

Research Article

Design and Test on Sowing Device of the Multi-functional Machine for Rice-wheat Cyclic Planting

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Abstract: In order to effectively eliminate the disadvantages of improper disposing of residues and fully exploit the advantages of no-tillage seed drill technology, a machine for rice-wheat cyclic planting was developed by designing and attaching drilling and ditching assembly to a combine harvesting assembly. Tests carried out on drilling practice showed that, multi-functional machine for rice-wheat rotation, rubber track was adopted to substitute the traditional land wheel for drilling driving, cannot only effectively get rid of the intermittent drilling, but also can easily achieve the speed synchronization of harvesting and sowing practice; within the limitation of designed walking velocity, mean values of the row consistency and stability of seeding quantity as well as seeding uniformity were $93.9 \pm 1.4\%$, $98.4 \pm 0.5\%$ and $76.2 \pm 5.3\%$ respectively, which could meet the performance requirement of rice direct seeding with soil cover; for a suitable broken rate, the working length of the fluted roller is preferred to be not less than 9.4 mm if NJ210-80 roller feed was chosen to drill rice, the transmission ratio can be increased to reduce the rotary speed of the fluted roller to acquire a suitable seeding quantity, if the value exceeds the agronomic requirement of the local seeding date.

Keywords: Combine harvester, direct seeding, multi-functional machine, rice-wheat rotation, testing

INTRODUCTION

As the two most important cereal crops, rice and wheat are contributing 45% of the digestible energy and 30% of total protein in the human diet (Evans, 1993). To meet the food demand of a rapidly expanding human population on this planet, rice and wheat are now grown in sequence on the same land in the same year over 26 Mha in South and East Asia (Timsina and Connor, 2001). Area for paddy planting in China is 25 million hectares, which accounts for 25% of the country's total cultivated area (Jiang and Xie, 2009). Intensification of rice-wheat cyclic planting systems in China has brought together conflicting and complementary practices, though which has substantially increased production of food and associated crop residues. Large amounts of residues produced in this system, usually considered a problem, for there is a brief interval and an acute shortage of agricultural laborers during the harvesting season, which not only created an urgent need for a multi-functional machine but also made it attractive for farmers to burn residues in the field to hasten and facilitate tillage for the next crop. Open-air burning has been banned by many governments, not only because of the recourse waste, but also the serious environmental

pollution problems, a large number of chemical fertilizers should be applied to farmland as well.

No-tillage with residue retention is a major step for enhancing sustainability of the rice-wheat cropping system, it is also an economically viable and erosion controlling crop production system. In this system, crops are planted directly into the previous crop's stubble with minimum soil disturbance (MNZTFA, 1998).

In comparison with the conventional tillage method, the no-tillage sowing method can not only lead to further nitrogen accumulation in the soil, but also improve soil aggregation and moisture holding capacity (Huang *et al.*, 2008). In addition, the no-tillage increases N and C concentration in soil, microbial carbon mass and bacterial and fungal population (Cookson *et al.*, 2008) and crop yield in the long production period (Huang *et al.*, 2008) while reducing the emissions of CO₂ and N₂O gases, fuel consumption and soil erosion (Buschiazzo *et al.*, 2007).

To solve the problems of brief interval and labor shortage in harvesting season and to facilitate the production of rice-wheat rotation, as well as to make best use of the advantage of no tillage seed drill technology, a multi-functional machine was developed by integrated drilling and ditching assembly with a full

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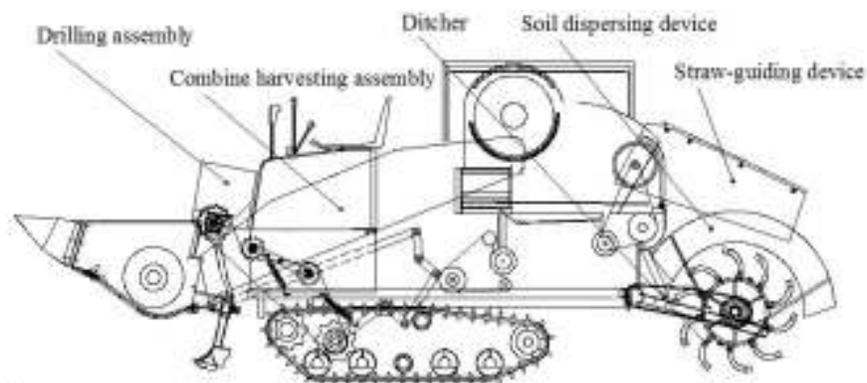


Fig. 1: Structure diagram of multi-functional machine

combine harvesting assembly (Chen *et al.*, 2009). The multi-functional machine is mainly consisting of a combine harvesting assembly, a drilling assembly, a straw guiding device, a ditching assembly and a soil dispersing device (Fig. 1).

By the use of this machine, operations of drilling and ditching could be conducted while harvesting, threshed straw could be gathered into the ditch for decomposition and the upturned soil could be dispersed to cover seeds while ditching. In this way, the integration of harvesting and sowing was achieved, straw disposing, ditching, soil dispersing and seed covering was realized synchronously. Rational arrangement of ditching position in turns for several years, the effect of straw returned back to the field combining minimal tillage, crop rotation and inter-planting could be achieved easily (Ekboir, 2003; Gemtos *et al.*, 1998). It is also beneficial to stable or increase the yield and improve the quality of crops.

Sowing performance has great influence on the yield in direct seeding system. An important criterion in evaluating sowing performance is seed spacing uniformity, for a uniform distribution of seeds can provide maximum space for each plant and increases yield due to the reduction of intra-specific competition (Heege, 1993). This study was undertaken to design the machine's drilling assembly and check its working performance.

MATERIALS AND METHODS

Materials: The key components of the drilling assembly are mainly consisting of a seeding box, 12 seed-metering devices, 12 seeding cups, 12 seed-guiding pipes and a seeding shaft (Fig. 2).

For the convenience of operator to observe the seed in the box as well as the working condition of seed-metering device, the drilling assembly was installed at the front of the manipulation platform and top of the header (Fig. 1).

Seeding box: Volume of the seeding box was determined as follows. As the volume density of rice is 561-591 kg/m³ and wheat is 790-819 kg/m³, (Zhou,

1994), direct seeding quantity requirement of rice is 90-240 kg/hm² and wheat is 180-225 kg/hm² (Chinese Standard GB/T25418, 2010; Chinese Standard JB/T9783, 2013), combine the 0.2-0.27 hm² plot features of rice-wheat rotation area, the calculated volume of the seeding box is 0.089-0.114 m³.

To match the width of sowing with the width of harvesting and for the convenience of installation of seed-metering devices and seeding cups, as well as to facilitate the operator to observe the cutter of the header, length, width and height of the seeding box was set as 2000 mm, 255 mm and 250 mm, respectively (Fig. 3), section sizes was showed as Fig. 3 and its volume can meet the design requirement.

Seed-metering device: Fluted-wheel feed with a lot of advantages such as simple structure, low cost, reliable work, convenient adjustment of seeding quantity and was produced according to the standard, where the NJ210-80 fluted-wheel feed was selected as the key component for seed metering. Its number of grooves is 10; diameter, groove radius and depth of the fluted roller are 40.2 mm, 6.4 mm and 4.1 mm, respectively, the maximum working length is 42 mm (Chinese Academy of Agricultural Mechanization Sciences, 1990).

Layout of the seed-metering device: To obtain rational planting density and ensure the yield, based on the local demand of 150 mm row spacing, combining 2000 mm sowing width and 200 mm ditching width, the row spacing of the position corresponding to the ditching device is 250 mm while the rest are all 150 mm, seed-metering device is 12.

Seeding quantity: Related references indicated that, seeding quantity Q_1 of the roller feed can be calculated according to the Eq. of (1)-(7) (Chinese Academy of Agricultural Mechanization Sciences, 1990):

$$Q_1 = \pi d L \gamma \left(\frac{a_0 f_q}{t} + \lambda \right) \quad (1)$$

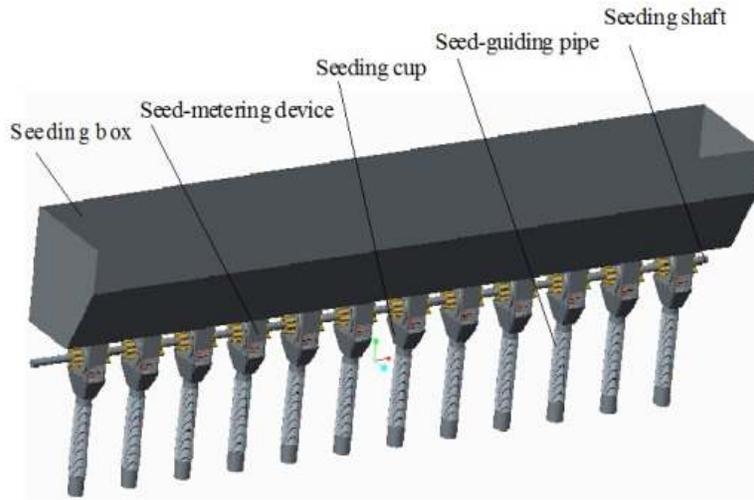


Fig. 2: Schematic diagram of drilling assembly

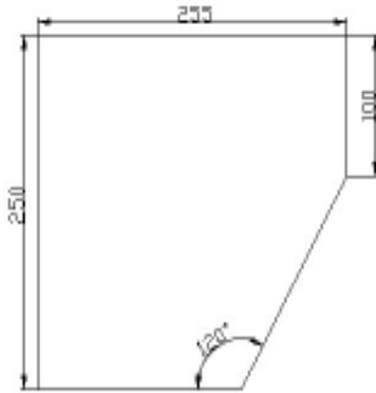


Fig. 3: Section size of seeding box

$$t = \frac{\pi d}{z} \quad (2)$$

$$f_q = f_1 + f_2 = \frac{d^2}{8}(\alpha - \sin \alpha) + \frac{r^2}{8}(\varphi - \sin \varphi) \quad (3)$$

$$R = \frac{d_g}{2} + r \quad (4)$$

$$\alpha = 2 \arcsin \frac{b}{d} \quad (5)$$

$$\varphi = 2 \arcsin \frac{b}{2r} \quad (6)$$

$$b = \sqrt{\frac{d^2}{2} + 2r^2 + \frac{d^2 r^2}{2R^2} - R^2 - \frac{d^4}{16R^2} - \frac{r^4}{R^2}} \quad (7)$$

where,

- d = The diameter of the fluted-roller, in cm
- L = The serviceable length of the fluted roller, in cm
- γ = The bulk density of the seed, in g/cm^3

- a_0 = The filling coefficient of seeds in the groove
- f_q = The sectional area of a single groove, in cm^2
- t = Groove pitch of the fluted roller, in cm
- λ = The special factor of the driving layer
- z = The grooves number
- b = The groove width, in cm
- r = The radius of the groove, in cm
- d_g = The root diameter of the groove, in cm; the unit of α and φ is radian; the unit of α and φ in $\sin \alpha$ and $\sin \varphi$ is angle

To get the sectional area of the groove f_q , on the basis of the given structure parameters of the NJ210-80 fluted-wheel feed of sowing device, according to the Eq. of (1)-(7), a 3D groove model was established and the area about 0.35 cm^2 of a single groove was acquired (Fig. 4).

Required seeding quantity of agronomic technology:

Sowing device is driven by CRT-400×90×48 rubber track (Chinese Standard JB/T6682, 2008) via an 8-tooth driving wheel, an 18-tooth driving sprocket and a 25-tooth driven sprocket. The 8-tooth driving wheel and the 18-tooth driving sprocket were installed on the same shaft; the 25-tooth driven sprocket was installed on the feeding shaft. One circle of the driving wheel, the operating area of the machine is $zP(1+\delta_i)$. According to the calculation method for the required seeding quantity of agricultural technology lists in Agricultural Machinery Design Manual, Vol. I (Chinese Academy of Agricultural Mechanization Sciences, 1990), the formula (8) can get:

$$Q_2 = \frac{zPQb(1+\delta_i)}{1000i} \quad (8)$$

where,

- z = The tooth number of the driving wheel
- P = The rubber track pitch, in mm

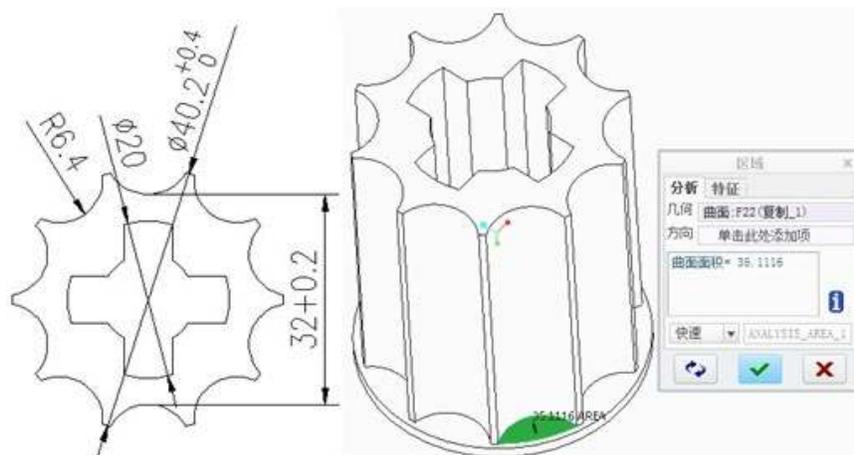


Fig. 4: Section size and three-dimensional model of fluted-wheel



Fig. 5: Seeding quantity calibration and broken rate test

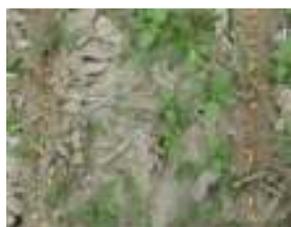


Fig. 6: Test on seeding uniformity

Table 1: Means and standard errors of the seed dimensions

Seed	Length (mm)	Thickness (mm)	Width (mm)
Value	6.8±0.16	2.1±0.04	2.7±0.06

- Q = The required seeding quantity of agronomic technology, in kg/hm^2
- b = The row spacing, in cm
- δ_i = The slip coefficient of the rubber track
- i = The transmission ratio

Working length of the fluted roller: To ensure the seeding quantity meet the requirement of agricultural technology, based on $Q_1 = Q_2$, there is:

$$\pi dL \gamma \left(\frac{a_0 f_q}{t} + \lambda \right) = \frac{zPQb(1 + \delta_i)}{1000i} \quad (9)$$

Based on the required seeding quantity and Formula (9), by substituting such parameters as the diameter of the fluted roller, groove pitch and number, sectional area

of the groove, row spacing and the track pitch, combining the filling coefficient of seeds in the groove at different roller length, as well as the special coefficient of the driving layer obtained in the related table, working length of the fluted roller can be calculated.

Test procedure: To get the relationship between seeding quantity and the working length of the fluted roller, so that the seeding quantity can be adjusted conveniently according to the agronomic requirements of different sowing date, which was tested when the agronomic requirement value was about 90, 140, 190 and 240 kg/hm^2 , respectively after the corresponding theoretical working length of the fluted roller was calculated according to Eq. (9), the seeds broken rate was tested as well (Fig. 5).

To get the influence of walking velocity on seeding performance, based on the working length of the fluted roller determined by the preliminary test, with reference to the standards of the fluted-wheel feed of sower and the testing methods of sowing in line (Chinese Standard JB/T9783, 2013; Chinese Standard GB/T9478, 2005), within the designed walking velocity, seeding uniformity, row consistency of seeding quantity, stability of total seeding quantity and seeds broken rate at different walking velocity was measured when the theoretical working length of the fluted roller was 9.4 mm (Fig. 6).

All the tests were carried out at Huanghai farm, Yancheng city, Jiangsu Province on June 6, 2013.

Seed: Paddy rice seed of 31.6 g/1000 seeds, moisture content of 12.8% and hulling rate of 2.3% were used for this study. Means and standard errors of the seed dimensions are given in Table 1. Seed dimensions were measured by using a vernier caliper with a sensitivity of 0.01 mm.

Seeding quantity: Calculated working length of the fluted roller was adjusted to 90, 140, 190 and 240

kg/hm² according to agronomic requirements in turns, the machine advanced 50 m at a designed walking velocity of 0.7 m/s, respectively, collected and weighed the seeds discharged by each seed-metering device and calculated the mean value for 5 times, then calculated the seeding quantity according to Eq. (10):

$$Q' = \frac{10q}{50am(1 + \delta_l)} \quad (10)$$

where,

Q' = The seeding quantity, in kg/hm²

q = The mean value of seeding quantity within 50 m, in g

a = The row spacing, in cm

m = The number of the seed-metering device

Broken rate: Took 5 samples from the seeds discharged by each seed-metering device in the seeding quantity commissioning test, 100 g for each and broken seeds weigh were measured by using a digital electronic scales with a sensitivity of 0.1 g, broken rate was calculated by subtracting the original value. It was repeated for 5 times.

Row consistency of seeding quantity: As the seeding quantity was calibrated according to the local seeding quantity requirement, collected and weighed the seeds discharged by the seed-metering device within 50 m at different walking velocity for 5 times, then calculated the standard deviation of the consistency of seeding quantity in each row and the variable coefficient according to Eq. (11)-(12) on the basis of the mean value of seeding quantity:

$$S = \sqrt{\frac{1}{n-1} \sum (X - x)^2} \quad (11)$$

$$a = \frac{100S}{x} \quad (12)$$

where,

S = The standard deviation of the row consistency of seeding quantity

n = The number of measured lines

X = The seeding quantity of each line

x = The mean value of seeding quantity

a = The variable coefficient of the row consistency of seeding quantity

Stability of seeding quantity: Added up the seeding quantity of each trip and calculated the mean value with the data acquired in the test of the consistency of seeding quantity in each row and then calculated the standard deviation as well as the variable coefficient of each trip according to Eq. (11) and Eq. (12).

Seeding uniformity: Seeding uniformity test was carried out just after the other tests were finished. In this practice, 5 pre-selected zones on the way there and back, as well as two left, two middle and two right sowing rows were selected for testing, where there was no soil particles covered on the discharged seeds; with 100 mm as a section, each row was divided into 30 sections vertically; counted the seeds in each section and calculated the mean value, with the reference of Eq. (11) and Eq. (12) to calculate the standard deviation and variable coefficient.

RESULTS AND DISCUSSION

Preliminary test: Means and standard errors of the seed dimensions were listed in Table 1. The agronomic requirement on seeding quantity, calculated working length of the fluted roller under different seeding quantity requirements based on Eq. (9), the actual seeding quantity and the broken rate of seed at different working length of the seed-metering device were shown in Table 2.

Results showed in Table 2 indicated that, under the rated rotary speed, the seeding quantity not only increased with the working length of the fluted roller, but also was basically consistent with the theoretical value, its maximum error was not more than 5%; with the increasing of the fluted roller working length, seeds broken rate of husking or shell breaking (Fig. 7) dropped quickly, the main reason may be the longer working length of the fluted roller, the lower pressure and frictional force between the seeds and the device; when the working length of the fluted roller was not less than 9.4 mm, means of the broken rate was not higher than 0.6%, which could meet the requirement of the National Standards of China JB/T9783-2013 (Chinese Standard JB/T9783, 2013).

If NJ210-80 roller feed is adopted to sow rice, its working length of the fluted roller is preferred to be not less than 9.4 mm. Such conditions, the rotary speed of the seeding shaft can be reduced by increasing the transmission ratio and the length of the fluted roller can be increased to acquire a suitable seeding quantity according to the seeding time and the local agronomic seeding quantity, in case the seeding quantity exceeds agronomic requirements.

Performance test: When the working length of the fluted roller was 9.4 mm and the seeding quantity was about 190 kg/hm², at different walking velocity within 50 m, test results of the row consistency, stability of total seeding quantity, broken rate and seeding uniformity were all shown in Table 3; paddy rice seeded directly by the multi-functional machine and to be harvested was shown in Fig. 8.

Table 2: Seeding quantity and broken rate

Seeding quantity requirement of agronomic /kg/hm ²	90	140	190	240
Calculated working length of feed roller/mm	4.8	7.1	9.4	11.6
Seeding quantity/kg/m ²	88.7±1.2	141.9±1.8	193.6±2.3	248.7±2.9
Broken rate/%	9.6±0.36	4.3±0.31	0.6±0.17	0.2 ±0.11

Table 3: Test results of working performance (working length of feed roller was 9.4 mm)

Working velocity /m/s (rotary speed of feed shaft/rpm)	Seeding quantity in 50 m/kg	Row consistency /%	Stability of seeding quantity/%	Broken rate/%	Seeding uniformity %
0.42 (25.2)	1.94±0.21	92.2±1.2	98.6±0.4	0.61±0.25	74.8±3.2
0.54 (32.4)	2.03±0.15	94.4±1.6	97.8±0.6	0.52±0.36	70.1±5.7
0.65 (39.0)	1.98±0.20	93.1±1.1	98.2±0.3	0.60±0.48	77.3±4.1
0.79 (47.4)	2.10±0.17	95.6±1.7	98.9±0.5	0.51±0.24	78.4±5.9
0.94 (56.4)	2.18±0.22	94.2±1.3	98.7±0.8	0.44±0.13	80.3±7.8



Fig. 7: Husk was removed for friction



Fig. 8: Paddy rice seeded directly of 200 kg/hm²

Results showed in Table 3 indicated that, at different walking velocity, the minimum and the maximum values of the seeding quantity within 50 m were 1.94±0.21 kg and 2.18±0.22 kg, row consistency of seeding quantity were 92.2±1.2% and 95.6±1.7%, stability of total seeding quantity were 97.8±0.6% and 98.9±0.5%, seeding uniformity were 70.1±5.7% and 80.3±7.8%, the seeds broken rate were 0.44±0.13% and 0.61±0.25%, respectively; all parameters increased slowly as the walking velocity speeded up except the broken rate, which may caused for the increased seeds disturbance of the fluted roller, such results met the statistical law as the seeding quantity increased and all of them could met the requirement of National Standards of China GB/T25418-2010 (Chinese Standard GB/T25418, 2010).

Figure 8 showed that, the paddy rice seeded directly by NJ210-80 roller feed was evenly and grew well; its measured yield was 7170 kg/hm². From the distribution of the paddy rice, conclusion could draw that, sowing device driven by rubber track can provide a guarantee for seeds drilled evenly and continuously, for the rubber track has hardly longitudinal slide, which could get rid of the practice of intermittent seeding.

CONCLUSION

By integrating drilling and ditching assembly with combine harvesting assembly to develop multi-functional machine for rice-wheat rotation is feasible; rubber track was adopted to drive sowing device, could not only effectively eliminate the intermittent seeding, but also could achieve the speed synchronization of harvesting and sowing easily; within the limitation of 0.7 m/s, at different walking velocities, mean values of the row consistency of seeding quantity, stability of total seeding quantity and seeding uniformity were 93.9±1.4%, 98.4±0.5% and 76.2±5.3%, respectively, which could met the performance requirement of rice direct seeding with soil cover; for a acceptable broken rate and a suitable seeding quantity, working length of the fluted roller is preferred to be not less than 9.4 mm, if NJ 210-80 roller feed is adopted to drill rice, operator can reduce the rotary speed of the fluted roller by increasing the transmission ratio, if the seeding quantity exceeds the agronomic requirement of the local seeding time.

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REFERENCES

- Buschiazzo, D.E., T.M. Zobeckd and S.A. Abascal, 2007. Wind erosion quantity and quality of an entic haplustoll of the semi-arid pampas of Argentina. *J. Arid Environ.*, 69: 29-39.

- Chen, Y.L., W.M. Ding, X.C. Wang and H.T. Yang, 2009. Design of harvest ditch and stalk-disposing machine. *T. Chinese Soc. Agric. Mach.*, 40(8): 62-66. (In Chinese with English Abstract)
- Chinese Academy of Agricultural Mechanization Sciences, 1990. *Agricultural Machinery Design Manual: Vol. 1*. China Machine Press, Beijing, China.
- Chinese Standard GB/T25418, 2010. Rice Direct Seeder with Soil Cover. Standards Press of China, Beijing, China.
- Chinese Standard GB/T9478, 2005. Testing Methods of Sowing in Line. Standards Press of China, Beijing, China.
- Chinese Standard JB/T6682, 2008. Combines-Rubber Track-Series Parameter. China Machine Press, Beijing, China.
- Chinese Standard JB/T9783, 2013. Fluted-Wheel Feed of Sower. China Machine Press, Beijing, China.
- Cookson, W.R., D.V. Murphy and M. Roper, 2008. Characterizing the relationships between soil organic matter components and microbial function and composition along a tillage disturbance gradient. *Soil Biol. Biochem.*, 40: 763-777.
- Ekboir, J.M., 2003. Research and technology policies in innovation system: Zero tillage in Brazil. *Res. Policy*, 32(4): 5735-5786.
- Evans, L.T., 1993. *Crop Evolution, Adaptation and Yield*. Cambridge University Press, Cambridge, pp: 500.
- Gemtos, T.A., S. Galanopoulou and C. Kavalaris, 1998. Wheat establishment after cotton with minimal tillage. *Eur. J. Agron.*, 8: 137-147.
- Heege, H.J., 1993. Seeding methods performance for cereals, rape and beans. *T. ASAE*, 36: 653-661.
- Huang, G.B., R.Z. Zhang, G.D. Lic, L.L. Li, K.Y. Chan, D.P. Heenan, W. Chen, M.J. Unkovich, M.J. Robertson, B.R. Cullis and W.D. Bellotti, 2008. Productivity and sustainability of a spring wheat-field pea rotation in a semi-arid environment under conventional and conservation tillage systems. *Field Crop. Res.*, 107: 43-55.
- Jiang, X.J. and D.T. Xie, 2009. Combining ridge with no-tillage in low land rice-based cropping system: Long-term effect on soil and rice yield. *Pedosphere*, 19(4): 515-522.
- MNZTFA, 1998. *Zero Tillage*. Manitoba-North Dakota Zero Tillage Farmers Association. Leech Printing Ltd., Brandon, Canada.
- Timsina, J. and D.J. Connor, 2001. Productivity and management of rice-wheat cropping systems: issues and challenges. *Field Crop. Res.*, 69: 93-132.
- Zhou, Z.E., 1994. *Agricultural Materials Science*. Agriculture Press, Beijing, China.