Indian Journal of Agricultural Sciences **93** (2): 190–194, February 2023/Article
https://doi.org/10.56093/ijas.v93i2.132319

Performance evaluation of an electronically controlled tractor-operated applicator for liquid urea application

PARVEEN DHANGER[1]*, ROHINISH KHURANA[1], ANOOP KUMAR DIXIT[1], MANJEET SINGH[1] and AMRIT KAUR MAHAL[1]

Punjab Agricultural University, Ludhiana, Punjab 141 004, India

Received: 16 January 2023; Accepted: 28 January 2023

ABSTRACT

Currently, granular urea (most commonly used fertilizer) is applied through broadcasting by farmers in the field. Granular urea causes significant losses due to slower soil mineralization rates, as well as ammonia volatilization and immobilization. Hence, fertilizing crops is becoming an increasingly difficult task due to low use efficiency and in mulch field conditions, it becomes more severe. The research done on mechatronic systems of applying liquid fertilizer by spot injection in field is limited. In the present study, the performance of the developed tractor operated liquid urea applicator consisting of electronic metering mechanism was evaluated at the Research Farm of Punjab Agricultural University, Ludhiana, Punjab during 2020–22. Research was done at two different types of soil (S1: sandy loam, and S2: loam) for three different forward speeds (3.6, 2.7, 1.8 km/h). Results obtained from experiments indicated that both soil type and forward speed had a significant ($P<0.05$) effect on the application rate of liquid urea. The best results were obtained without affecting crop yield at a forward speed of the machine 2.7 km/h with the application rate of 1090.85 litre/ha and 1035.18 litre/ha, fuel consumption 4.13 litre/h and 4.02 litre/h and crop yield 39.50 q/ha and 39.63 q/ha, for soil type S1 and S2 respectively. The cost of operation of machine was found 1996.53 ₹/ha. Developed tractor operated liquid urea applicator would help in improving conventional practices which are not aligned with environmental protection (e.g. gaseous emissions and nutrient losses) and boost the adoption rate of mechanized fertigation in the crops.

Keywords: Applicator, Electronic metering, Liquid urea, Mulch field

Crop fertilization is a type of high intensity work (Cheng *et al.* 2017). The method and type of fertilizer application to the crop have significance role in smooth uptake of nutrients by the plant (Ismail *et al.* 1991, Gu and Gao 2000). Excess nitrogen losses were caused by the widely used fertilizer urea (Adjetey *et al.* 1999). Urea alone accounted for more than 60% of all chemical fertilizer consumption each year (Anonymous 2021, 2022). A slower rate of soil mineralization, as well as increased nitrogen de-nitrification, immobilization, and more ammonia volatilization take place in the straw mulch field (Tian *et al.* 2001, Dhanger *et al.* 2021). As a result, a low amount of nitrogen will be available for plant uptake (Rahman *et al.* 2005, Chakraborty *et al.* 2008). So, there is a need to apply fertilizer at a suitable site in a proper way that meets best management practices (BMP) principles. Deep nitrogen placement is the most effective method for decreasing nitrogen oxide emissions from both fertilized conventional tillage and no-till drill soils (Liu *et al.* 2006). In comparison to solid fertilizer, liquid fertilizer had the advantages of high fertility and easy absorption, as well as ease of application and reduced pollution (Salah 2006, Spangberg *et al.* 2011, Canfora *et al.* 2015). As a result, the need for liquid fertilizer application machinery will increase in the future (Qiu 2016).

To overcome the challenge of liquid urea application in high-residue fields in no-till wheat farming, a self-propelled walk-behind type nitrogen (liquid urea) applicator was developed and evaluated in high residue field (Singh *et al.* 2013, Parveen 2022). This machine had a mechanical metering system, which faces limitations during liquid urea application. At present, limited research units are engaged in the research of electronically controlled liquid fertilizer application machinery (Zhan 2015, Qi *et al.* 2020). Hence, there was a need to develop and evaluate a liquid urea applicator consisting of an electronic metering mechanism to apply liquid urea below the residue mulch into the upper layer of soil surface under high mulched no-till.

MATERIALS AND METHODS

The present study was carried out at the Research Farm of Punjab Agricultural University (PAU), Ludhiana,

[1]Punjab Agricultural University, Ludhiana, Punjab. *Corresponding author email: parveenfmpe@gmail.com

Punjab during 2020–22 to evaluate the performance of the developed tractor operated liquid urea applicator consisting of electronic metering mechanism.

Machine description: It is a tractor-operated mounted type machine for liquid urea application in a straw mulch field consisting of two main systems, viz. electronic metering mechanism and wheel assembly unit. A wheel assembly unit comprised of the rotary wheel unit, injector, MS frame, spring clamp, center circular shaft, bearings, seal rings, O-rings and U-clamp. The center shaft played the role of axial positioning in the liquid urea injector. The rotary wheel containing hollow spoke pipe was moved in the forward direction to make a circular motion. The bearings, seal rings and O-rings played the sealing role in the central hub of the wheel. The developed machine consists of five rotary wheels. The liquid urea injector wheels are towed wheel. A tractor pulls the urea injection wheels to realize the operation of the liquid urea injection application. Each wheel of machine injects the liquid urea at spacing of 300 mm and up to 60 mm depth in the soil or straw. The row spacing of the rotary wheels was adjustable and could be adjusted according to the spacing given in the crop. Spot injection method is preferred due to advantage of less disturbance of soil and also prevents loss of ammonia in environment.

In electronic metering mechanism water pump, limit switch, proximity sensor, relay and solenoid valve were provided for cutoff mechanism. The key component of the control system was the electronic metering mechanism, which acts as a controller for the input information. Complete hardware selection of electronic components was based on the system design requirements. The independent cut-off would take according to the speed of the rotary wheel. A specially designed circuit regulates the whole cut-off mechanism. The amount of fertilizer injected per unit area was consistent and ensured fertilizer injection uniformity in field operations. From the literature analysis of the control system, it was found that the fertilizer injection of the liquid fertilizer affected by the following factors: accuracy of solenoid valve, response time of relay, processor operating speed, tractor travel speed and relay switching time. Simultaneously, an ARDUINO, communication module, flow sensor, power module and display were provided for the flow measurement of the system with a power source of 12V DC power. A complete water pipeline structure was also developed including water pump, distributor pipe and pressure gauge. The liquid urea travelled from the fertilizer tank to the soil via different components attached to the pipeline system. The machine performs all processes (injection, cutoff, and flow measurement) in a single pass.

Evaluation procedure: The developed tractor operated liquid urea applicator was evaluated in the straw mulch field where wheat was sown with the Happy Seeder machine. The crop (HD 2967) was sown in the first week of November and harvested in the first week of April. Agronomic practices recommended by the Punjab Agricultural University (PAU), Ludhiana were followed and dependent parameters (application rate, fuel consumption and crop yield) were recorded on the basis of the independent operational parameters. In Happy Seeder sown wheat crop, recommended urea application dose is 40 kg before the first irrigation and 40 kg before the second irrigation. The same procedure had been followed in the experiments. The field evaluation of tractor-operated liquid urea applicator was conducted at the research farm of Punjab Agricultural University (PAU), Ludhiana, Punjab during 2020–22. The experiment was conducted at two locations having different soil types, viz. sandy loam (S1) and loam (S2) at three forward speeds, viz. 3.6 (F1), 2.7 (F2) and 1.8 km/h (F3) for application of liquid urea in mulch field. The location of the study was at two places, viz. Department Research Farm-1 (Near Gate No. 4) and Department Research Farm-2 (Near Punjab Remote Sensing Centre), Farm Machinery Power Engineering, Punjab Agricultural University, Ludhiana. The experimental layout and treatments were designed in completely randomized block design (CRBD). Due to different locations, the dependent parameters were initially analyzed for variance of homogeneity between different soils using Levene's test. The dependent parameters were checked with the help of a post-hoc test (Tukey adjustment) at 5% level of significance. Manual broadcasting of granular urea was taken as a control (C) treatment for the comparison in the experiments. The views of tractor-operated liquid urea applicator for liquid urea application during operation in the field are shown in Fig 1 (a) and (b) respectively.

The effect of the forward speed of the applicator and different soil types was evaluated on the performance of the liquid urea applicator in terms of application rate (A_R), fuel consumption (F_C) and crop yield (C_Y). The application rate of liquid urea (litre/ha) was calculated from total discharge of liquid and measured by re-filling the tank with a measuring flask in the measured area corresponding to the three-forward speed. Fuel consumption of the tractor was measured by fitting a fuel meter with a fuel flow meter having a 1.0 ml least count. The fuel meter reading was measured before and after the operation. The test was repeated three times in the field and average fuel consumption was taken later. It was expressed as litres per hour. The formula used for fuel consumption is given below:

$$\text{Fuel consumption, litre/h} = \frac{\text{Fuel consumed (ml)}}{\text{Time (s)}} \times 3.6$$

After the operation of straw incorporation, the wheat crop was sown using a Happy Seeder. After the application of urea as per the experimental study, the yield of wheat was measured from each plot treatment on quintal per hectare basis (Dhanger *et al.* 2022). The other operational parameters performed in all the treatments were the same except for the methods of urea application. Statistical analysis was carried out at 5% level of significance using statistical software SAS 9.3 for Analysis of variance and post hoc (Tukey's) test for comparisons of different treatment combinations. The significance or non-significance between treatments was evaluated at 5% level with the help of a post-hoc test for

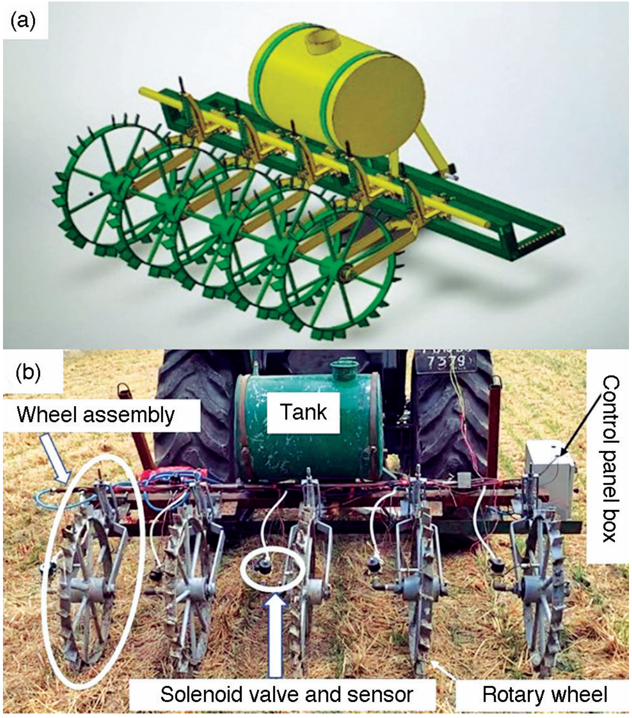

Fig 1 View of tractor-operated liquid urea applicator with the electronic metering system; (a), CAD and; (b), infield during operation.

comparison. The straight-line method was used to calculate the economics of tractor-operated liquid urea applicator including the components such as variable cost, fixed cost, operating cost, etc. while payback period and benefit-cost ratio were determined using BIS code IS 9164.

RESULTS AND DISCUSSION

Application rate of liquid urea: The statistical analysis revealed that the effect of different soil type and forward speed on application rate was found significant (P<0.05). The value of coefficient of variance (CV) was 2.7 and mean application rate of liquid urea was found 1134.27 litre. When forward speed was increased, injection time for liquid urea was less. It resulted in a lower amount of liquid urea injected per injection. It was observed from mean values, the application rate was increased with a decrease in forward speed. The application rate was found more in S1 type of soil in comparison to soil type S2. Furthermore, different type soil also had the effect of liquid urea injection due to differences in soil properties. Maximum LS-mean of application rate of liquid urea (1625.66 litres) was found in the S1*F3 combination of treatment which could be due to the lower forward speed and soil type (S1). The minimum application rate of liquid urea (726.50 litres) was obtained from the S2*F1 treatment at maximum forward speed and soil type S2 [Fig 2(a)]. The application rate during the field experiments and lab evaluation was found almost in similar trend with respect to the forward speed of the machine. However, the application rate differed significantly. The treatment effect of application rate on individual soil types (S1 and S2) corresponding to forward speed was found significant (Fig 2 (b)). Whereas effect of replications in both soil type was found non-significant at the 5% level of significance. Variance of homogeneity between different soil types (S) was homogenous at the 5% level of significance for application rate. This allowed further analysis of variance (ANOVA) of the data on the application rate corresponding to soil type and forward speed. The effect of soil type (S) and forward speed (F) on application rate was significant at 5% level of significance. Additionally, replication effect corresponding to soil showed non-significant effect at the 5% level of significance. The first order interaction soil type and forward speed (S*F) was non-significant at 5% level of significance for application. Different combinations of forward speed in ascending order for application rate were: F1, F2 and F3.

Furthermore, the comparison between the treatments Tukey multiple comparison test was performed. LS-mean of application rate also depicts that each soil level differed significantly from each other. The application rate for combination of treatments S1*F1, S1*F2 and S1*F3 was significant to each other at 5% level of significance. Similarly, combinations of treatments S2*F1, S2*F2, and S2*F3 were also significant to each other. Further, non-significant difference was observed between S1*F1 and S2*F1 the combination of treatments.

Fuel consumption: The effect of different soil type and forward speed was found non-significant at 5% level of significance. The value of coefficient of variance (cv) was 0.80 and mean fuel consumption in the field was found 4.26 litre/h. The fuel consumption has no systemic relationship between soil type (S) as well as forward speed (F). Maximum fuel consumption (4.53 litre/h) was found in S2*F3 combination of treatment, whereas minimum fuel consumption (4.07 litre/h) was measured from the S2*F2 combination of treatment as shown in Fig 2 (b). However, combination of treatment fuel consumption was found non-significantly different at 5% level of significance from each other. Further, S1*F1 and S2*F3 combination of treatment were found significant (P<0.05) to each other [Fig 2 (b)].

Treatment's effect on fuel consumption in soil (S1) corresponding to forward speed was found significant, whereas, in soil (S2) the effect was found non-significant. The effect of replication of forward speed on both soil type was also non-significant. The effect of replication of forward speed on both soil type was also non-significant at 5% level of significance. Variance of homogeneity between different soil types (S) was tested using Levene's test for homogeneity of variance for fuel consumption. It shows that variance was homogenous at 5% level of significance for fuel consumption. This allowed further analysis of variance (ANOVA) of the data on the fuel consumption corresponding to soil type and forward speed. The effect of forward speed (F) on fuel consumption was significant and effect of soil type (S) was non-significant. Additionally, replication effect corresponding to soil also showed non-significant effect at 5% level of significance. The first order interaction soil

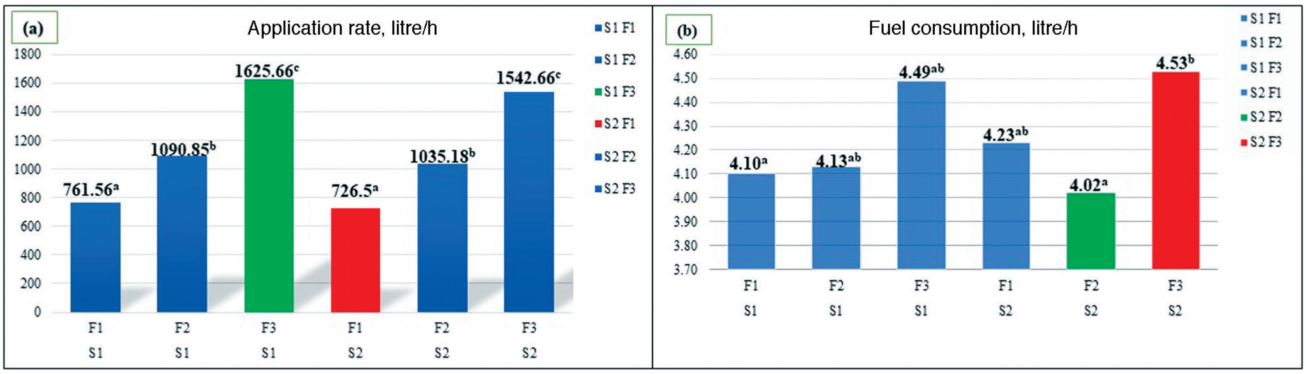

Fig 2 Data graph; (a), application rate and; (b), fuel consumption at different forward speed (F) and soil type (S). Means with same small letter are not significantly (P>0.05) different.

type and forward speed (S*F) was also non-significant at 5% level of significance for application rate. Further, Tukey multiple comparison test was performed for comparison between the treatments. The fuel consumption for most of combination of treatments was observed non-significant to each other at 5% level of significance except S1*F1 and S2*F3, S2*F2 and S2*F3 treatment combinations.

Crop yield: In the experiment, the broadcasting method of urea application was used as a control to compare liquid urea application by applicator in the field. The statistical analysis revealed that the effect of different soil type and forward speed was found significant at 5% level of significance. The value of coefficient of variance (CV) was 1.89 and average crop yield was found 37.53 q/ha in the field. The crop yield of wheat had decreased with increase in forward speed, and also changed with change in soil type. Maximum crop yield (40.40 q/ha) was found in S1*F3 combination of treatment, whereas minimum yield (32.60 q/ha) was obtained from the treatment S2*B (Control). However, crop yield significantly differed at 5% level of significance. Crop yield in both soil types was found significantly (P<0.05) different from each other. The effect of replication of forward speed on both soil type was found non-significant. Variance of homogeneity between different soil types (S) was tested using Levene's test for homogeneity of variance for the crop yield. It showed that variance was homogenous at 5% level of significance for crop yield. This allowed further analysis of variance (ANOVA) of the data on the crop yield corresponding to soil type and forward speed. The effect of forward speed (F) on crop yield was found significant and effect of soil type (S) was observed non-significant. Additionally, replication effect corresponding to soil was found non-significant. The first order interaction soil type and forward speed (S*F) was also non-significant at 5% level of significance for crop yield.

The crop yield for the treatments of broadcasting in each soil was observed not significant to each other. It was also observed from the experiment that effect of forward speed (F1) had a significant effect on the yield in comparison to other forward speed (F2 and F3). The yield of the crop was increased with a decrease in forward speed due to the injection of more liquid urea. The higher amount of liquid urea discharged may result in more availability of nitrogen to plants in mulch field. As the forward speed was increased the injection amount of liquid urea decreased that was not easily available for the plants. The further broadcasting of granular urea might result in less availability due to straw mulch field. The reason may be non-availability of nitrogen to uptake by the crop, as lots of amount of urea was retained in the straw, which resulted in volatilization losses (Table 1).

Economics of tractor operated liquid urea applicator: Total cost of liquid urea application was found to be ~1997 ₹/ha. The profit per hectare was found ₹144 as compared to custom hiring charges. The developed machine had a payback period of 1.5 years with a benefit-cost ratio of 1.2.

An electronically controlled tractor-operated applicator for liquid urea application was developed at PAU, Ludhiana. It was evaluated for the performance in actual field conditions of paddy straw mulched field that indicated that the effect of forward speed significantly affects fuel consumption, application rate and wheat yield. It outperformed at a forward speed of 2.7 km/h, applicator rate

Table 1 Statistics of soil type (S) and forward speed (F, km/h) effect on application rate (A_L, litre/ha) and crop yield (C_Y, q/ha)

Head	DF		Sum of square		Mean of square		F-value		p-value		Significance	
	A_L	C_Y	A_L	C_Y	A_L	C_Y	A_L	C_Y	A_L	C_Y	A_L	C_Y
S	1	1	18470.4	10.6	18470.4	10.6	81.5	21.1	<.0001	0.0006	S	S
rep (S)	4	4	1805.0	6.0	451.2	1.5	1.9	3.0	0.1887	0.0617	NS	NS
F	2	3	2149489.0	154.7	1074744.5	51.5	4745.5	102.4	<.0001	<.0001	S	S
S*F	2	3	1951.21	3.6	975.6	1.2	4.3	2.4	0.0537	0.1175	NS	S

S, Significant at 5%; NS, Non-significant; and DF, Degrees of freedom.

ranged from 1035–1090.85 litre/ha with fuel consumption of 4.02–4.13 litre/h in sandy loam and loam soil type. This proposed technology is electronic driven and pertinent for upgrading conventional practices that are not compatible for environmental protection (e.g. gaseous emissions, soil compaction, soil erosion and nutrient losses) and also complementary to precision agriculture practices. The economic benefits of mechanized crop fertigation are of great significance and will also play a strong role in promoting the sustainable development of agriculture in the country.

ACKNOWLEDGMENT

The authors are grateful for the funding provided under CAAST and AICRP on FIM by ICAR for the smooth conduction of this research.

REFERENCES

Adjetey J A, Campbell L C, Searle P G E and Saffigna P. 1999. Studies on depth of placement of urea on nitrogen recovery in wheat grown on a red-brown earth in Australia. *Journal of Nutrient Cycling in Agroecosystems* **54**: 227–32.

Anonymous. 2021. Annual Report 2019–20, Department of Fertilizers, Ministry of Chemicals and Fertilizers, Government of India. https://fert.nic.in/sites/default/files/2020-09/Annual-Report-2019–20.pdf (Visited on 02/02/2022).

Anonymous. 2022. Consumption of fertilizers. https://www.indiastat.com/data/agriculture/total-consumption-fertilisers/data-year/all-years (Visited: 04/02/2022).

Canfora L, Malusa E, Salvati L, Renzi G, Petrarulo M and Benedetti A. 2015. Short-term impact of two liquid organic fertilizers on *Solanum lycopersicum* L. rhizosphere Eubacteria and Archaea diversity. *Applied Soil Ecology* **88**: 50–59.

Chakraborty D, Nagarajan S, Aggarwal P, Gupta V K, Tomar R K, Garg R N and Kalra N. 2008. Effect of mulching on soil and plant water status, and the growth and yield of wheat (*Triticum aestivum* L.) in a semi-arid environment. *Agriculture water Management* **95**(12): 1323–34.

Cheng Y, Ying Z, Zhou Z, Zhang Z, Qi X, Song C and Li K. 2017. Variables of pneumatic fertilizer injection machine based on PID algorithm design and experiment of fertilizer injection control system. *Journal Shenyang Agricultural University* **48**: 320–27.

Dhanger P, Jain M, Rani V, Kumar H, Jaideep J, Mor A and Sachin. 2021. Comparison of the energy consumption in traditional and advanced paddy residue management technologies for wheat sowing. *Indian Journal of Traditional Knowledge* **20**(3): 846–51.

Dhanger P, Jain M, Rani V, Kumar M and Ghanghas S. 2022. Paddy straw management practices in Northern India for improved efficiency and techno-economic feasibility. *Indian Journal of Agricultural Sciences* **92**(4): 526–30.

Gu J and Gao H. 2000. Prospects of technological innovation for improving fertilizer utilization. *Transaction of the Chinese Society of Agriculture Engineering* **2**: 17–20.

Ismail K M, Wheaton F W, Douglass L W and Potts W. 1991. Modeling ammonia volatilization from loamy sand soil treated with liquid urea. *Transactions of the ASAE* **34**: 756–63.

Liu X J, Mosier A R, Halvorson A D and Zhang F S. 2006. The impact of nitrogen placement and tillage on NO, N_2O, CH_4 and CO_2 fluxes from a clay loam soil. *Journal of Plant and Soil* **280**: 177–88.

Parveen. 2022. 'Design, Development and Evaluation of Electronic Metering Mechanism for Liquid Urea Application in Straw Mulch Field'. PhD Thesis, Punjab Agricultural University, Ludhiana, India.

Qi J T, Tian X L, Li Y, Fan X H, Yuan H F and Zhao J L. 2020. Design and experiment of a subsoiling variable rate fertilization machine. *International Journal of Agriculture and Bio-Engineering* **13**: 118–24.

Qiu T. 2016. Research on fertilizer injection technology in the process of wheat planting. *Cultivation and breeding* **3**(1): 20.

Rahman M A, Chikushia B J, Saifizzamanb M and Laurenc J G. 2005. Rice straw mulching and nitrogen response of no-till wheat following rice in Bangladesh. *Field Crops Research* **91**(1): 71–81.

Salah M A. 2006. Effect of nitrogen and manure fertilizer on grain quality, baking and rheological properties of wheat grown in sandy soil. *Journal of the Science of Food and Agriculture* **86**: 205–11.

Singh J, Mahal J S, Manes G S and Singh M. 2013. Development and evaluation of nitrogen (liquid urea) applicator for straw mulched no-till wheat. *Agricultural Engineering International: CIGR Journal* **15**(4): 30–38.

Spangberg J, Hansson P A, Tidaker P and Jonsson H. 2011. Environmental impact of meat meal fertilizer vs. chemical fertilizer. *Resources Conservation and Recycling* **55**: 1078–86.

Tian G, Cai Z, Cao J and Li X. 2001. Factors affecting ammonia volatilization from a rice-wheat rotation system. *Chemosphere* **42**(2): 123–29.

Zhan L. 2015. 'Design and test analysis of the constant ratio fertilizer injection control system of the dual-variable fertilizer injection machine'. MSc Thesis, Shihezi University, Shihezi China.