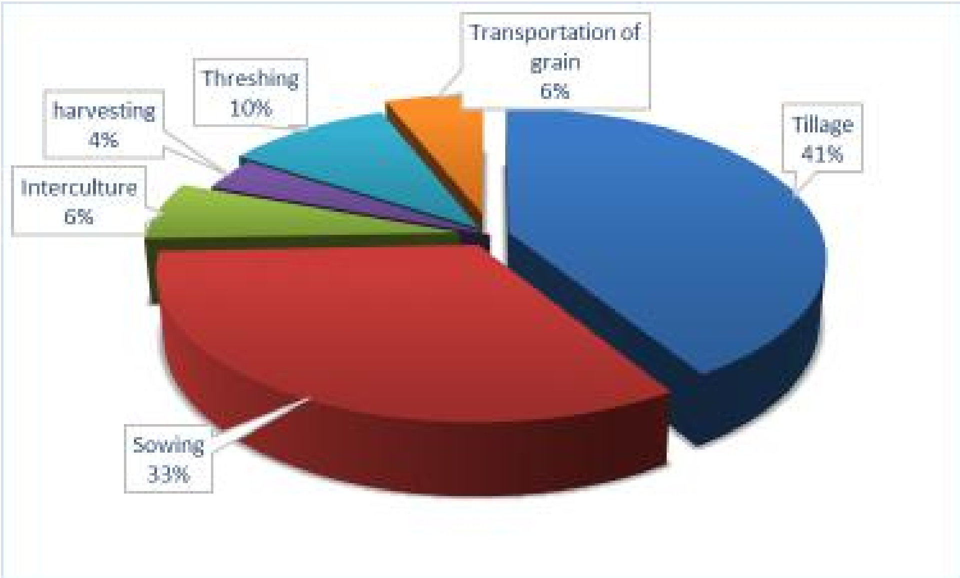


Fig 4.44 Operation wise energy (MJ/ha) consumption for treatment CSCFD

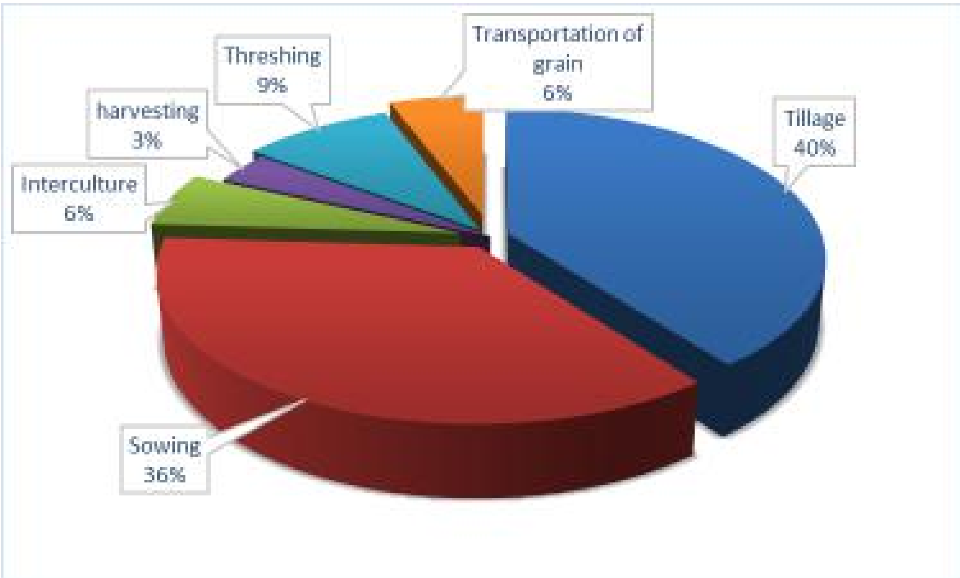


Fig 4.45 Operation wise energy (MJ/ha) consumption for treatment SCPAFD (water only)

SUMMARY AND CONCLUSION

The Indian agriculture is diverse and complex with irrigated, rain fed areas, mountainous, coastal areas, marginal to large farms and subsistence to commercial agriculture. So far, only 33% area has been covered under assured irrigation and rest depends upon rainfall, with large spatial and temporal variation causing wide variability in production and productivity of different crops in these areas. Rain fed farming constitutes about 67% of total cultivated area (i.e.118 Mha) in India and contributes 42% to food production with average productivity of 0.7 to 0.8 t/ha. Due to unavailability of sufficient soil moisture in-situ or as irrigation, the main winter crops like wheat, gram and mustard cannot be cultivated despite the suitability of the soil. For proper germination and healthy initial growth, seed vigor and timeliness of sowing are most important aspects. It has been established that the delay in sowing causes a loss in the yield to extend of 35 to 40 kg/ha per day (Hobbs, 1985). In northern India, the recommended sowing period is from 15 th to 30 th November, the yield loss due to delayed sowing starts after the recommended period. Under such situations, efficient placement of seed at proper depth is must using suitable seeding equipment.

The present study on design development and evaluation of seed cum pressurized aqueous fertilizer drill for crops like wheat, soybean, chickpea, mustard etc. in rain fed areas as well as moisture deficit areas was done. The pressurized pumping system with variable nozzle opening, was chosen to facilitate smooth and desired discharge in uniform pattern with high levels of maneuverability. The design variables of pumping system included speed of centrifugal pump, in-line pressure, nozzle size. The task also included design of power transmission system to operate metering system to obtain desired discharge. The amount of additional moisture was estimated based on the soil type and available moisture. After estimation of moisture deficits capacity range of suitable aqueous fertilizer applicator was determined. The additional soil moisture in rain fed areas depends primarily on soil type and initial moisture apart from climatic conditions. For the soil types suitable for wheat cultivation, moisture deficits were estimated based on soil moisture retention characteristics. The study were conducted for the different types of soils for the estimation of rate of aqueous fertilizer, moisture content, absorption of moisture from soaked seed and absorption of moisture to seed from the soil. It helped determining required time period of moisture availability to ensure germination. In fact, to allow the seed to germinate applied moisture must remain above critical limit for certain period of time. Moisture absorption pattern by seed was determined by soaking seed sample in water for time period of 5, 10, 15, 30, 60, 120, 240 and 360 minutes. Water absorption by seed placed in soil at three soil moistures i.e. 12.1, 9.24 and 5.25% was determined after lapse of 1, 2 and 3 days. This helped determining minimum soil moisture in clay loam soil of experimental field to allow optimum germination. Another experiment was conducted to determine time of emergence of wheat seed at different depth of 2.5, 5, 7.5 and 10 cm experiment was conducted in the field as exactly same interval of moisture levels was difficult to maintain. This helped in determining germination pattern with differential soil moisture and sowing depth and thus, provided critical combination of depth-moisture level to allow germination. The applicator for applying aqueous fertilizer which is a part of seed cum pressurized aqueous fertilizer drill was designed keeping in view the required additional moisture and other related design features of a seed drill for the different crops. Design of proposed machine consisted of component of design of mainframe, metering system for aqueous fertilizer, furrow opener and a power transmission system. The design of a suitable pumping system to meter and disperse required amount of aqueous fertilizer in the furrow along with the seed was main innovative job of the study. The aqueous fertilizer metering was attained by designing a suitable pumping system to deliver a measured quantity of aqueous fertilizer. Based on information available on pumping system and requirements of aqueous fertilizer pumping, a centrifugal pump assisted to deliver aqueous fertilizer was found suitable. The whole system was designed keeping in view the different variables of aqueous fertilizer metering system. The design variables of the pumping system included five levels of speed i.e. 666, 999, 1332, 1665 and 1998 rpm with four levels of pressure i.e. 0, 2, 4 and 6 kg /cm^2 and three levels of nozzle sizes i.e. 8, 10 and 12 mm. Design values of variables were investigated by studying their influence pattern on discharge from different nozzle size with respect to different rotational speed and in line pressure. The pumping system was tested using power from 45 hp tractor through its PTO drive. The power transmission system was developed taking universal coupling fitted to PTO. Having done the above, seed cum pressurized aqueous fertilizer drill was fabricated. The fabricated pumping system was test evaluated for discharge at different rates of aqueous fertilizer and also with other sowing systems. The final design values of the pumping system for fabrication was kept 10mm nozzle opening. However, provision was kept to have variable nozzle opening to meet the specific requirements. The other component of the machine were designed and developed keeping in view the functional requirements of different components and their matching with pumping system. This included development of nozzles, nozzle frame, lever for changing the nozzle opening tubes for supply of aqueous fertilizer to furrow opener. Two storage tanks of 540 mm dia. and 200 litre capacity were mounted on both sides of the pumping system. The design values of the other components of seed cum pressurized aqueous fertilizer drill like furrow opener, seed box along with seed metering device and power transmission system from prime mover to the machine were designed. The pumping system, thus designed and developed was mounted on a seed drill operated by a matching tractor. The prototype was tested using a 45 hp tractor which supplied power for operating different functional component of the machine. The functional test of the machine was conducted in the laboratory. Field test were conducted in the experimental farm of college of agricultural engineering. The field experiments were laid out following a randomized block design. Wheat crop was sown by applying different levels of aqueous moisture. The data on soil parameters, machine parameters and crop parameters were taken. The influence of aqueous fertilizer application was studied on different crop growth parameters. As per the working principle of the seed cum pressurized aqua fertilizer drill may be the better solution for the effect of agro-climatic changes in agricultural situations. This may take care of the situation such as dry spell maintained or improve the soil health as well as environment. Some of the major conclusions could be drawn:

5.1 Soil moisture environment of seed for application of aqueous fertilizer

1. For clay loam soil an application range of aqueous fertilizer was 0.23-1.59 liter per meter for raising moisture from 8 to 16 % to germination moisture of 27 per cent. Whereas, for loamy sand soil an application range of aqueous fertilizer was 0.15 - 0.92 liter per meter for raising moisture from 3 to 7 % to germination moisture of 14 per cent and for sandy loam soil an application range of aqueous fertilizer was 0.17-1.34 liter per meter for raising moisture from 4 to 12 % to germination moisture of 20 per cent.
2. Moisture absorption pattern under soaked condition showed that a 100% variation in incremental weight was observed during 5 to 30 minutes. Beyond 30 minutes absorption rate got slowed down. Soaked seed attain 17.7% moisture content in 60 minutes after soaking. Thus, the germination moisture content for seed will required within one hour.
3. In case of pattern of moisture absorption by seed from soil, it was concluded that for attaining optimum germination moisture for seed, a moisture level of above a range of 9.24 to 12.1 % needs to be maintained. This warrants timeliness of sowing operation in the soil of moisture deficit areas.
4. Based on the observation on time of emergence with different moisture level and soil depth, it concluded that a soil moisture level above 10% and depth of 2.5-5.0 cm are most favorable for seed germination. Seeding depth beyond 7.5 cm must be avoided in any case, the seeding depth for wheat must be within the range of 2.5-5 cm.
5. Keeping in view the desired discharge for pressurized aqua fertilizer metering system in present study, a centrifugal pump with a discharge of 60 l/min was selected. Overall size and discharge capacity range, capacity to handle viscous fluid and pressure developed for desired discharge were other prominent criteria for selection. The total volume of applied aqueous

fertilizer could be controlled by varying the forward speed of the machine to some extent.

5.2 Design values of pressurized aqueous fertilizer metering mechanism

1. The main design variables of pressurized aqua fertilizer metering system were rotational speed of pump, calibrated line pressure and nozzle size in that order of importance. Pump rotational speed influenced discharge directly in a linear manner at fully opened valve for all pump speeds for each nozzle size. A discharge range of 0.69 to 1.41, 0.74 to 1.531 and 0.72 to 1.48 l/s could be attained by varying the pump speed from 666 to 1998 respectively, for three nozzle sizes of 8, 10 and12 mm, respectively.
2. For each pump rotation discharge from 8, 10 and 12 mm nozzle sizes was almost same so, a positive displacement centrifugal pump was an appropriate selection and same output was obtained irrespective of nozzle sizes with minor variations. Keeping total discharge and pattern of aqueous fertilizer flow from nozzles a 10 mm nozzle size was found optimum.
3. As line pressure increased the discharge rate decreased. A reduction of 2 to 6 times in the flow was obtained by creating the line pressure through control valve at rotational speed of 1998 to 666 rpm. A discharge showed an excellent correlation with pump rotational speed. The selected design values for pressurized pumping system were pump rotational speed from 666, 999, 1332 or 1665 rpm, line pressure of 0, 2 or 4 kg/cm^2 with nozzle size of 10 mm.
4. In pressurized aqueous fertilizer metering system, discharge rates decreased with increase in assumed forward speed for constant levels of pump rotational speed and line pressure. The developed pressurized system is capable of delivering a maximum 3600 l/h and minimum of 369 l/h of aqueous fertilizer.

5.3 Performance Parameters

1. The field experiments revealed that by using the aqueous fertilizer application the germination were advanced by two to three days. Aqueous fertilizer increased crop growth parameters particularly those which are related to crop growth like germination start, germination count and number of plants/m^2.
2. A field capacity, field efficiency and fuel consumption to be was found 0.35, 0.36 and 0.38 ha/h and 65.5, 66.6 and 70.3% and 10.85, 9.97 and 8.42 lit/ha in case of seed cum pressurized aqueous fertilizer drill, zero till seed cum fertilizer drill and conventional seed cum fertilizer drill respectively. Field efficiency and Fuel consumption of zero till and conventional seed drill was less than seed cum pressurized aqueous fertilizer drill by 8.1 and 22.3%, because field capacity of ZTSCFD and CSCFD is more than SCPAFD.
3. The draft for seed cum pressurized aqua fertilizer drill, zero till seed cum fertilizer drill and conventional seed cum fertilizer drill was found 3.6, 3.0 and 2.31 kN respectively. In case of SCPAFD draft was 16.6 and 35.8% more than ZTSCFD and CSCFD respectively due to the weight of machine..
4. A maximum of 45% and 39% increase in germination count, a maximum of 23% and minimum of 19.5% increase in plant height was observed with aqueous fertilizer rate of 6500 and 4500 l/ha as compared to the zero till and conventional SCFD (controlled plots). Aqueous fertilizer gave enhanced growth performance parameters i.e. number of shoot/plant, number of ear head/m length, plant height, and length of ear head in addition to better germination.
5. Root length 30 DAS, 60 DAS and 90 DAS was observed maximum 21.7% and minimum 11.5%, maximum 20.8% and minimum 13.19% and maximum 26.59% and minimum 19.81% respectively with aqueous fertilizer rate 6500 and 4500 l/ha compared with least root length of non-aqueous fertilizer treatment i.e. ZTSCFD.

6. Dry root weight for aqueous fertilizer was maximum 37.5% and minimum 26.4% higher than non-aqueous fertilizer treatments. A maximum of 25.3% and minimum of 19.9% increase in grain yield was observed due to application of aqueous fertilizer at the rate of 6500 and 4500 l/ha, respectively. The both grain and straw yield were influenced by application of aqueous fertilizer and with enhanced aqueous fertilizer rates, both the yield parameters registered increase.
7. The net income was maximum 32.25% more than the controlled treatments (i.e. zero till and conventional seed drill) with aqueous fertilizer rate 6500 l/ha and minimum 28.8% with aqueous fertilizer rate of 4500 l/ha.
8. Total maximum energy consumption were obtained 4324.74 MJ/ha with SCPAFD (with water only) followed by 4298.6 with aqueous fertilizer rate 6500 l/ha. and minimum energy requirement were obtained 3222.83 MJ/ha for ZTSCFD.

Based on findings of the studies, it was concluded that the developed seed cum pressurized aqua fertilizer drill is the best solution for deficit soil moisture content areas (in M.P. the fellow land is available approximately 25% of total cultivated area in rabi season, apart from the deficit soil moisture content cultivated area. This fellow land may also be utilized by this machine) and had significant effects over the existing sowing systems. Application of aqueous fertilizer increased the germination rate as well as the fertilizer use efficiency in terms of all the crop parameters specially grain yield which is directly influence the economic condition of the farmers.

Statistical analysis shows that the aqueous fertilizer rate of 5500 l/ha is significantly more beneficial and also saves enormous amount of water per ha. compared to the conventional irrigation methods like flood and sprinkler system which requires more than 4 lakh liter per hectare.

SUGGESTION FOR FUTURE WORK

Design, Development and evaluation of seed cum pressurized aqueous fertilizer drill has taken as the present study, it has proven useful for precision seeding of different crops by controlled application of aqueous fertilizer according to soil moisture as well as crop conditions. Some of the suggestions for future are given as follows:

1. Capacity of aqueous fertilizer tank should be increase.
2. Furrow opener i.e. “inverted T” type should be used and modify for the precision placement of aqueous fertilizer.
3. Pump should be replaced with the aluminum pump for light weight point of view.
4. Centre of gravity should be calculate for better stability.
5. Provision may also be provided for the spraying of herbicide and micronutrients.
6. The machine should be test evaluated to accommodate other different crops in dry land and rain fed areas.
7. Mechatronic system may be used for controlling seed and aqua fertilizer rates.

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APPENDICES

Appendix 1

a) **Estimation of placement of aqueous fertilizer with respect to seed (0 cm depth)**

Lateral spacing, cm	Rep	% Before sowing	After sowing	3 DAS	6 DAS	9 DAS
2.5	R1	6.20	20.32	13.80	9.54	7.24
	R2	5.95	19.51	13.25	9.16	6.95
	R3	6.45	21.13	14.35	9.92	7.53
5	R1	6.12	18.44	11.20	8.74	6.82
	R2	5.88	17.70	10.75	8.39	6.55
	R3	6.36	19.18	11.65	9.09	7.09
7.5	R1	6.00	16.95	9.70	7.90	5.90
	R2	5.76	16.27	9.31	7.58	5.66
	R3	6.24	17.63	10.09	8.22	6.14

b) **Estimation of placement of aqueous fertilizer with respect to seed 2.5 cm depth**

Lateral spacing, cm	Rep	% Before sowing	After sowing	3 DAS	6 DAS	9 DAS
2.5	R1	6.20	21.17	14.38	9.94	7.54
	R2	5.95	20.32	13.80	9.54	7.24
	R3	6.45	22.02	14.96	10.34	7.84
5	R1	6.12	18.44	11.76	9.10	7.10
	R2	5.88	17.70	11.29	8.74	6.82
	R3	6.36	19.18	12.23	9.46	7.38
7.5	R1	6.00	17.66	11.24	8.32	6.20
	R2	5.76	16.95	10.79	7.99	5.95
	R3	6.24	18.37	11.69	8.65	6.45

c) **Estimation of placement of aqueous fertilizer with respect to seed 5 cm depth**

Lateral spacing, cm	Rep	% Before sowing	After sowing	3 DAS	6 DAS	9 DAS
2.5	R1	6.20	21.13	14.35	9.92	7.53
	R2	5.95	20.28	13.78	9.52	7.23
	R3	6.45	21.98	14.92	10.32	7.83
5	R1	6.12	19.18	11.65	9.09	7.09
	R2	5.88	18.41	11.18	8.73	6.81
	R3	6.36	19.95	12.12	9.45	7.37
7.5	R1	6.00	17.63	10.09	8.22	6.14
	R2	5.76	16.92	9.69	7.89	5.89
	R3	6.24	18.34	10.49	8.55	6.39

d) **Brief specification of centrifugal pump used**

Model	Size	Speed (rpm)	Min Capacity	Max. Pressure
MBG 12	1 HP	1660	50 lph	12 kg/cm^2

Appendix 2

A. Temporal changes in soil moisture after sowing with application of aqueous fertilizer (5 cm depth) for the year 2015

Particulars	Rep	Mc(%db) at the time of sowing	Mc(%db) just after sowing	Mc(%db) after 3 DAS	Mc(%db) after 6 DAS
Aqueous rate, 6500 l/ha	R1	12.50	32.80	28.70	24.60
	R2	12.00	31.49	27.55	23.62
	R3	13.00	34.11	29.85	25.58
Aqueous rate, 5500 l/ha	R1	12.47	29.52	25.88	22.23
	R2	11.97	28.34	24.84	21.34
	R3	12.97	30.70	26.91	23.12
Aqueous rate, 4500 l/ha	R1	12.10	27.15	24.28	21.41
	R2	11.62	26.06	23.31	20.55
	R3	12.58	28.24	25.25	22.27

B. Temporal changes in soil moisture after sowing with application of aqueous fertilizer (10 cm depth) for the year 2015

Particulars	Rep	Mc(%db) at the time of sowing	Mc(%db) just after sowing	Mc(%db) after 3 DAS	Mc(%db) after 6 DAS
Aqueous rate, 6500 l/ha	R1	14.37	30.64	27.52	24.39
	R2	13.80	29.41	26.41	23.41
	R3	14.94	31.87	28.62	25.37
Aqueous rate, 5500 l/ha	R1	14.14	29.39	26.92	24.44
	R2	13.57	28.21	25.84	23.46
	R3	14.71	30.57	27.99	25.42
Aqueous rate, 4500 l/ha	R1	14.18	27.25	25.32	23.39
	R2	13.61	26.16	24.31	22.45
	R3	14.75	28.34	26.33	24.33

Appendix 3

A. Temporal changes in soil moisture after sowing with application of aqueous fertilizer (5 cm depth) for the year 2016

Particulars	Rep	Mc(%db) at the time of sowing	Mc(%db) just after sowing	Mc(%db) after 3 DAS	Mc(%db) after 6 DAS
Aqueous rate, 6500 l/ha	R1	13.35	31.74	28.52	25.30
	R2	12.82	30.47	27.38	24.29
	R3	13.88	33.01	29.66	26.31
Aqueous rate, 5500 l/ha	R1	13.55	29.36	25.65	21.93
	R2	13.01	28.19	24.62	21.05
	R3	14.09	30.53	26.67	22.81
Aqueous rate, 4500 l/ha	R1	13.80	27.83	24.42	21.00
	R2	13.25	26.72	23.44	20.16
	R3	14.35	28.94	25.39	21.84

B. Temporal changes in soil moisture after sowing with application of aqueous fertilizer (10 cm depth) for the year 2016

Particulars	Rep	Mc(%db) at the time of sowing	Mc(%db) just after sowing	Mc(%db) after 3 DAS	Mc(%db) after 6 DAS
Aqueous rate, 6500 l/ha	R1	15.87	29.98	28.31	26.64
	R2	15.24	28.78	27.18	25.57
	R3	16.50	31.18	29.44	27.71
Aqueous rate, 5500 l/ha	R1	15.90	28.35	26.84	25.32
	R2	15.26	27.22	25.76	24.31
	R3	16.54	29.48	27.91	26.33
Aqueous rate, 4500 l/ha	R1	16.00	27.73	25.60	23.47
	R2	15.36	26.62	24.58	22.53
	R3	16.64	28.84	26.62	24.41

Appendix 4

Pressure, discharge and speed (8mm Nozzle)

Speed rpm	**Pressure Kg/cm^2**	**Discharge (l/m)**		
		R1	**R2**	**R3**
1998	0	1.4125	1.4233	1.4316
	2	1.1855	1.1944	1.2014
	4	0.8998	0.9066	0.9119
	6	0.8155	0.8217	0.8265
1665	0	1.1259	1.1344	1.1411
	2	1.0069	1.0146	1.0205
	4	0.8181	0.8243	0.8291
	6	0.6789	0.684	0.688
1332	0	0.8092	0.8153	0.8201
	2	0.621	0.6257	0.6294
	4	0.5397	0.5438	0.547
	6	0.4088	0.4119	0.4143
999	0	0.8349	0.8412	0.8461
	2	0.6547	0.6596	0.6635
	4	0.4517	0.4551	0.4578
	6	0.298	0.3003	0.302
666	0	0.6877	0.6929	0.697
	2	0.3746	0.3774	0.3797
	4	0.3103	0.3127	0.3145
	6	0.1217	0.1226	0.1233

Appendix 5

Pressure, discharge and speed (10mm Nozzle)

Speed rpm	Pressure Kg/cm^2	Discharge (l/m)		
		R1	R2	R3
1998	0	1.5328	1.5023	1.5062
	2	1.2864	1.2608	1.264
	4	0.9764	0.957	0.9594
	6	0.8849	0.8673	0.8696
1665	0	1.2217	1.1974	1.2005
	2	1.0926	1.0709	1.0737
	4	0.8877	0.87	0.8723
	6	0.7366	0.722	0.7239
1332	0	0.878	0.8606	0.8628
	2	0.6739	0.6605	0.6622
	4	0.5856	0.574	0.5755
	6	0.4436	0.4347	0.4359
999	0	0.9059	0.8879	0.8902
	2	0.7104	0.6962	0.6981
	4	0.4902	0.4804	0.4817
	6	0.3234	0.3169	0.3177
666	0	0.7462	0.7314	0.7333
	2	0.4065	0.3984	0.3994
	4	0.3367	0.33	0.3309
	6	0.132	0.1294	0.1297

Appendix 6

Pressure, discharge and speed (12mm Nozzle)

Speed rpm	Pressure Kg/cm^2	Discharge (l/m)		
		R1	R2	R3
1998	0	1.4848	1.4644	1.4573
	2	1.2461	1.2289	1.2231
	4	0.9458	0.9328	0.9283
	6	0.8572	0.8454	0.8414
1665	0	1.1835	1.1672	1.1616
	2	1.0584	1.0439	1.0389
	4	0.8599	0.8481	0.844
	6	0.7136	0.7038	0.7004
1332	0	0.8505	0.8388	0.8348
	2	0.6528	0.6438	0.6407
	4	0.5673	0.5595	0.5568
	6	0.4297	0.4238	0.4217
999	0	0.8776	0.8655	0.8614
	2	0.6881	0.6787	0.6754
	4	0.4748	0.4683	0.466
	6	0.3132	0.3089	0.3074
666	0	0.7229	0.7129	0.7095
	2	0.3938	0.3883	0.3865
	4	0.3262	0.3217	0.3202
	6	0.1279	0.1261	0.1255

Appendix 7

Cone index of soil of experimental field (after tillage)

Depth (mm)	Cone Index (kPa)
25	138.8
50	192.9
75	468.46
100	652.28
125	796.76
150	957.62
Average	534.47

Cone index of soil of experimental field (before tillage)

Depth (mm)	Cone Index (kPa)
25	148.18
50	218.19
75	520.64
100	735.67
125	867.82
150	1023.26
Average	585.62

Appendix 8

Germination count per meter row (2015)

Treatments	Germination /m 10 DAS	Germination/m 18 DAS	Tiller per Plant	Plant Population/m	Plant height 90DAS (cm)	Length of ear head 90DAS (mm)
6500 l/ha	74.00	110.00	4.00	150.00	92.00	14.60
5500 l/ha	71.00	106.00	4.00	146.00	90.00	14.30
4500 l/ha	66.00	95.00	3.00	124.00	86.00	13.70
ZTSCFD	44.00	60.00	2.50	102.00	76.00	11.40
CSCFD	42.00	56.00	2.50	105.00	74.00	10.60
SCPAFD (water only)	51.00	65.00	2.50	110.00	74.70	10.40

Germination count per meter row (2016)

Treatments	Germination /m 10 DAS	Germination/m 18 DAS	Tiller per Plant	Plant Population/m	Plant height 90DAS (cm)	Length of ear head 90DAS (mm)
6500 l/ha	71.00	106.00	4.00	145.00	91.00	13.80
5500 l/ha	68.00	101.00	4.00	142.00	88.00	13.20
4500 l/ha	64.00	90.00	3.00	122.00	87.00	13.00
ZTSCFD	41.00	61.00	2.50	103.00	70.00	9.2
CSCFD	39.00	58.00	2.50	101.00	72.00	11.300
SCPAFD (water only)	47.00	60.00	2.50	100.00	71.00	8.90

Appendix 9

Crop data at the time of harvesting (2015)

S.No.	Treatments	Grain yield, kg/ha	Straw grain ratio	1000 grain weight (gm)
1.	6500 l/ha	5230.00	1.58	47.00
2.	5500 l/ha	5180.00	1.50	43.60
3.	4500 l/ha	5010.00	1.49	41.80
4.	CSCFD	4200.00	1.35	36.00
5.	ZTSCFD	4070.00	1.32	33.70
6.	SCPAFD (water only)	3907.00	1.29	30.90

Crop data at the time of harvesting (2016)

S.No.	Treatments	Grain yield, kg/ha	Straw grain ratio	1000 grain weight (gm)
1.	6500 l/ha	5062.00	1.53	43.50
2.	5500 l/ha	4950.00	1.51	42.60
3.	4500 l/ha	4720.00	1.48	40.80
4.	CSCFD	4170.00	1.32	34.30
5.	ZTSCFD	4035.00	1.29	36.70
6.	SCPAFD (water only)	3780.00	1.23	32.10

Appendix 10

Performance parameters of different sowing systems

S.N.	Particulars	SCPAFD	ZTSCFD	SCFD
1.	Type of soil	Clay loam	Clay loam	Clay loam
2.	Topography	Plain	Plain	Plain
3.	Av. depth of operation, (cm)	5	5	5
4.	Av. speed of operation, (km/h)	3	3	3
5.	Draft, (KN)	3.6	3	2.31
6.	Field capacity, (ha/h)	0.35	0.36	0.38
7.	Time required for 1 ha, (h/ha)	2.63	2.77	2.63
8.	Theoretical field capacity, (ha/h)	0.54	0.54	0.54
9.	Field efficiency, (%)	65.5	66.6	70.3
10.	Fuel consumption, (l/h)	3.8	3.6	3.2
11.	Fuel consumption, (l/ha)	10.85	9.97	8.42

Appendix 11

Data sheet and cost of materials for fabrication of seed cum pressurized aqueous fertilizer drill

S. No.	Part of Machine	Material/Measured		Rate	Cost, Rs
		X section (mm × mm × mm)	Qty/No.		
1.	Main frame Strip	65×65×8 1800×600 70×70×8	35 kg 25	30/kg 30/kg	1050 750
2.	Furrow opener Tyne Shovel	50×20 40×6	45 (9 No.) 9 No.	30/kg 72/No.	1350 648
3.	Seed box (incl seed metering)			5500	5500
4.	Ground wheel Chain sprocket	360	1 No. 3 No.	500	500 600
5.	Hitch attachments	50×12	20 kg	30/kg	600
6.	Aqua ferti frame Aqua ferti tank Aqua ferti distributing line	65×65×8 PVC	25 kg 2 No	30/kg 750	750 1500
7.	Centrifugal pump		1 No.	4500	4500
8.	Nozzles		18	12	216
9.	Drive mechanism Bearings Pulleys Drive accessories		 4 No. 4 No.	 300 400	 1200 1600 1500
10.	GI pipe Fitting accessories	50	10 ft	40/ft 500	400 500
11.	Seed carrying tubes Aqua ferti carrying tubes	25.4 10	9 No.(12m) 18 No. (18m)		200 300
12.	Total cost (Rs.)				24264

Total material cost of seed cum pressurized aqua ferti drill = Rs. 24264
Fabrication charges @ 40% of material cost = Rs. 9705.6
Total cost = Rs. 33969.6
Profit at 10% of machine = Rs 3396.96
Total cost of seed cum pressurized aqua fertilizer drill = Rs. 37365/-

Appendix 12

Calculation of cost of operation of prototype seed cum pressurized aqua fertilizer drill

Following assumptions were taken while calculating the cost of operation of machine.

Assumptions:

i. Average annual use	200 hours
ii. Life of machine	10 years
iii. Salvage value	10 per cent of initial cost

A. Fixed cost

Cost of seed cum pressurized aqua ferti drill with all accessories,
Rs. = 37365

Depreciation/h, Rs. = ((37365-3736.5)/10*200) = 16.81

Interest on investment /h @ 10 per cent per annum,
Rs. = [(37365+3736.5)/2]*[0.1/200)] = 10.27

Taxes, insurance and shelter charges/h @ 2 per cent of initial cost per annum,
Rs = (37365/200)*(2/100) = 3.73

Total fixed cost of seed cum pressurized aqua ferti seed drill/h
Rs. = 30.81

Annual fixed cost of pressurized drill / h,
Rs. = 30.81*200 = 6162

B. Variable cost

Repair and maintenance cost, /h @ 5 per cent of initial cost per annum,
Rs. = (37365/200)*(5/100) = 9.34

Assumptions:

i. One labour is required for to utilize the capacity of the seed cum pressurized aqua ferti drill.

ii. Wage rate of Rs. 250 per man per day of 8 hours

Labour cost of one person (Rs./h) = Rs. 31.25

Total operating cost (Rs./h) = 30.81 + 9.34 + 31.25 = Rs. 71.4

Total cost of operation of seed cum pressurized aqua fertilizer drill (Rs./h) = Rs. 71.40

Appendix 13

Calculation of cost of operation of seed drill

The following assumptions were taken while calculating the cost of operation of machine.

Assumptions:

i. Average annual use	200 hours
ii. Life of machine	10 years
iii. Salvage value	10 per cent of initial cost

A. Fixed cost

Cost of seed drill with all accessories, Rs. = 15000

Depreciation/h, Rs. = ((15000-1500)/10*200) = 6.75

Interest on investment /h @ 10 per cent per annum,

Rs. = [(15000+1500)/2]*[0.1/200)] = 4.125

Taxes, insurance and shelter charges/h @ 2 per cent of initial cost per annum,

Rs = (15000/200)*(2/100) = 1.5

Total fixed cost of seed drill/h Rs. = 12.375

Annual fixed cost of pressurized drill / h,

Rs. = 12.375*200 = 2475

B. Variable cost

Repair and maintenance cost, /h @ 5 per cent of initial cost per annum,

Rs. = (15000/200)*(5/100) = 3.75

Total cost of operation of seed cum fertilizer drill (Rs./h) = Rs. 32.25

Appendix 14

Calculation of cost of operation of Tractor

The following assumptions were taken while calculating the cost of operation of machine.

Assumptions:

i. Initial cost	Rs. 500000
i. Average annual use	200 hours
ii. Life of machine	10 years
iii. Salvage value	10 per cent of initial cost

A. Fixed cost

Cost of tractor with all accessories, Rs.	= 500000
Depreciation/h, Rs. = ((500000-50000)/10*200)	= 225
Interest on investment /h @ 2 per cent per annum,	
Rs. = [(500000+50000)/2]*[0.02/200)]	= 27.5
Taxes, insurance and shelter charges/h @ 1 per cent of initial cost per annum,	
Rs = (500000/200)*(1/100)	= 25
Total fixed cost of tractor/h Rs.	= 277.5
Annual fixed cost of tractor / h,	
Rs. = 277.5*200	= 55500

B. Variable cost

Repair and maintenance cost, /h @ 2 per cent of initial cost per annum,	
Rs. = (500000/200)*(2/100)	= Rs. 50
Fuel charges @ 3.5 l/h = 3.5*55	= Rs. 192

Total cost of operation of tractor (Rs./h) = Rs. 519.5

Total cost of operation of Tractor Drawn seed cum pressurized aqua fertilizer drill (Rs. / h)

Rs. 519.5+32.25+71.40 = Rs. 623.15

Appendix 15

Sources wise energy requirement of different treatments, MJ/ha

S.N.	Treatments	Man	Diesel	Electricity	Seed	Fertilizer	Tractor	Machine	Total
1	Aqueous fertilizer rate 6500 l/ha	455.41	2649.92	226.78	1176	2000	136.98	186.48	6831.57
2	Aqueous fertilizer rate 5500 l/ha	460.64	2649.92	226.78	1176	2000	110.35	184.71	6808.4
3	Aqueous fertilizer rate 4500 l/ha	465.01	2649.92	217.12	1176	2000	108.35	181.77	6798.17
4	ZTSCFD	511.59	1524.29	227.38	1176	2000	76.05	165.09	5680.4
5	CSCFD	472.71	2010.35	244.56	1176	2000	136.65	198.57	6238.84
6	SCPAFD (6500 l/ha water only)	457.54	2649.92	242.17	1176	2000	110.02	175.59	6811.24

Appendix 16

Operation wise energy requirement of different treatments, (MJ/ha)

S.N.	Treatments	Tillage	Sowing	Interculture	harvesting	Threshing	Transportation of grain	Total
1.	Aqueous fertilizer rate 6500 l/ha	1713.92	1539.04	255.41	153.72	389.75	246.76	4298.6
2.	Aqueous fertilizer rate 5500 l/ha	1713.92	1539.04	255.63	147.97	380.35	246.76	4283.67
3.	Aqueous fertilizer rate 4500 l/ha	1713.92	1539.04	259.23	146.53	368.68	246.76	4274.16
4.	ZTSCFD	-	2130.38	336.45	133.6	375.64	246.76	3222.83
5.	CSCFD	1713.92	1379.73	261.8	147.17	411.62	246.76	4161
6.	SCPAFD (6500 l/ha water only)	1713.92	1572.21	254.45	146.53	390.87	246.76	4324.74

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EFFECT OF AQUEOUS FERTILIZER ON SOIL MOISTURE CONTENT, DEPTH OF SEEDING AND SEEDLING EMERGENCE FOR WHEAT

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ABSTRACT

The soil moisture and the depth of seeding are the important factors, which determine the germination of seed in rain fed areas. A study was undertaken to determine the time of emergence of wheat seed. Pot experiment was conducted in the college of agricultural engineering, JNKVV, Jabalpur. The wheat seed GW-273 were used with four levels of moisture content, i.e. 100%, 85%, 65% and 50% of field capacity (15.7%, 13.53%, 10.41% and 8.1% (DB)) and four levels of seeding depth were considered i.e. 2.5, 5, 7.5 and 10 cm. The laboratory results show that there was significant interaction observed with seed-depth, depth-moisture and moisture-seed. The time of emergence was prolonged for the 8.1% moisture content of 5-12 days. Hence, moisture availability and depth of seeding will influence the time of emergence.

***KEYWORDS:** Soil Moisture, Depth of Seed, Field Capacity, Time of Emergence & Clay Loam*

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Original Article

INTRODUCTION

India has an estimated 142 Mha cultivated area, of which about 57 Mha is irrigated and remainder 85 Mha is rain fed. Due to unavailability of sufficient soil moisture in the form of irrigation, main winter crop like wheat cannot be cultivated despite the suitability of the soil. Soil moisture stress assumes a major limiting factor determining the growth and yield of wheat in peninsular India. Moisture stress is one of the abiotic stresses, which affect the productivity. Emergence is probably the single most important event that affects the success of an annual crop. Rapid, uniform and complete emergence of vigorous seedlings, leads to high grain yield potential by shortening the time from sowing to complete ground cover, allows the establishment of an optimum canopy structure to minimize interplant competition, maximize crop yield. In rain fed areas, the depth of seedling and the available moisture, which influences the emergence of seedlings. The available moisture, water holding capacity and wilting point are mainly depends on type soil i.e. soil texture. For particular soil, it is necessary to calculate the requirement of soil moisture, which is necessary for proper germination of seed. Moisture requirement mainly depends on the root zone depth of the seed and type of seed. Moisture requirement for wheat in rain fed area is more than a gram. So, the aqua fertilizer applicator has its limiting conditions, it can't carry additional aqua fertilizer, it adds additional load on the tractor. So it is necessary to evaluate the interactions between depths of seeding, available moisture, which determines the capacity of aqua fertilizer. Hence, keeping in above view the pot experiment was conducted.

Hossein N, M, et al., (2009) conducted a pot experiment and compared the influence of different soil moisture content on seed emergence, and reported that the early emergence was observed in 10-50% field capacity as compared to 25% of field capacity. Maliwal et al., (2000) conducted a pot experiment at different moisture content of cotton seed to determine the seed emergence and reported highest and lowest germination was at 23.8 and 12% moisture content, respectively. Philip et al., (2009) conducted experiments on for seed to determine the germination and reported that the growth and biomass were higher at greater soil moisture variability and seed germination. Molatudi. Et al., (2009) studied the effect of seed size and planting depth on maize seedling emergence and growth and reported that the planting depth showed significant differences on the emergence of seedlings. Saeed et al., (2007) studied the effect of planting depth on seedling emergence and reported that emergence was decreased as depth of planting was increased. Stephen A. Et al., (2010) conducted experiments to determine the effects of planting depth, sediment grain size, and nutrients on 2 different seeds and reported that seedling emergence was inversely proportional to seedling emergence.

MATERIAL AND METHODS

Determination of Available Soil Moisture

Available soil moisture is a basic requirement of seed germination. In dry land areas, moisture availability at time of sowing is a major problem. To begin with, determination of available moisture at sowing depth was done and based on that estimation of aqueous fertilizer requirement in a given area was determined. The available soil moisture is the moisture that plants can use and it depends on soil texture also. The available soil moisture was calculated by using the formulae

ASM, (%) = FC, (%) - WP, (%)

Where,

ASW = Available soil moisture, %

FC = Field capacity, the upper limit of available moisture in which drainage ceases (Occurs at soil moisture tensions of 1/10 bar (10 container) for sandy soil and 1/3 bar (33 container) for other soils.

WP = Wilting point or lower limit of the soil moisture at which plant wilt permanently (Permanent wilting point occurs at 15 bars of soil moisture tension)

This will be helpful in determining the moisture requirement if soil type and soil texture pattern is known for dry land areas. With the help of above data total water and available water for different texture soils were also determined. Water holding capacity, in terms of available water in percent, for different soil texture designation was determined with the help of field capacity and wilting point levels of various texture soils.

Determination of Aqueous Fertilizer Requirement

The requirement of aqueous fertilizer in a given soil moisture environment depends on soil texture, field capacity, wilting point and available moisture in a particular soil. The first step in this direction was to estimate the requirement of additional soil moisture, which is just sufficient to meet the moisture abundantly, because moisture applicator has its own limitations w.r.t. Water carrying capacity and mode of aqueous fertilizer application. Also, any excess volume of water would be a hindrance in proper sowing of seed alongside of aqueous fertilizer. The estimation of aqueous fertilizer was done using the following formula.

V_1= (FC-WP) x ρ x d x w x n x W

Where,

V_1 = Amount of aqueous fertilizer, vol. l/ha;

FC = Field capacity, %;

WP = Wilting point, %;

ρ = Density of soil, g/cc;

d = Depth of seed placement, cm;

w = Width of root spread per meter row length, cm;

n = no of turns of seed drill per hectare and

W = Width of seed drill, cm

Time of Seedling Emergence

Pot experiment was conducted to determine the seedling emergence at the laboratory of college of agricultural engineering, Jabalpur. The wheat crop variety GW 273 was undertaken for the study. Polyvinyl chloride (PVC) pots of diameter; 13 cm and height; 10cm were used for seedling emergence test. Soil collected from the field was dry and filled with pot. Measured volume of water was added to each pot, which helped to compute the moisture content on a volumetric basis. The graded wheat seed was used for the experiment. Ten seeds were placed at 2.5, 5, 7.5 and 10 cm depth in part in the first week of December 2016. Four levels of soil moisture (100, 85, 65 and 50% of field capacity on dry weight basis) were considered for the study. The complete randomized design, factorial was undertaken with three replications. The soil moisture was tried to be constant throughout the experimentation by adding water to pot at each two day intervals. The water requirement was calculated on the weight loss basis. The number of days were recorded as the seedling grows up to 3mm height, and considered as time of emergence.

RESULTS

Aqueous Fertilizer Requirement for Clay Loam Soil

The aqueous fertilizer requirement for wheat in clay loam soil condition was found to be in the range of 5500-6500 l/ha, considering 9% soil moisture as wilting point. It is the utmost importance for determining the size of the aqua fertilizer drill.

Time of Emergence of Wheat at different Soil Moisture Levels

The soil moisture 100, 85, 65 and 50% of field capacity on volumetric basis was found equivalent to 15.7%, 13.53%, 10.41% and 8.1% on a dry basis, respectively in clay loam soil. In given depth of 5 cm of soil, with increased soil moisture content from 8.1 to 15.7, the time of emergence decreased from 9 to 4 days. For moisture variation, of 10.41 to 15.7, the time of emergence decreased from 6 to 4 days. Similarly for moisture variation of 15.7 and 8.1%, the time of emergence ranged as 4-7 and 9-12 for the depth 5 and 10 cm, respectively. There was significant interaction observed between depth-moisture, depth-seed and moisture-seed. The time of emergence of wheat seeds is given in the table below.

Table 1: Time of Emergence at different Soil Moisture and Varying Seeding Depth

S. No.	Time of Emergence, Days				
	Moisture Content (db)	Seeding Depth (Aqueous Fertilizer)			
		2.5	5.0	7.5	10
1.	15.7	3	4	6	9
2.	13.53	4	5	8	10
3.	10.41	4	5	8	11
4.	8.1	5	7	9	12

Table 2

S. No.	Time of Emergence, Days				
	Moisture Content (db)	Seeding Depth (Controlled)			
		2.5	5.0	7.5	10
1.	15.7	4	7	9	10
2.	13.53	4	7	10	11
3.	10.41	5	8	11	11
4.	8.1	6	9	12	12

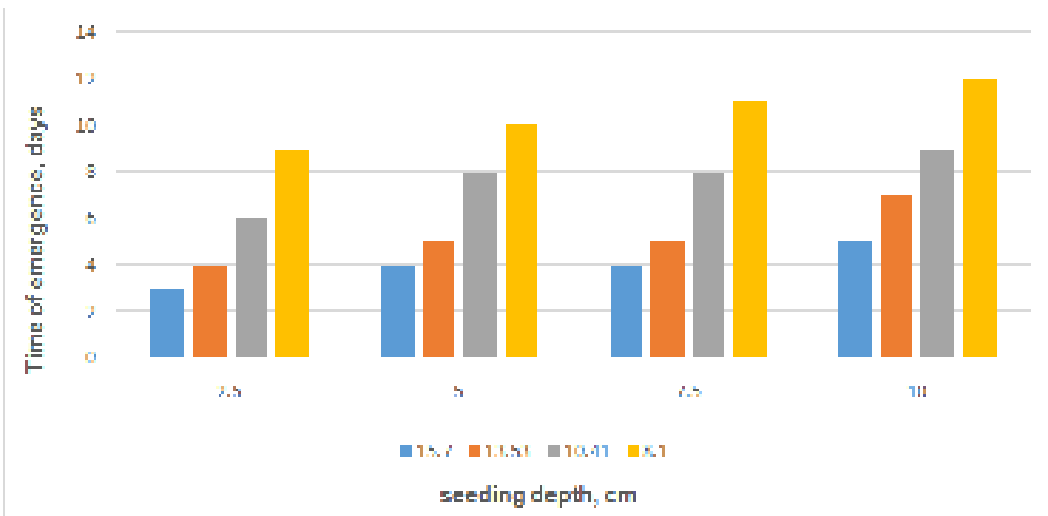

Figure 3.1: Time of Emergence for Aqueous Fertilizer

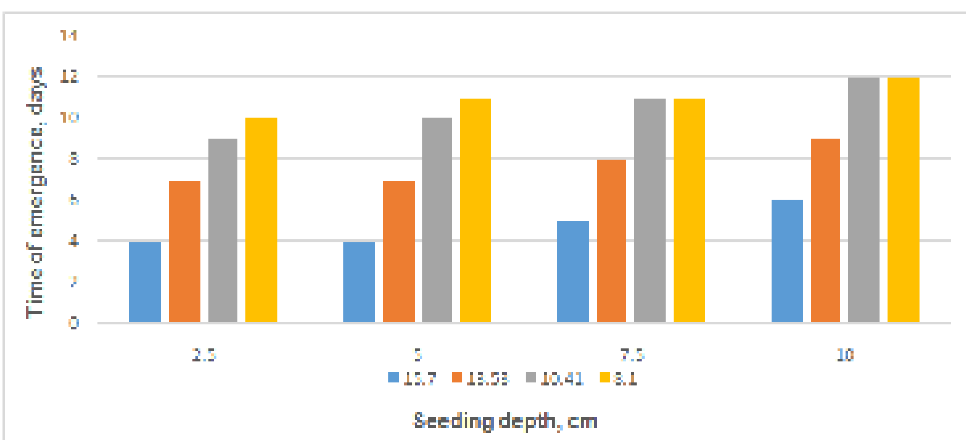

Figure 3.2: Time of Emergence (Controlled)

DISCUSSIONS

The requirement of aqua fertilizer for the clay loam soil is 5500-6500 l/ha estimated. The aqua fertilizer requirement for chickpea was calculated about 7500-8500 l/ha (Raghvendra et al.) hence, the requirement of aqua fertilizer lower than chickpea. So, this parameter decides the capacity of the aqua fertilizer tank, this reduces the extra load on the tractor. Time of emergence was excessively long i.e. 9-12 days for the depth of sowing 10 cm. Hence, the optimum depth of sowing was 5 cm because of this depth the water is easily available to the plants and also, it reduces the draft.

CONCLUSIONS

The depth of seeding and available moisture is influenced by time of emergence. The time of emergence was prolonged, as the soil moisture and seeding depth varies. There was significant interaction observed between controlled and aqua fertilizer doses, and also significant interaction was observed between seed-depth, moisture–seed and depth moisture.

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Design and development of tractor drawn seed cum pressurized aqueous fertilizer drill

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ABSTRACT

The present study was undertaken to investigate design values of pressurized pumping system. To begin with the estimated range of moisture requirement required to attain sowing moisture for different soil type was determined. For loamy sand soil an application range of aqueous fertilizer was 0.15-092 liter per meter for raising moisture from 3 to 7% to germination moisture of 14 per cent. Whereas, for sandy loam soil the same was 0.17-1.34 liter per meter for raising moisture from 4 to 12 % to germination moisture of 20 per cent and for loam soil it was 0.23-1.59 liter per meter for raising moisture from 8 to 16 % to germination moisture of 27 per cent. Based on estimation, an aqueous fertilizer requirement of 5500 to 8000 l/ha was required in experimental field with clay loam soil. To optimize different pump variables for required discharge rate five levels of pump rotational speeds i.e. 1998, 1665, 1332, 999 and 666 rpm, four levels of line pressure staring from fully opened valve i.e. gauge pressure of 0 kg/cm^{2,} by reducing valve opening area up to 2, 4 and 6 kg/cm^2 and three levels of nozzle sizes i.e. 8, 10 and 12 mm were taken. Pump rotational speed influenced discharge directly in a linear manner at fully opened valve for all pump speeds for each nozzle. As line pressure increased the discharge rate decreased. A reduction to the flow of 2 to 6 times was obtained by creating the line pressure through control valve at rotational speed of 1998 to 666 rpm. The selected design values for pressurized pumping system were pump rotational speed from 666, 999, 1332 and 1665 rpm, line pressure of 0, 2 or 4 kg/cm^2 and nozzle size of 10 mm.

Key words: Aqueous fertilizer, Discharge, Germination, Moisture content, Nozzle size, Pressure.

INTRODUCTION

In India, the un-irrigated area was 63.30 % of net sown area during 2014-2015 which shows above 60% of net sown area is without assured irrigation (Anonymous 2015). The agricultural output, in this area depends on trends of monsoon. In fact, crop cultivation is a difficult task due to uncertainty and deficit of soil moisture during sowing time, which causes the problem in germination of seed and good establishment. For proper germination and growth of plant; precise placement of seed with optimum required soil moisture content, nutrients and other climatic conditions. This machinery plays a vital role in seedbed preparation as well as in seed placement along with aqua fertilizer (Which also supplement the water) for healthy initial growth. Placements of aqua fertilizer also have greater significance for enhancing the agriculture production. But in moisture deficit areas the applied basal dose of fertilizer remains unavailable due to inadequate soil water to dissolve, dilute and convey it to root depth level in winter and summers.

This problem can be solved by using aqueous fertilizer, because these fertilizers are energy saving, economical and they can be applied uniformly with the flexibility in formation of different grades. This may facilitate successful germination and initial root and shoot development of the plants. Application of aqueous fertilizer at root zone depth can be achieved by using suitable aqua fertilizer Seeding/planting machine. To supplement soil moisture and nutrient requirements of different crops, a continuous or intermittent supply of aqueous fertilizer may be needed. A suitable technology is required for application of aqueous fertilizer alongside of seed (Dey A.K. 2004).

Pressurized metering system will prove useful for precision seeding of different crops in deficit moisture condition areas by controlled application of aqua-fertilizer according to soil moisture.

MATERIALS AND METHODS

Estimation of aqueous fertilizer requirement for selected soil-moisture-crop conditions

Determination of available soil moisture (ASM): To begin with, determination of available moisture at sowing depth was done and based on that estimation of aqueous fertilizer requirement in given area was determined. The available soil moisture is the moisture that plant can use and it depends on soils texture also. The available soil moisture was calculated by using the formula:

$$\text{ASM, (\%)} = \text{FC, (\%)} - \text{WP, (\%)} \quad \text{...eq. (1)}$$

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Where,
ASW = Available soil moisture, %;
FC = Field capacity, the upper limit of available moisture at which drainage ceases (Occurs at soil moisture tensions of 1/10 bar (10 centibar) for sandy soil and 1/3 bar (33 centibar) for other soils; and
WP = Wilting point or lower limit of the soil moisture at which plant wilt permanently (Permanent wilting point occurs at 15 bars of soil moisture tension).

Determination of aqueous fertilizer requirement: The requirement of aqueous fertilizer in a given soil moisture environment depends on soil texture, field capacity, wilting point and available moisture in a particular soil. The first step in this direction was to estimate the requirement of additional soil moisture which is just sufficient to meet the moisture requirement for germination. It is not possible to provide extra moisture abundantly, because moisture applicator has its own limitations w.r.t. water carrying capacity and mode of aqueous fertilizer application. Also any excess volume of water would be a hindrance in proper sowing of seed alongside of aqueous fertilizer. The estimation of aqueous fertilizer was done by using the following formula:

V_1= (FC-WP) x ñ x d x w x n x W …eq. (2)

Where,
V_1 =Amount of aqueous fertilizer, vol. l/ha;
FC = Field capacity, %;
WP = Wilting point, %;
ñ = Density of soil, g/cc;
d = Depth of seed placement, cm;
w = Width of root spread per meter row length, cm;
n = No. of turns of seed drill per hectare and
W = Width of seed drill, cm

Design values of seed cum pressurized aqua fertilizer drill: Based on the information of obtained soil moisture requirements for different types of soil in dry land and rain fed areas and placement the different components of drill were developed. Apart from fertilizer metering system, the pressurized aqua fertilizer drill consisted of the following critical components.

1.Main frame
2.Seed hopper
3.Seed metering mechanism
4.Tubes for seed and aqueous fertilizer
5.Furrow opener
6.Ground wheel

Need based modifications have been done for the above said components.

Main frame: Frame was subjected to torsion and bending due to induced draft. Design was based on the stresses produced in the frame, the following assumptions were taken.

Width of furrow opener = 6 cm
Depth of furrow opener = 8 cm
Soil resistance = 0.5 kg/cm^2
Cross- section of furrow = 6 x 8
Cross -sectional area =48 cm^2
Draft = soil resistance (kg/cm2) x cross- sectional area of furrow (cm)
= 0.5 x 48
= 24 kg
Torque produced on toolbar (T) = 0.5 × 8 × 6 × 0.4 (clearance from ground) × 9 (no. of tyne)
= 86.4 kg-cm

In addition to torque the bending moment is also produced in the toolbar. The toolbar can be assumed as simply supported frame. The maximum bending moment will be at the centre. The reactions at each of the two supports is = 24 × 9/2 = 108 kg

The maximum bending moment at the centre is calculated as

M = 3.5 P × 2.5 x – 3Px – 2Px – Px
= 9.15 Px – 6Px = 3.15 Px
= 3.15 × 24 × 45 = 3400 kg-cm

T_e = $(M^2 + T^2)^{1/2}$ …………………………………….. eq. 3
= $[(3400)^2 + (8640)^2]^{1/2}$
= 9284 kg-cm

The maximum shear stress developed at the centre of toolbar is given by

$S_s/y = T_e/I$ ……………………………………………………... eq. 4

Where,
S_s = shear stress at section
Y = distance of outermost fibre from neutral axis
T_e = equivalent torque
I = moment of inertia (bd^3/12 for rectangular section and for square section b = d)

Let Ss = 500 kg/cm^2
I = bd^3/12 …. eq. 5
= d^4/12

Therefore,
I/Y = (d^4/12)/d/2 = d^3/6 …. eq. 6
d^3 = 6 Te/Ss
= 9284 × 6/500 = 111.4 cm^3
d = 4.81 cm or 5 cm.

So, size of toolbar is 50 × 50 mm.

Tank for liquid fertilizer storage: The aqueous fertilizer needs to be carried along with the pressurized aqua fertilizer seed drill for continuous application in the field. Dey et al. (2004) mounted the aqueous fertilizer tank of 500 litre capacity at the rear of the peristaltic pumping based aqua fertilizer seed drill. The machine during its operation in the field faced serious instability problem in vertical direction. To counter the challenge in the present design of the experimental setup two tanks were mounted on a platform made of m.s. flat of size 40×10 mm on the both sides of aqueous fertilizer metering pumping system. Two cylindrical tank of 200 litre capacity each with a vertical opening were mounted on main frame

Seed hopper: Considering physical and engineering properties of wheat and seedling requirement the trapezoidal cross section hopper was fabricated with side wall slope 15° to the horizontal. The vertical rollers were mounted at bottom. The bottom of the box is flat and rounded at the corners. The location of box in seed drill was kept 145 mm above the ground. The appropriate height helps preventing the excessive bending of seed delivery tubes. The length and width of the rectangular cross section of seed flowing were kept as 70 and 25 mm, respectively.

Seed metering mechanism: Seed metering mechanism is very important component of sowing machine and its function is to distribute seed uniformity at desired application rate with minimum damage. In case of seed drill, the metering mechanism precisely controls seed flow in a row tithe help of bulk seed metering mechanism. To achieve uniform seed flow in the row the metering device needs to draw seed from bulk and deliver those to seed tube. The commonly recommended metering system on seed drill are internal double run, stationary opening seed metering with agitator and fluted roller type.

Furrow opener: The single shovel type furrow opener was used to apply the required amount of aqueous fertilizer in the furrow alongside of the seed.

The vertical roller metering mechanism: Vertical roller metering mechanism consists of roller with spherical cells on the periphery of roller. The roller was made up of aluminum, mild steel and nylon of 5 cm diameter for laboratory study. The drive from ground wheel was transmitted through the main shaft using chain-sprockets with the transmission ratio of 0.5 (ground wheel to seed plate). The angle of metering device was kept as 15° to the horizontal.

Ground wheel: The ground wheel was provided to drive the metering mechanism. The speed of metering was controlled by the ground wheel through power transmission system of chain and sprocket mounted on the shaft of ground wheel and metering mechanism. The specified range of diameter of ground wheel as per RNAM test code is 350-450 mm keeping dimension of other components of machine particularly frame size and furrow opener height, ground wheel was taken as 360 mm which confirms the specified range. The wheel rim was made of mild steel flat with 100 mm width and 1.6 thicknesses. Lugs of 25*5mm were provided, on the periphery of the wheel for better traction.

Drive mechanism of the pump: This seed cum pressurized aqua fertilizer drill was planned to be operated by a 45 hp tractor. Different moving component of the machine were supplied power from the tractor. The centrifugal pump used to supply aqueous fertilizer to the nozzles was powered by the PTO drive of the selected tractor with speed of 540±10 rpm. A suitable power transmission system was designed and fabricated to accomplish this task. The power transmission designed taking universal coupling fitted to PTO, cone pulleys, two shafts of dia.32mm, four bearings (P207), followed by two cone pulleys of cast iron of size 2016-1004 mm dia. and connected to another cone pulley of size 2540-762 mm through v-belt drive and further it is connected to the centrifugal pump.

Nozzles of distributor along with plastic tubes: Three different sizes of nozzles along with tubes of dia. 8, 10 and 12 mm were used for carrying aqueous fertilizer.

Fitting of the pipes with pressure-volume control valve: This type of aqueous fertilizer metering was continuously subjected to the pressurized flow under pump operation a pipe of G.I. material was used instead of plastic for fitting. A G.I. pipe having a diameter 5 cm was used to facilitate flow through distributor from tank with the help of pump. The pressure and volume control valve was fitted in between the pump and the distributor for calibration of discharge w.r.t. pressure.

Test procedure for experiment: The instrumentation for measurement of rpm, time and discharge included Tachometer, Stopwatch, Beaker and Measuring cylinder etc. The study included determination of discharge rate from the all tubes for various levels of nozzle size, rpm and pressure.

Rotational speed of pump: Different levels of pump rotational speed 1998, 1665, 1332, 999 and 666 rpm (Table 1) were obtained by varying PTO rpm from 300, 250, 200, 150 and 100 with the help of throttle.

Pressure levels: Provision of pressure-volume control valve was made to restrict flow of aqueous fertilizer which creates relative pressure between pump and valve. Four levels of line pressure, staring from fully opened valve i.e. gauge pressure of 0 kg/cm^2, similarly 2, 4 and 6 kg/cm^2 (Table 1) were maintained in order to vary discharge rates for each level of pump speed.

Measurement of discharge w.r.t time: The discharge from tubes was measured with three replications to minimize error.

Table 1: Plan of experiments

Variables	Levels of variables	Measured parameter
Nozzle size	8, 10 and 12 mm	Discharge (lit/ sec)
Rotational speed of pump	1998, 1665, 1332, 999 and 666 rpm	
Line pressure	0, 2, 4 and 6 kg/cm^2	

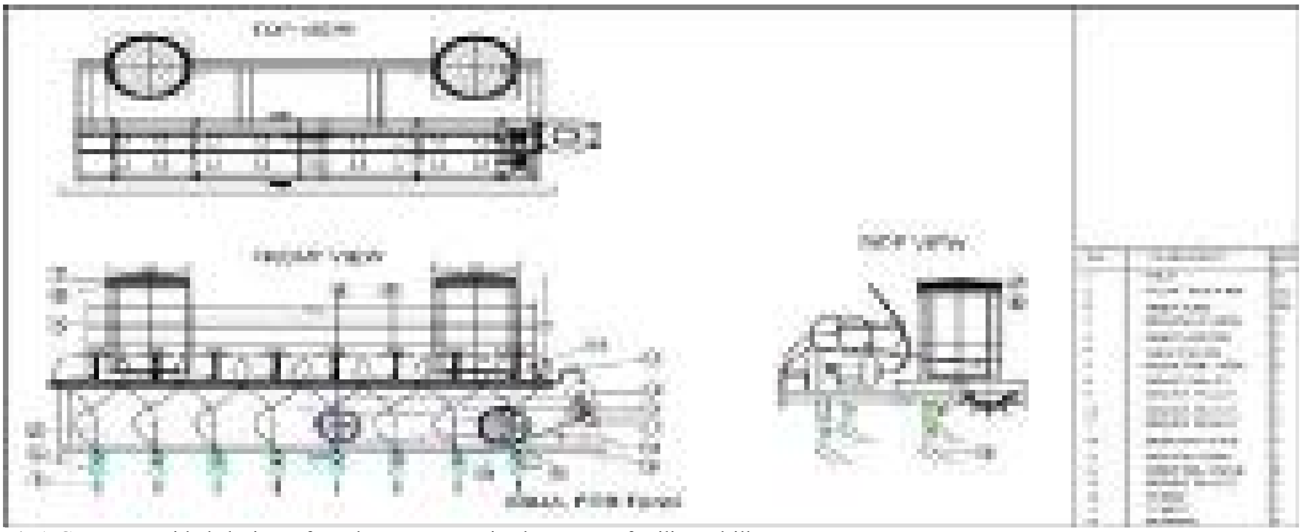

Fig1: Computer aided design of seed cum pressurized aqueous fertilizer drill

Discharge from nine tubes was measured with 1000 ml beakers were placed at the discharge end of tube. But due to pressurized aqueous fertilizer it permitted less time to collect discharge from each tube. So that all nine tubes bind at one end of frame then discharge was measured w.r.t. time with help of bucket and measuring cylinder of 1000 ml of capacity. Precise measurement of time was done by Stopwatch.

Fabrication of tractor operated nine row pressurized aqua fertilizer system: The final design values of different component were determined (Fig 1) . The fabrication of different component and their assembling was done in the workshop of College of Agricultural Engineering Jabalpur. Thus, the prototype was ready for test evaluation (Fig. 2).

RESULTS AND DISCUSSION

Extra water requirement to acquire germination soil moisture at given initial moisture for different soils: Different areas face different levels of moisture deficit. At the same time, there is possibility of crop germination and growth over a small range of soil moisture level. With these facts in view, an analysis was done to evaluate water requirement for given initial soil moisture to obtain germination moisture for three different soil types namely loamy sand, sandy loam and loam soil. A brief description in respect of above is presented below for different soils, separately.

Loamy sand soil: The water requirement was estimated for raising the soil moisture level to 14 %, suitable for germination in loamy sand soil, from the assumed soil moisture of 3, 5 and 7 per cent. The water requirement ranged from 0.15-0.23, 0.29-0.46, 0.44-0.69 and 0.44-0.92 liter per meter for depth of application of 2.5, 5, 7.5, and 10 cm, respectively for variation initial moisture from 7 to 3 per cent. The maximum water requirement observed was 0.92 lit per meter for depth of 10 cm and initial moisture content of 3% and minimum requirement was 0.15 liter per meter for 2.5 cm and initial moisture of 7 per cent. It was noticed that for loamy sand soil an application range of aqueous fertilizer was 0.15-0.92 liter per meter (Fig. 3).

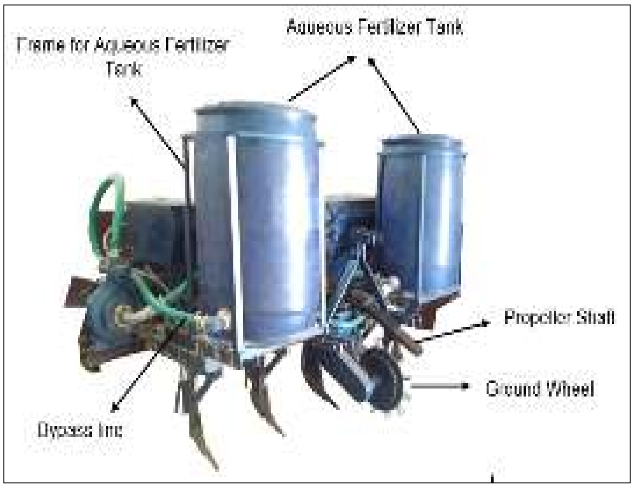

Fig 2: Developed seed cum pressurized aqueous fertilizer drill

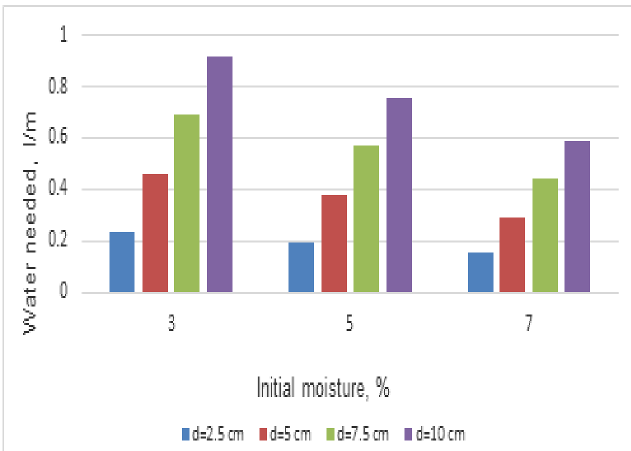

Fig 3: Requirement of additional moisture for different depth of sowing (AGM, 14%)

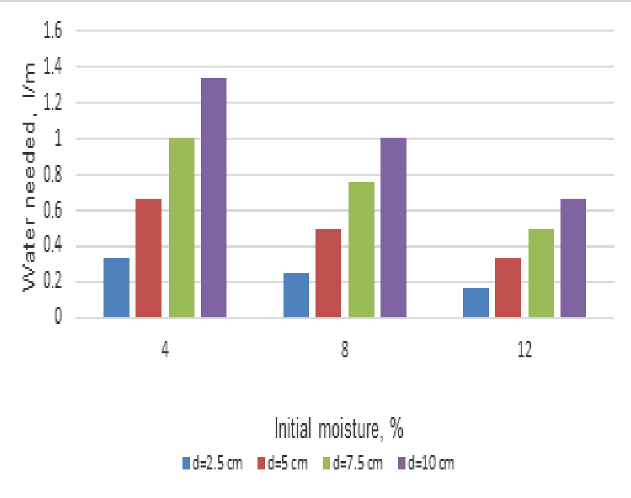

Fig 4: Requirement of additional moisture for different depth of

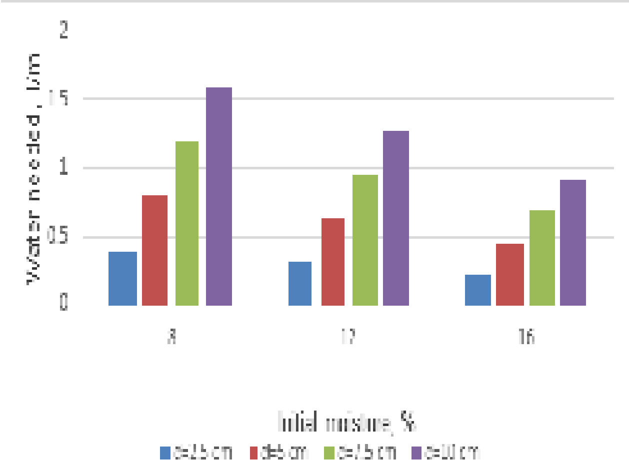

Fig. 5: Requirement of additional moisture for different depth of sowing (AGM, 27%) Aqueous fertilizer requirement for clay loam soil of experimental field

Sandy loam soil: The water requirement was estimated for raising the soil moisture level to 20 %, suitable for germination in sandy loam soil, from the assumed soil moisture of 4, 8 and 12 per cent. The water requirement ranged from 0.17-0.34, 0.34-0.64, 0.50-1.01 and 0.67-1.34 for depth of application of 2.5, 5, 7.5, and 10 cm, respectively for variation initial moisture from 12 to 4 per cent. The maximum water requirement observed was 1.34 lit per meter for depth of 10 cm and initial moisture content of 3% and minimum requirement was 0.17 liter per meter for 2.5 cm and initial moisture 12 per cent. It was noticed that for loamy sand soil an application range of aqueous fertilizer was 0.17-1.34 liter per meter (Fig. 4).

The water requirement was estimated for raising the soil moisture level to 27 %, suitable for germination in loam soil, from the assumed soil moisture of 8, 12 and 16 per cent. The water requirement ranged from and 0.23-0.40, 0.46-0.80, 0.69-1.20 and 0.92-1.59 liter per meter for depth of application e.g. 2.5, 5, 7.5 and 10 cm, respectively for variation initial moisture from 16 to 8 per cent.. The maximum water requirement observed was 1.59 lit per meter for depth of 10 cm and initial moisture content of 8% and minimum requirement was 0.23 liter per meter for 2.5 cm and initial moisture 16 per cent. It was noticed that for loam soil an application range of aqueous fertilizer was 0.23-1.59 liter per meter (Fig. 5).

Aqueous fertilizer requirement for clay loam soil of experimental field: The proposed aqueous fertilizer applicator at the time of sowing is to provide maximum additional moisture to facilitate germination in soil. Thus, keeping in view the available moisture at about wilting point and minimum germination moisture of above 8% and also the limitations of seed drill to carry large volume of aqueous fertilizer, the aqueous fertilizer requirement with clay loam soil was finalized as 5500-7500 l/ha. Kamal Kant et al., (2007) estimated aqueous fertilizer requirement with sandy loam soil was 8000-10000 l/ha. Anonymous (1996) also estimated same requirement in their experiment at WTC, IARI, New Delhi.

Discharge v/s pump rotational speed at various levels of nozzles at fully open valve

The influence of pump rotational speed on discharge rates was evaluated. The discharges from three levels of nozzle sizes i.e. 8, 10 and 12 mm were recorded for five levels of pump rotational speeds e.g. 666, 999, 1332, 1665 and 1998 by keeping when pressure and volume control valve was fully open. It was observed that the pump rotational speed directly influenced the discharge in linear manner for different levels of nozzle sizes, Figure 6-9. The trend was observed very similar when nozzle sizes increased from 8 to 12 mm. Generally the discharge from nine different nozzles was same because nozzle openings were uniformly spaced.

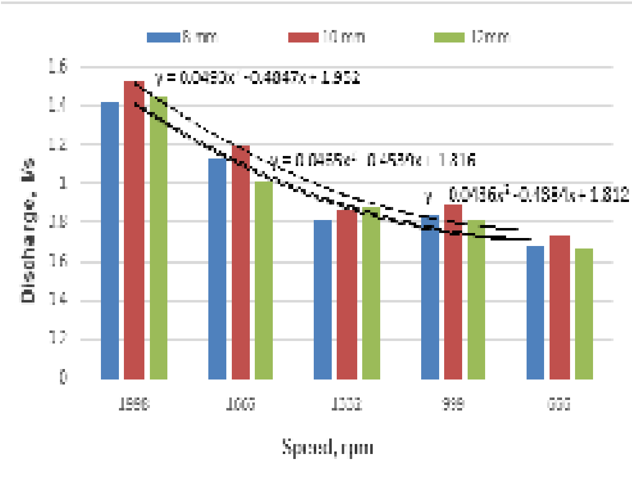

Fig 6: Discharge at different nozzle sizes at various rotational speeds of pump at fully open valve

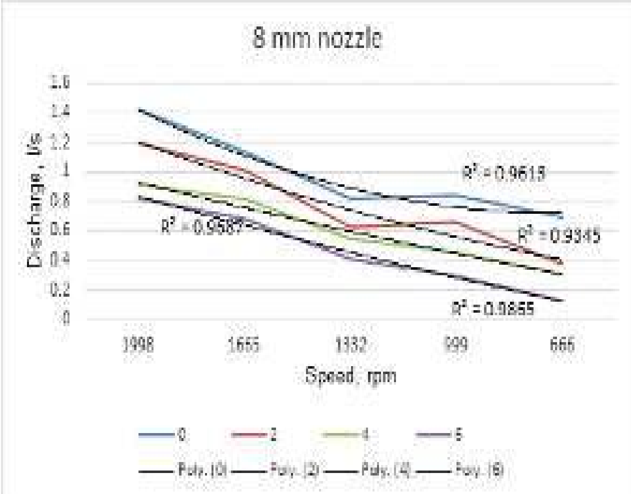

Fig 7: Discharge vs rotational speed of pump for various levels of line pressure of aqueous fertilizer

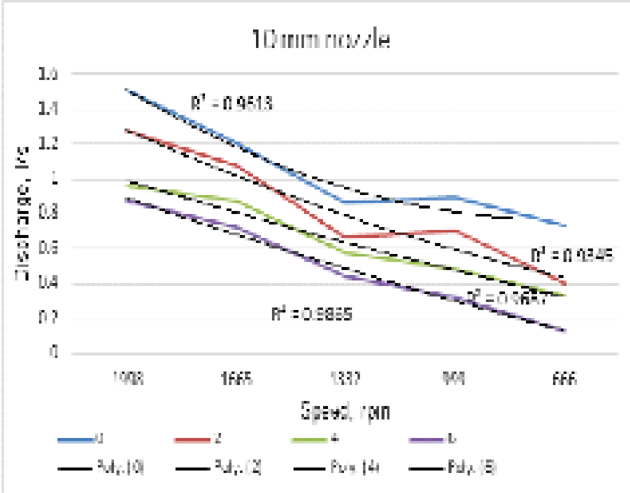

Fig 8: Discharge vs rotational speed of pump for various levels of line pressure of aqueous fertilizer

Minor variation noticed due to possible minute variation in nozzle sizes while fabricating.

The discharge from nozzle diameter of 8, 10 and 12 mm openings increased linearly with increase in pump rotational speed from 666-1998 rpm, Figure 6. For 8 mm nozzle size, the range of discharge was 0.69 to 1.41 l/s for pump speeds range of 666 to 1998 rpm. For 10 mm nozzle size, the range of discharge was 0.74 to 1.53 l/s for pump speed range of 666 to 1998 rpm. For 12 nozzle size, the range of discharge was 0.72 to 1.48 l/s for pump speeds range of 666 to 1998 rpm. At 1665 rpm the three nozzles sizes gave discharge of 1.13, 1.21, and 1.17 l/s. The discharge increased by 63.77, 69.44 and 49.25%, for increased in rpm from 666 to 1665 for three nozzle sizes of 8, 10 and 12 mm, respectively.

Similarly, the observed increase in discharge due to speed changes from 1665 to 1998 rpm was 25.66, 28.57 and 45 % for three nozzle sizes of 8, 10 and 12 mm. The results indicated that nearly uniform variation in discharge was obtained over speed range of 666 to 1998 rpm. This variation in discharge was as per expectation. More the pump speed of a centrifugal pump, which is positive displacement pump, more will be discharge. Thus, the pumping system used for metering aqueous fertilizer was capable to give a discharge variation of to 0.13 to 1.21 l/s for different nozzle sizes.

Statistical analysis was done to know the relative performance of the pressurized aqua fertilizer metering system for discharge rates at various pump rotational speed for different nozzle size. The discharge obtained at pump rotational speed of 666, 999, 1332, 1665 and 1998 was significantly at 1% level.

Discharge vs. nozzle sizes at pump rotational speed at fully open valve: The discharge rate for various levels of nozzle sizes at pump rotational speeds levels i.e. 666, 999, 1332, 1665 and 1998 rpm at fully opened valve was recorded. It was observed that discharge rate is similar for each nozzle size i.e. 8, 10 and 12 mm for various levels of pump rotational speeds, The experimental set up results showed that at 666 rpm the discharge from three nozzles i.e. 8, 10 and 12 mm were 0.69, 0.73 and 0.70 l/s, which confirmed the principle of mass conservation in the pipe flow. At 1998 rpm, the three nozzle sizes of 8, 10 and 12 mm gave discharge of 1.42, 1.51 and 1.46 l/s. respectively, in the same order which showed relative higher value for 10 mm. As expected, the discharge from different nozzle sizes at same rotational speed of pump should almost be the same. The aqueous fertilizer was pumped by centrifugal pump and the latter being a positive displacement pump discharge should be same irrespective of nozzle sizes. However, minor variation in discharge may be witnessed due to deviation in nozzle size from design value caused while fabricating the same. At

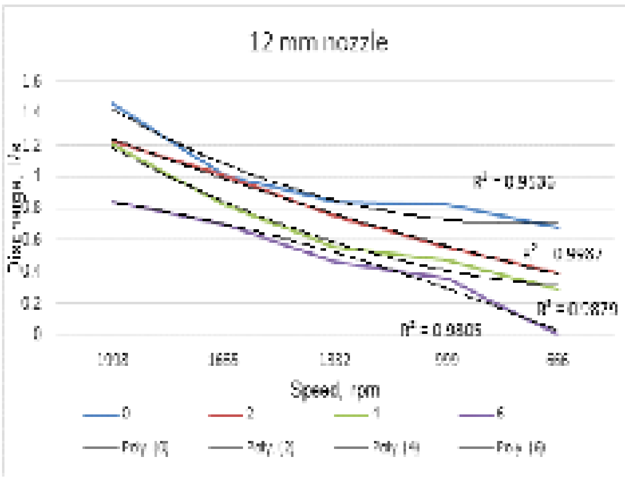

Fig 9: Discharge vs rotational speed of pump for various levels of line pressure of aqueous fertilizer

Table 2: Statistical analysis for discharge, pump speed and pressure

Source	DF	SS	MSS	Fcal		Ftab 5%	Ftab 1%
S	4	12.582	3.145	55419.38	**	2.45	3.48
P	3	7.023	2.341	41245.02	**	2.68	3.95
SxP	12	0.342	0.029	502.17	**	1.83	2.34
D	2	0.062	0.031	545.02	**	3.07	4.79
SxD	8	0.008	0.001	17.86	**	2.02	2.66
PxD	6	0.005	0.001	13.29	**	2.18	2.96
SxPxD	24	0.000	0.000	0.16	ns	1.61	1.95
Error	120	0.007	0.000				
Total	179	20.028					
SE=	0.025	CV%=	3.413				

lower diameter, the line pressure will increase leading to variation in pump efficiency also. In addition, there could be possibility of slippage in belt pulley system of power transmission at lower size of nozzle due to development of higher line pressure. Having given scope for above variables, the discharge from different nozzle sizes at a given rpm should be same.

It was observed that velocity of discharge increased for smaller nozzle size i.e. 8 mm than 10 mm and 12 mm. This causes the problem of seed and soil displacement. Hence nozzle size of 8 mm was not used for fabrication of pressurized aqueous fertilizer metering system. (Table 2)

CONCLUSION

The main design variables of pressurized aqua fertilizer metering system were rotational speed of pump, calibrated line pressure and nozzle size in that order of importance. Pump rotational speed influenced discharge directly in a linear manner at fully opened valve for all pump speeds for each nozzle size. A discharge range of 0.69 to 1.41, 0.74 to 1.531 and 0.72 to 1.48 l/s could be attained by varying the pump speed from 666 to 1998 respectively, for three nozzle sizes of 8, 10 and 12 mm, respectively. For each pump rotation discharge from 8, 10 and 12 mm nozzle sizes was almost same so, a positive displacement centrifugal pump was an appropriate selection and same output was obtained irrespective of nozzle sizes with minor variations. Keeping total discharge and pattern of aqueous fertilizer flow from nozzles a 10 mm nozzle size was found optimum. In pressurized aqueous fertilizer metering system, discharge rates decreased with increase in assumed forward speed for constant levels of pump rotational speed and line pressure. The developed pressurized system is capable of delivering a maximum 3600 l/h and minimum of 369 l/h of aqueous fertilizer with refilling time of 6.66 to 65 minute, respectively.

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