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Microcontroller based granular urea application attachment for rice transplanter

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ABSTRACT

Transplanting and fertilizer application for rice production in Bangladesh are tedious, time consuming and laborious task, and mostly done manually. Mechanical transplanting of rice becoming popular in the country in recent years and few machines have been developed for granular urea deep placement, however, having some limitations. Placing granular urea precisely along with rice transplanting, an attempt was under taken to design and fabricate an electronic control granular urea applicator to be attach with a 4-row walk behind type rice transplanter. Fabrication of the electronic granular urea applicator was done in the workshop of the Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh. Physical structure of the attachment was assembled with available parts of BARI granular urea applicator. A DC gear motor was coupled with metering disk shaft to rotate and pick granular urea from hopper. Moreover, its speed was synchronized with the picker speed of the rice transplanter by a microcontroller Arduino Mega 2560. A computer program was developed and compiled successfully into Arduino IDE, where an equation was derived and incorporated into loop control structure. The program can also be used for any kind of applications where variable rate is required. The machine was found successful in test run and laboratory-based experiments. Average spacing of granular urea placement was found 34.71 cm with 1.38% missing hill, Its power requirement was found about 20 W. This innovation provided options for performing granular urea application and rice transplanting, two most laborious tasks simultaneously which might minimize the cost of production as well as human drudgery with an error free manner.

Introduction

Rice (*Oryza sativa* L.) is the major food crops nearly half of the world's population. It becomes second largest grain crop after corn in more than 100 countries spread across six continents and in varying agroecological and socioeconomic conditions. The total rice-cropped area and milled rice production in the world were 161.48 million hectares and 481.54 million tons, respectively in 2016 (IRRI, 2017). Bangladesh became the fourth largest rice growing nation after China, India and Indonesia occupying 11.38 million hectares of land with a milled rice production of 34.71 million MT (BBS, 2016). With increasing rate of 2 million people per year, total cultivable land is decreasing 80,000 ha annually due to urbanization, changes in food habit, competition with new crops (Kabir *et. al.*, 2016).

Few of the operations of rice production are being partially mechanized in recent time. However, transplanting of paddy is still manual and recognized as most tedious and time-consuming task that requires about 123-150 man h ha^{-1} and roughly 19-22% of the total labor requirement of rice production (Islam *et. al.*, 2015). Generally, this task is commonly practiced as a method of weed control in wet or puddled soil. It requires less seed but much more labor compared to direct seeding. Manual transplanted paddy also requires longer time to mature due to transplanting shock. Whereas, mechanical rice transplanting increases yield and labor productivity with reduced production cost. Recently, farmers are rapidly adopting transplanting machines because of labor shortage at pick transplanting period.

Besides, transplanter can be used to apply chemical fertilizers as an integral operation during transplanting. Usually, farmers apply urea fertilizer by broadcasting into

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standing water or irrigated paddy fields resulting about 60% loss of the fertilizer as greenhouse gas, deep percolation into the groundwater and runoff to surrounding canals and rivers that pollutes these water sources (Iqbal, 2009). The process results in a huge loss for farmers as well as creating a critical negative impact on the environment. Deep placement of nitrogen fertilizer (N) is an alternative solution for increasing the N use efficiency of wetland rice production and minimizing the adverse effects of fertilizer on the environment (Bautista *et al.,* 2001). In recent time, considerable amount of urea is manufactured as granules. Granules are larger, harder and more resistant to moisture. As a result, granular urea has become a more suitable material for fertilizer blends. It was observed that the application of Urea Super Granule (USG) in rice production significantly reduces the N loss from soil and increased affectivity by 20% to 25% (BRRI, 2008). However, manual application of granular urea at accurate pace is labor intensive, cumbersome and very slow method. It takes 200–300 man-h to apply urea granule in one hectare of land. There are few mechanical granular urea applicators available in the country which is not efficient and much labor is still needed to push or pull during operation (Ahmed *et al.,* 2014). The operators complain about back pain, suffer from fatigue in legs and fingers. Maintaining accurate depth and spacing for an operator is very difficult. Therefore, performance of the fertilizer applicators and the yield of rice are found unsatisfactory (Sultana, 2010).

The precision agriculture is an emerging option for improving efficiency of crop production inputs, like seed, fertilizer, herbicide etc. The use of sensors and micro-computers into agricultural machinery provide useful information to optimize the overall operations and productivity. Re-engineering the existing mechanical technology combined with precise ICT based technology results in improvement of productivity and accuracy as well as reducing the cost of production and human drudgery. Hossen *et al.* (2016) modified an existing rice transplanter for transplanting paddy and apply prilled urea at a certain depth simultaneously and reported 20-30% saving of fertilizer use in rice production. In this study, an attempt was made to design and fabricate a micro-controller based granular urea applicator as an attachment with a 4-row walk behind type rice transplanter for simultaneous rice planting and granular urea application, and determine missing rate, power consumption and distribution pattern of the applicator.

Materials and Methods

Experimental design

A microcontroller based granular urea applicator was designed to be attached with a walk behind type rice transplanter (Daedong DP-480, Korea, 3 kW, 1800 RPM engine) and it was fabricated at the engineering workshop of the Department of Farm Power and Machinery, Bangladesh Agricultural University. The linear spacing between pickers of the rice transplanter was 30 cm. It is required to place the granular urea in the middle of two consecutive rows of seedling hills (Figure 1). From BARI developed (Bangladesh Agricultural Research Institute) granular urea applicator the metering disks, hoppers with discharge tubes were used in this experiment and assembled with 5 mm mild steel frame. Hopper and metering device were aligned vertical and the clearance between the two-metering disks were kept 60 cm. Electronic circuit-controlled DC gear motor (China, 30 RPM, Nominal voltage 12V, Torque 137 oz-in, Gear ratio 100:1, Output shaft style D-shaft and diameter 6mm) was incorporated on the metering disk shaft. Motor D-shaft (half circular shaft) and metering disk shaft were coupled with a pulley. The motor was rigidly attached with the steel frame structure which was attached behind the transplanter maintaining the alignment with the cups (Figure 2). The whole attachment was weighed 5.66 kg. Arduino Mega 2560 microcontroller was programmed considering input variable as the time interval of two consecutive picker action of the rice transplanter. As an output, smooth change in RPM of DC motor was considered. A computer program was developed and compiled into Arduino IDE. A couple of laboratory tests were conducted to determine missing rate, power consumption and application pattern of the applicator along with rice transplanting.

Electronic circuit design

The applicator was featured with DC gear motor which was controlled with an electronic circuit. An H-bridge motor controller (L298N, China) was incorporated with Arduino Mega 2560 microcontroller board (Italy) to drive the DC motor. The Arduino Mega 2560 microcontroller board was programmed with the calibration of motor RPM considering dynamic ratio of transplanting speed and granular urea application. Time requirement for the single pick of plural forks (picker) of the rice transplanter was considered as an input data to adjust the output value as well as precise rotational speed for the DC motor. A Reed switch (china) with a magnet arrangement was attached into the crank of transplanting rotor shaft (Figure 3) which reeds every rotation of the shaft. Time interval for every two successful reed data were collected continuously and considered as an input value for the designed system. The rate of application of granular urea is directly related to the seedling picking rate. For every two-consecutive picking of seedlings one granular urea need to be applied.

A DC supply (Lithium polymer 3-cell battery) source was connected with the circuit. This multi-cell battery can provide 3 different voltages such as 5 V, 12 V and 24 V whereas 12 V and 5 V were supplied into the motor controller and Arduino Mega 2560, respectively. Figure 4 shows the flow diagram of the electronic system.

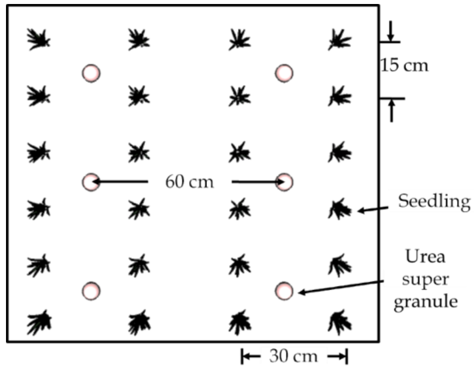


Fig. 1 Rice seedling and granular urea placement

(a) Granular urea applicator attachment with rice transplanter

(b) Modified granular urea applicator structure

Fig. 2 Structural design of granular urea applicator

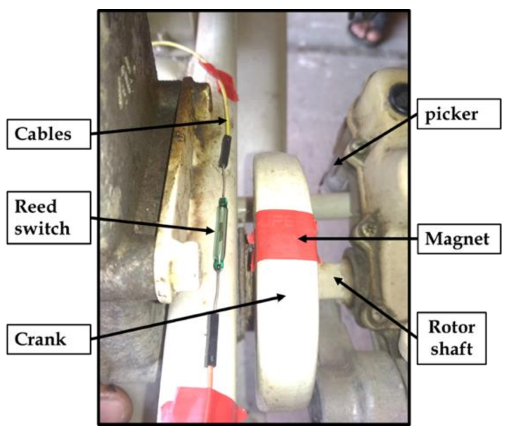


Fig. 3 Reed switch arrangements

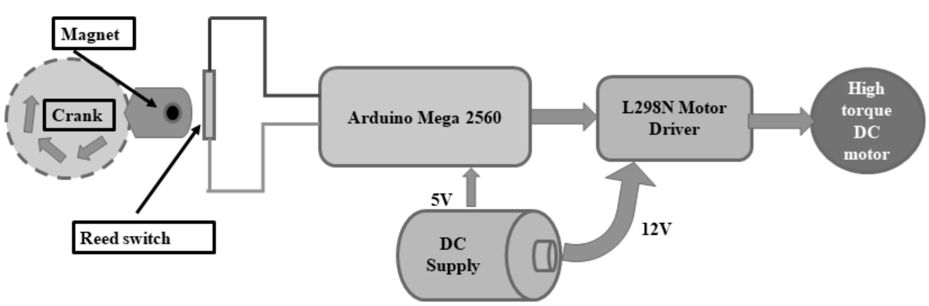


Fig. 4 Diagram of the electronic system

The ENA pin of L298N motor driver was connected to pin 10 of PWM section of Arduino board with the connector. Similarly, IN1 and IN2 pins were connected to pin 9 and 8, respectively into PWM section. A common ground pin was short circuited. In output section of motor driver L298N (China), O1 and O2 were connected with 12V DC motor. For laboratory testing, a multimeter was connected to read output voltage from this terminal. A 12 V battery was connected into VCC pin of L298N. A magnetic hall sensor (reed switch) RL2 was connected with the analog input A3 on Arduino board.

Selection of DC motor and power consumption

RPM of the DC gear motor was chosen by analyzing the relative dynamic motion of the transplanter and granular urea application. Forward speed of the rice transplanter was obtained by recording time required for the rice transplanter to travel a 20 m distance in the field. The speed of transplanting can be computed using the following Eqn. 1. (Hunt, 1962)

$$S = \frac{D}{t} \times 3.6 \tag{1}$$

where, S is the transplanting speed in km/hr, D the distance in m, t the time required to cover the distance D in s.

Average speed of the rice transplanter was found $2.15\ \text{km h}^{-1}$ Which is equal to normal walking speed of an operator. 15 cm hill to hill distance (dense planting) and four granules need to apply between eight hills require a full revolution of the metering disk. The RPM needed for the metering disk shaft was found 29.86. Therefore, maximum 30 RPM DC gear motor was selected to supply required torque for rotation of the granular urea metering disk and it was available in local market. Power requirement of the designed applicator was found by measuring supplied voltage and corresponding current at the time of full load operation. The following Eqn.2 was used to measure power requirement of the designed applicator.

$$P = V \times I \tag{2}$$

where, P = power in watts, V = applied voltage in volts and I= current in ampere.

Time required applying granular urea

To determine time requirement of two consecutive picks, 10 video shots were taken by a camera with 30 fps for the picker activity within an operating condition of rice transplanter and saved as MPEG-4 Part 14 file format. The videos were played back into a media player software Daum Player (version: 1.6.55390, Daum Kakao Corporation 2006-2015) on a PC. The picker speed was so fast that the count by human eye was difficult whereas for easy count those videos were played with a playback speed of 0.3*X*. Eqn. 3 was used to determine time required for a single pick.

$$\text{Time required for two consecutive pick} = \frac{t}{N} \tag{3}$$

where, t = time (s), N = no. of picks within time t. Table 1 show the recorded data for number of picks in 10 s where time requirement for two consecutive picks was calculated using Eqn.1. Moreover, time requirement for applying two consecutive granular urea applications is double of time required for two consecutive picks. Here, maximum and minimum time interval range was considered to apply granular urea for further necessary calculations. Average time required for two corresponding picks for transplanting picker was found 0.30 s. The maximum and minimum values of 37 and 33 nos. picks yields 0.2702 s and 0.303 s of time interval for consecutive picks, respectively. Whereas, it indicates 0.5404 s and 0.606 s time interval to apply two consecutive granular urea respectively. If transplanter speed increases, the picker speed will also increase. Therefore, two consecutive pick require less time. Simultaneously, it is also same for granular urea application. Less time requirement means the metering device will rotate with higher speed as a result the DC motor needs to run with higher speed. Motor controller receives the value range 0-255 from the arduino program where higher value indicates the higher speed of motor. A relationship was established with higher value of microcontroller as 255 with lower value of interval time 0.5404 s i.e. 540.4 ms. For minimum value of 33 no. of pick in 10s indicates 24.75 RPM of the motor.

Table 1 Time required applying granular urea

Sl. no.	No. of pick in 10 s	Time required for two consecutive pick, s	Time interval to apply granular urea, s
1	33	0.30	-
2	33	0.30	-
3	33	0.30	-
4	33	0.30	-
5	33	0.30	-
6	36	0.28	-
7	37	0.27	-
8	33	0.30	-
9	33	0.30	-
10	33	0.30	-
Avg	33.7	0.30	-
Max	37	0.2702	0.5404
Min	33	0.3030	0.606
Std	1.49	0.01	

Avg. = average, Max = maximum, Min = minimum, and Std = standard deviation

Arduino program development

Arduino 1.8.5 IDE was installed into a PC and used to write down and compile programs. As per setup of system, the variables were declared first. Analog input A3 pin was declared as the reed function having constant integer value with 0 or 1. Time at initial condition was set at value of zero, variable time (time1), and "intervaltime" was declared as unsigned long. Here "intervaltime" variable was the time requirement for single pick of rice transplanter picker. The floating-point number was set for "value" variable which stands for the value from 0 to 255. This was the output variable resulting value to motor controller for smooth change in voltage output. In this system, the value 0 means the output volt was 0 and 255 means the output 12V. So, any value can be converted by the motor controller to drive a DC motor with exact amount of voltage. Arduino PWM pin 10, 9 and 8 were defined EnA, in1 and in2, respectively. Then the void setup () was declared as the 3 pins were in output mode. The main function voidmotorOne() was created where digitalWrite(in1, HIGH); digitalWrite(in2, LOW); analogWrite(enA, value) were defined. Only EnA was analog which had variable "value". A loop control structure was created where reedState variable was read from the digital reed when the reed occurs (High). Time in ms was recorded and saved into "time1" variable. "intervalTime" variable was determined by subtracting previous value of time where the previous value was initially defined as zero. This variable was the time interval of two successful reeds which was same as the time interval of two consecutive pick of rice transplanter. After that the recorded value of latest time was kept as an initial value of time for executing forward of program as well as for finding next time interval. In every time of program execution, new time interval was generated and it was used for generating a new value. The developed program was compiled in Arduino IDE in a PC (Windows 10 Pro, 2015 Microsoft Corporation, Intel Core (TM) i5-42000U CPU @ 1.60GHz, 64-bit operating system, x64-based processor)

Missing rate and distribution pattern

Average 2.7 g sized granular urea was collected from the local market of Mymensingh district. Hopper was filled 70% of its volume with granular urea to minimize breakage losses due to overload of the metering device. Two buckets were placed just below the two falling points and the system was started and continued for a minute. The number of revolution and granular urea was counted and recorded. This experiment was repeated for 14 times and missing percentage was calculated using following Eqn. 4 (Alam *et al.,* 2014):

$$\%\ \text{Missing} = \frac{\{(a \times b) - c\}}{(a \times b)} \times 100 \qquad (4)$$

where, a = number of turns/min, b = number of cups, and c = number of granules collected/min.

In order to simulate field condition, the rice transplanter along with the granular urea applicator attachment was run over a grass land about 10 m. Three different trials were repeated and the spacing between each granule was measured by measuring tape. About 30 data were recorded for each trial and these data were compiled, tabulated and analyzed by IBM SPSS Statistics (version 20) in accordance with the objective.

Results and Discussion

Time interval for granular urea application

From Table-1 30 RPM (full speed) of the motor indicates the value of 255 which is directly related with time interval of 540.4 ms. Corresponding lowest value was 210.375 for 24.75 RPM which indicates the time interval of 606.00 ms. From this relationship, Eqn. 5 was developed by interpolation and plugged into loop control structure of arduino program to generate the precise value of variable "value" for precise voltage supply to motor controller.

$$\text{Time interval value}, X = Y_2 + (X_2 - X) \times \frac{Y_1 \sim Y_2}{X_1 \sim X_2} \qquad (5)$$

where, X_1 = 540.4 ms, X_2= 606 ms, Y_1 = highest value (255), Y_2 = lowest value (210.375).

To apply granular urea at precise position along with rice transplanting, the arduino receives successful reeds from reed switch at operating condition of transplanter. The time interval for consecutive successful reed is determined continuously by arduino and it was incorporated into loop control structure of arduino program. The values generated from the program is send to the motor controller to convert/analyze in terms of voltage output to drive DC motor with a variable speed. The speed variation results variable speed of metering disks as well as the placement of granular urea. The developed program not only be used for granular urea applicator but also for any variable applications where output variable changes on the basis of input.

Missing rate

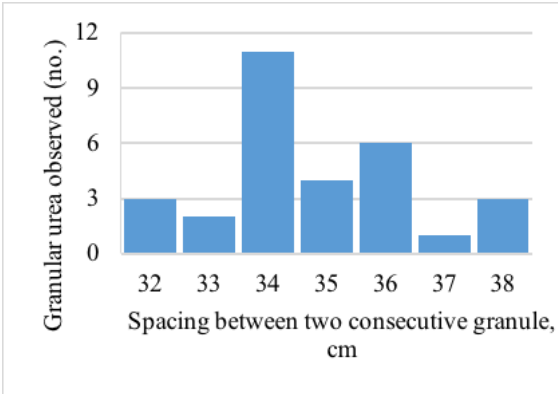
Percent missing of granular urea in a laboratory test was determined by using Eqn. 3 and presented in Table 2. In laboratory condition the device showed missing rate of 1.38% with respect to average 26.93 number of turns and 106.14 numbers of granules which can be negligible. The system also resulted that average 19.85 W power was required at 1.64 A average current. Moreover, it could be concluded that the system was run successfully in the laboratory basis. This level of accuracy obtained because of the laboratory experiment where there was no dynamic motion created to the applicator which may cause vibration.

Table 2. Missing percentage of granular urea associated with power consumption

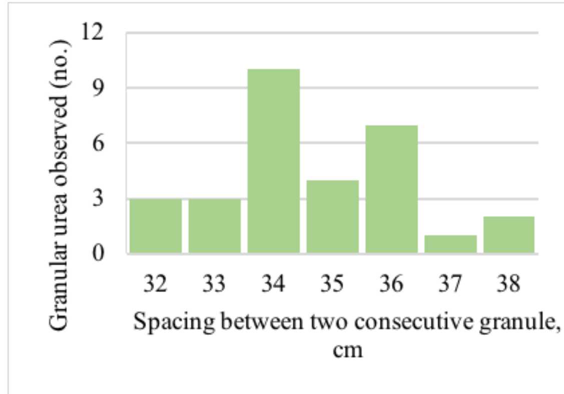
Sl. no.	No. of turns	No. of granules	% Missing	Supplied voltage, V	Current I, A	Power, W
1	26	104	0.00	12.22	1.77	21.63
2	27	107	0.93	12.15	1.78	21.63
3	27	106	1.85	12.20	1.30	15.86
4	26	104	0.00	12.19	1.50	18.29
5	27	105	2.78	12.19	1.75	21.33
6	26	106	1.92	12.21	1.74	21.25
7	28	111	0.89	12.19	1.68	20.48
8	28	110	1.79	12.11	1.62	19.62
9	27	106	1.85	12.06	1.68	20.26
10	28	111	0.89	12.10	1.60	19.36
11	26	103	0.96	12.01	1.62	19.46
12	27	105	2.78	12.05	1.58	19.04
13	26	106	1.92	12.05	1.61	19.40
14	28	110	1.79	12.05	1.68	20.24
Average	26.93	106.14	1.38	12.13	1.64	19.85
Maximum	28	111	2.78	12.22	1.78	21.63
Minimum	26	103	0	12.01	1.30	15.86
Standard dev.	0.83	2.70	0.92	0.07	0.13	1.54

Table 3. Distribution pattern of Granular urea

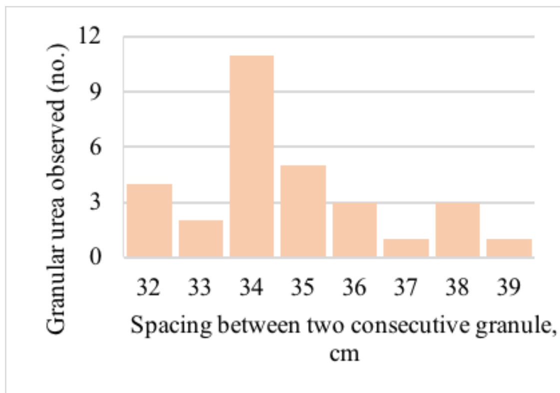
Sl. no.	Trial-1		Trial-2		Trial-3	
	Reading, cm	Distance, cm	Reading, cm	Distance, cm	Reading, cm	Distance, cm
	0	0	0	0	0	0
1	35	35	36	36	35	35
2	70	35	70	34	67	32
3	106	36	106	36	101	34
4	140	34	141	35	137	36
5	176	36	174	33	171	34
6	211	35	210	36	208	37
7	244	33	245	35	244	36
8	282	38	279	34	279	35
9	316	34	312	33	314	35
10	352	36	344	32	352	38
11	390	38	382	38	386	34
12	426	36	416	34	420	34
13	461	35	452	36	454	34
14	495	34	485	33	492	38
15	532	37	520	35	531	39
16	566	34	554	34	564	33
17	598	32	589	35	598	34
18	632	34	621	32	632	34
19	666	34	658	37	667	35
20	699	33	690	32	700	33
21	733	34	724	34	732	32
22	771	38	758	34	767	35
23	805	34	794	36	805	38
24	839	34	828	34	839	34
25	873	34	864	36	871	32
26	909	36	898	34	905	34
27	943	34	934	36	937	32
28	979	36	972	38	973	36
29	1011	32	1006	34	1007	34
30	1043	32	1040	34	1041	34
Average		34.77		34.67		34.70
Max		38		38		39
Min		32		32		32
Std Dev.		1.68		1.60		1.88



(a) Trial-1



(a) Trial-2



(c) Trial-3

Fig. 5 Distribution pattern of granular urea

Distribution pattern

Distribution pattern of granular urea is shown in Table 3. Average distances of granular urea were 34.77 cm, 34.67 cm and 34.70 cm for three trials, respectively which were almost similar but the requirement of two consecutive granular urea spacing was 30 cm. Figure 5 shows that the distribution pattern of granular urea declined in grass field. From these three figures it was clearly visible that the spacing of 34 cm was found higher in number. The physical design of metering device of attachment and furrow opener and closer may cause such displacements of granules from accurate placement. It could be reduced by adjusting the falling time through discharge tube to the field in a certain depth. Therefore, displacement for the vibration of machine is beyond control to adjust. However, this spacing will not affect the corresponding granule placement throughout the operation since both transplanting and granule application tasks are done simultaneously by the same machine unit.

Conclusion

Rice transplanting and fertilizer application are most laborious tasks in rice production system. Timeliness of operation, optimum yield and lowering production cost are the most desirable aspects to make the production system profitable. In recent years, mechanical rice transplanting became popular in Bangladesh due to its higher productivity and advantage over manual transplanting and shortage of laborer during peak planting season. Chemical fertilizer application especially urea as granular form is also becoming popular due to increase in rice yield and environment friendly. This research provided an option for performing both the tasks simultaneously with a single machine. A micro-controller based granular urea applicator was designed and fabricated for simultaneous operation of transplanting and granular urea application. A computer program for the microcontroller was developed and compiled successfully. The attachment was operated successfully along with rice transplanter and resulted 1.38 percentage of missing rate with 34.71 cm average spacing for granular urea. Power requirement of the system was about 20 W. Electronic aid over urea deep placement provides more accurate placement of granular urea at proper spacing. The developed system might be a promising technology to apply granular urea which may increase production.

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