

**DESIGN AND DEVELOPMENT OF TRACTOR
OPERATED SEEDER FOR WHEAT AS RELAY
CROP IN COTTON**

Dissertation

**Submitted to the Punjab Agricultural University
in partial fulfilment of the requirements
for the degree of**

**DOCTOR OF PHILOSOPHY
in
FARM POWER AND MACHINERY
(Minor Subject: Mechanical Engineering)**

By

**Manpreet Singh
(L-2011-AE-84-D)**

**Department of Farm Machinery & Power Engineering
College of Agricultural Engineering and Technology
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2015

CERTIFICATE I

This is certified that the dissertation entitled, “**Design and development of tractor operated seeder for wheat as relay crop in cotton**” submitted for the degree of Ph.D., in the subject of **Farm Power and Machinery (Minor Subject: Mechanical Engineering)** of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Manpreet Singh (L-2011-AE-84-D)** under my supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigation has been fully acknowledged.

(Dr. Jaskarn Singh Mahal)

Major Advisor

Dean, COAE&T

PAU, Ludhiana

CERTIFICATE II

This is certified that the dissertation entitled, “**Design and development of tractor operated seeder for wheat as relay crop in cotton**” submitted by **Manpreet Singh (L-2011-AE-84-D)** to the Punjab Agricultural University, Ludhiana, in partial fulfilment of the requirements for the degree of Ph.D, in the subject of **Farm Power and Machinery** (Minor Subject: **Mechanical Engineering**) has been approved by Student’s Advisory Committee after an oral examination on the same.

(Dr. Jaskarn Singh Mahal)
Major Advisor

(Dr. Kanchan K. Singh)
External Examiner
Assistant Director General (Engineering)
Indian Council of Agricultural Research
Krishi Anusandhan Bhawan - II
PUSA, New Delhi - 110 012

(Dr. Gursahib Singh Manes)
Head

(Dr. (Mrs.) Neelam Grewal)
Dean, Post Graduate Studies

ACKNOWLEDGEMENT

It gives me immense pleasure to express my deep sense of gratitude and feeling of respect to my Major advisor Dr. Jaskarn Singh Mahal, Sr. Research Engineer cum Dean College of Agricultural Engineering and Technology, PAU for his incessant help, judicious guidance and invaluable suggestions during the course of investigation.

I avail this opportunity to express my deep sense of gratitude and heartfelt reverence to my co-major advisor Dr. H S Sidhu, Sr. Research Engineer, Borlaug Institute for South Asia (BISA), Ludhiana for his valuable guidance, whole hearted co-operation, enthusiastic inspiration at every stage of project work, without whose guidance and inspiration the work could not have taken present shape.

I am sincerely grateful to my advisory committee members, Dr. Gursahib Singh Manes, Sr. Research Engineer cum Head, Department of FM&PE, Dr. Manjeet Singh, Research Engineer, Department of FM&PE, Dr. V S Hans, Director, School of Energy studies in Agriculture, Dr. Amrit Kaur Mahal, Associate Professor, Department of Math, Stat and Physics, PAU for their keen interest and thoughtful suggestions during entire research programme.

I am unable to find distinctive words of deep sense of gratitude to Dr. M L Jat, Senior cropping system Agronomist, International Maize and Wheat Improvement Centre (CIMMYT), India who helped, encouraged and guided me since formulation to execution of research work. I will fail in my duty if I forget Dr. Yadvinder Singh, INSA fellow, Department of Soils, PAU who provided me insightful guidance and constant encouragement throughout the research programme.

The author acknowledges the financial support of (CIMMYT) under CGIAR Research Program on WHEAT (CRP 3.1) for development and evaluation of the Relay Seeders. The Land and other resources provided by BISA are thankfully acknowledged.

I cannot forget to render my heartfelt thanks to Dr. Anoop Kumar Dixit research Engineer, of Department of FM&PE, PAU for his helping and friendly attitude during the course of study. I am also thankful to Dr. Sashi Kumar Singh, Associate Professor and Dr. Rohinish Khurana, Associate Professor of Department of FM&PE, PAU, Ludhiana for their guidance during the course work.

I am also thankful to Er. Chetan Singla, Er. Assem Verma, Dr. Rajesh Goyal, Er. Arshdeep Singh and Er. Bhupinder pal Singh for always providing me encouragement, inspiration and moral support.

Special thanks to Mr. Pankaj Sharma, Farm Manager, BISA, for providing all kinds of help for smooth running of the project. I cannot forget to render my heartfelt thanks to Mr. Parvinder Singh, Scientist, BISA for his valuable help in execution of experimental work. I am also thankful to Mr. Rakesh Choudhary, Mr. Opinder Singh for their help in experimental work.

The author feel, great pleasure to acknowledge Jagajit Industries, Cheema Mandi, Mansa (Punjab), India for their help in fabrication of Relay Seeders. I am also thankful to Sh. Varinder Kumar (Pandit Ji) and Mr. Shiva for development and evaluation of Relay Seeder at BISA, Ludhiana.

Special thanks to Testing centre team, S. Satnam Singh, Foreman, S. Gurumukh Singh, Mechanic, S. Kesar Singh, Mechanic(Retd.), Sh. Swran Singh, Helper, Devi Lal, Ramdass, Dharminder Singh of Department of FM&PE for providing timely help whenever needed.

Words are not my command to extend my immense gratitude to my parents, my wife, and daughters (Ananya and Maanya) whose love and affection had always stood by me and provided constant encouragement during the course of my research work. I appreciate my wife, Er. Amina Raheja for her help in making machinery drawings in Autocad interface.

Deep in my heart, I appreciate the help of those whose name I might have missed.

(Manpreet Singh)

Title of Dissertation : Design and development of tractor operated seeder for wheat as relay crop in cotton
Name of the student and Admission No. : Manpreet Singh (L-2011-AE-84-D)
Major Subject : Farm Power & Machinery
Minor Subject : Mechanical Engineering
Name and Designation of Major Advisor : Dr. Jaskarn Singh Mahal Sr. Research Engineer cum Dean
Degree to be awarded : Ph.D.
Year of award of Degree : 2015
Total pages in Dissertation : 102 + Appendices + Vita
Name of the University : Punjab Agricultural University, Ludhiana-141004

ABSTRACT

Wheat planting after cotton is usually delayed due to late cotton picking and time needed for seedbed preparation, resulting in low wheat yield. Few farmers sow wheat through broadcasting in standing cotton for timely sowing but on a small scale. This methodology has also limitations of poor germination and low fertilizer use efficiency. Therefore, to study feasibility of relay seeding of wheat in cotton, a prototype of high clearance platform (110 cm from ground) for tractor was developed to facilitate the movement of tractor in standing cotton. Experiments were carried out to evaluate the performance of newly developed Relay Seeders (RS) attached to high clearance four-wheel tractor for seeding wheat in standing cotton planted at row spacing of 67.5 cm and 101.0 cm. Replicated field experiment included two cotton hybrids having different canopy cover (RCH 776 and MRC 7017), two RS for different row spacing and three types of furrow openers (strip till rotor-STR, zero till double disc-ZTDD and zero till tine-ZTT). The RS with double disc opener vis-à-vis conventional till wheat (CTW) were also evaluated on five farmers' fields. The forward speed of travel of ZTDD openers was 9.3% and 16.6% higher than the speed with STR and ZTT openers respectively. STR openers consumed more fuel (12.36 L ha⁻¹) than ZTT (8.57 L ha⁻¹) and ZTDD openers (9.15 L ha⁻¹). Number of cotton bolls detached from plants due to operation of tractor mounted RS was significantly lower in 101.0 cm cotton row spacing compared with 67.5 cm row spacing. Overall loss of cotton balls due to the movement of tractor and RS was under 2%. Relay planting of wheat using high clearance tractor allowed one additional boll picking leading to increase in seed cotton yield by about 12% compared with conventional crop. Cotton genotypes and relay seeders had no effect on wheat emergence and wheat yield. Relay seeders with STR and ZTDD furrow openers performed better in terms of wheat emergence and grain yield compared to ZTT openers. Wheat sowing using RS was advanced by 31 days, which increased grain yield by 18.8% as compared with CTW. Net returns from CW system with relay seeding of wheat were Indian Rs. 19,282 to 26,332 per ha higher as compared with conventional CW system. Results from on-farm participatory trials revealed that wheat yield under relay seeding on average increased by 6.4% compared to CTW.

Keywords: Cotton-wheat system, Furrow openers, High clearance tractor, Relay wheat, Relay seeder

Signature of Major Advisor

Signature of student

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List of Abbreviations and Symbols

°	Degree
\$	USD
%	Percent
BISA	Borlaug Institute for South Asia
CIMMYT	International Centre for Maize and Wheat Improvement
CG	Centre of gravity
cm	Centimeter
CT	Conventional tillage
CTW	Conventional tillage wheat
CW	Cotton wheat
CV	Coefficient of variance
DF	Degree of freedom
FOS	Factor of safety
h	Hour
ha	Hectare
hp	Horse power
J	Journal
kg	Kilogram
kg ac ⁻¹	Kilogram per acre
kW	Kilo watt
l	Liters
L ha ⁻¹	Liter per hectare
LSD	Least square difference
MB	Manual Broadcast
mm	Millimeter
Mpa	Mega Pascal
MS	Mild steel
N	Newton
NS	Non significant
P	Probability value
PAU	Punjab Agricultural University
PTO	Power take off
rpm	Revolutions per minute
Rs	Indian Rupee
RS	Relay seeder
SAS	Statistical Analysis Software
SE	Standard error
STR	Strip tillage rotor
ZTDD	Zero till double disc
ZTT	Zero till tine

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) wheat (*Triticum aestivum* L.) is a well established crop production system of north-western plains of the Indian sub-continent and adjoining areas of the Punjab-Sindh provinces of Pakistan. Cotton-wheat (CW) is the second most important cropping system after rice-wheat in this region, and is practiced on about 4.02 million ha (Mayee *et al* 2008). In India, CW cropping system was followed on an area of 1.6 million ha during 2012 with contributions of 0.59, 0.48 and 0.52 million ha by different states; Haryana, Punjab and Rajasthan respectively (Anon 2015). In addition, there are pockets of CW system in Madhya Pradesh, Gujarat and Maharashtra provinces of India. The uniqueness of the CW system is the grain and cash cropping, which improves the economy of farmers through the cultivation of cotton as an industrial commodity and wheat as a component of food security. The system got further impetus with the introduction of dwarf wheat cultivars requiring lower temperature for good germination than that for traditional tall Indian and Pakistani wheat varieties. The normal wheat sowing time in the region is last week of October to first fortnight of November. Delay in wheat sowing causes marked reduction in its productivity (Anon 2014).

Wheat planting after cotton harvest is often delayed due to late pickings of cotton and subsequent tillage and field operations for wheat planting. The sowing of wheat after 20th November in this region reduces the productivity at the rate of 1.0-1.5 % per day (Nasrullah *et al* 2010). On an average, productivity of wheat in CW system is about 3.2 t ha⁻¹ against the wheat productivity of about 4.7 t ha⁻¹ in rice-wheat system of Indian Punjab (Butter *et al* 2013). Late sowing of wheat due to late harvesting of cotton significantly reduced the wheat yield in all the genotypes by six per cent (Singh *et al* 2011). Punjab province is a major contributor of wheat in Pakistan where most of the area under wheat comes after cotton and rice crops. Wheat sowing under these two cropping systems especially cotton-wheat cropping system is delayed which causes significant yield reduction. Usually low yields are obtained by conventional methods of wheat planting. For a rapidly growing population of the country, the food security seems under threat by yield stagnations. (Nasrullah *et al* 2010). Khan *et al* (2002) reported that only 20% of wheat is sown at the optimum sowing time, i.e. the first fortnight of November, while the remaining sowing is done from late November (30%) to December (50%) in the cotton zone of Punjab, Pakistan. Ali *et al* (2013) reported that there is almost 60% yield gap in wheat production that needs to be narrowed. The main factors

contributing toward low productivity include late planting of wheat crop due to delayed harvesting of Kharif crops such as rice, cotton and sugarcane, as well as shortage of irrigation water, and sub optimal management practices. Similarly, in northern China a large proportion of the wheat area is planted under the wheat-cotton cropping or the wheat/maize relay systems. Late harvesting of the cotton or maize crops may lead to delayed wheat sowing. Because of low temperatures in late fall or early winter leading to insufficient temperature accumulations, late sown winter wheat does not develop adequately to set a sound foundation to enable development sufficient spike numbers at harvest resulting in substantial yield reductions. Late sowing leads to small and weak seedlings that develop fewer roots and no, or fewer, tillers in the fall (Wang *et al* 2009). In CW system, early cotton picking for timely sowing of wheat seems impossible due to indeterminate nature of the cotton cultivars and low temperature during boll opening stage. As a result, wheat establishment after cotton is delayed by about a month.

Delay in wheat sowing without disturbing the cotton crop can be avoided by timely relay planting in standing cotton. The relaying of wheat by surface seeding into standing water in cotton was successfully demonstrated by Khan and Khaliq (2005). Relaying wheat by surface seeding produced 69.4% higher grain yield than sowing after harvest of cotton. Yield, yield components, and quality traits of cotton were not affected significantly by any of the relay cropping system. Substantially higher net field benefit was obtained from relay cropping system as compared to wheat followed by cotton. Therefore, timely wheat sowing in CW system is possible only by relay cropping of wheat into standing cotton using zero tillage technique. Preliminary study on relay planting of wheat in standing cotton has shown promising results (Anon 1993a).

However, none of the present planters are capable of seeding wheat in standing cotton crop. A 2-wheel self-propelled relay seeder was developed in the year 2008 under the Cereal Systems Initiative for South Asia (CSISA) programme of CIMMYT, Ludhiana, India in collaboration with a local farm machinery manufacturer, Amar Agro Industries, Ludhiana, India. The relay seeder has the capability of opening a narrow strip (25-35 mm) using straight steel blades on the rotor in front of zero till (Inverted T-type) furrow opener to facilitate placement of seed and fertilizer while moving between the two rows of standing cotton (generally 675 mm apart). The yield gains in wheat with relay seeder were higher by 41.2% in 2009-10 and 11.8 % in 2010-11 than the conventional crop planted after cotton (Butter *et al* 2011). The timely sowing of wheat with insignificant damage to cotton was demonstrated through engine operated relay planting. However, for popularising the relay planting in CW

rotation in South Asia, self propelled small machine is insufficient. High capacity tractor operated relay seeders for this purpose are required that can cover an area of 480 thousand hectares in just 2-3 weeks time in the state of Punjab under CW system. Early planting of wheat in CW system will maximize the crop productivity and income of the growers. Development and evaluation of an innovative tractor operated wheat seeder can facilitate direct drilling of wheat into standing cotton for timely sowing of wheat, for enhancing wheat productivity and profitability of CW system in South Asia.

Therefore, there is a need of a tractor operated high clearance relay seeder with a swath width equal to 3-4 rows of cotton crop. High capacity tractor operated relay seeder can improve productivity and profitability of CW system for which no data is available and the study being undertaken with following objectives

1.1 Objectives

- i) To design and develop tractor operated high capacity relay seeder for seeding wheat in standing cotton crop
- ii) To evaluate the performance of relay seeder for sowing wheat into different cotton varieties, geometries of standing cotton using various type of furrow openers

REVIEW OF LITERATURE

Cotton-Wheat is the second most important cropping system after rice-wheat in South Asia. Sowing of wheat after cotton usually gets delayed due to late cotton picking coupled with time needed for seed bed preparation resulting in low wheat productivity in CW system. Relevant literature is briefed below:

2.1 Status of wheat sowing in cotton wheat rotation

Khan *et al* (2002) reported that only 20% of wheat is sown at the optimum sowing time, i.e. the first fortnight of November, while the remaining sowing is done from late November (30%) to December (50%) in the cotton zone of Punjab, Pakistan. In aforementioned cropping systems 70% wheat is sown after the harvest of cotton and rice crops, which results in delayed wheat sowing by 45-60 days. Mid November is the optimum time for wheat planting; any further delay results in yield reduction by 50 kg ha⁻¹ per day. This reduction in yield is primarily attributed to poor and erratic germination because of low ambient temperature that prevail at that time. Moreover, late planted wheat plants have to complete all growth and developmental stages in lesser time as starch accumulation process is terminated at the same specific temperature irrespective of time of sowing because of photosensitive nature of wheat.

Mayee *et al* (2008) reported that Cotton-Wheat Production System (CWPS) is followed on 1.40 million ha and on 2.62 million ha in India and Pakistan respectively. The total area under CWPS comes to about 4.02 million ha in the north-western plains of India and Pakistan, Fig. 2.1. CWPS covers about 82 to 93% of the total cotton area but encompasses only 22 to 25% of the total wheat area in this belt. In India, only 18 to 20% of wheat area is covered by cotton-wheat rotation against around 33% in the Punjab and Sindh provinces of Pakistan. On an average, productivity of 18 q ha⁻¹ of seed cotton and 32 q ha⁻¹ of wheat grain can be realized. Being a cash (cotton being industrial product) and grain cropping system, it ensures food security with financial security.

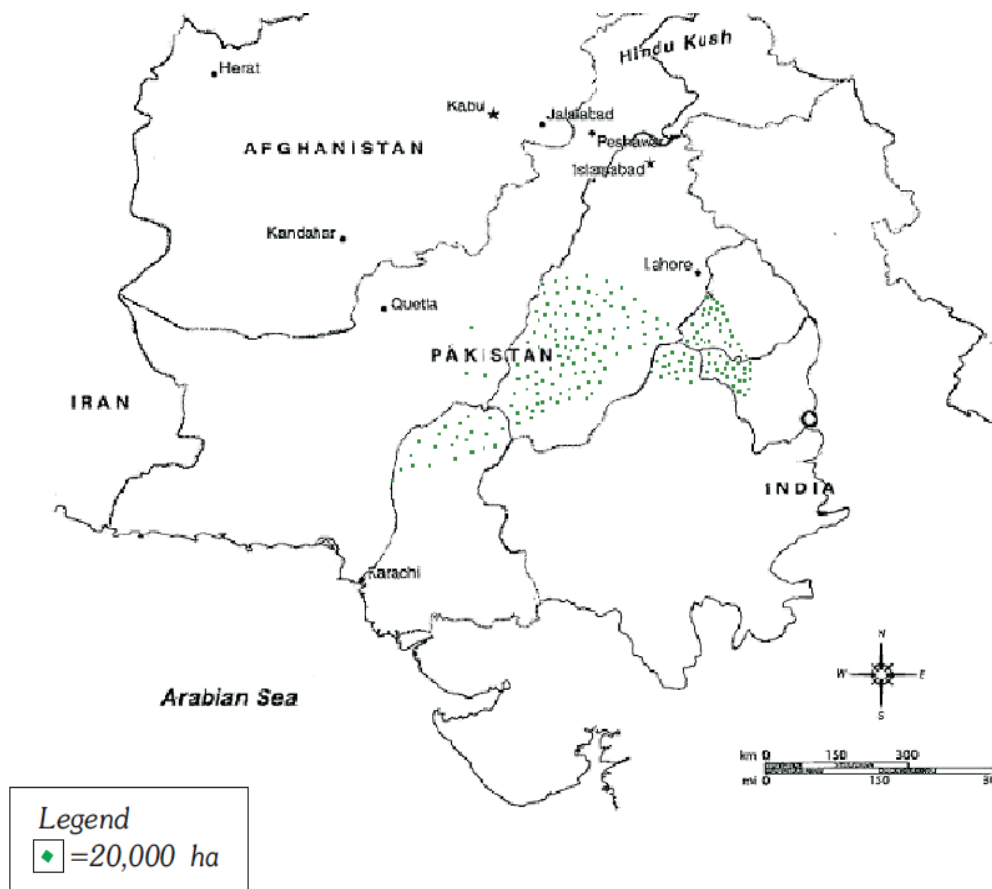


Fig. 2.1: Cotton-wheat production area in the north-western plains of India and Pakistan

Ali *et al* (2013) reported that there is almost 60% yield gap in wheat production that needs to be narrowed. In Pakistan, average yield is 21% lower than global average of 3086 kg ha⁻¹, 13% lower than 2802 kg ha⁻¹ of India and 49% lower than world best yield of 4762 kg ha⁻¹ achieved by China. The main factors contributing toward low productivity include late planting of wheat crop due to delayed harvesting of Kharif crops such as rice, cotton and sugarcane, as well as shortage of irrigation water, and sub optimal management practices.

2.2 Relay seeding v/s intercropping

Willey (1979) suggested that the main way to achieve complementarily, or cooperation, between crop components is to develop crop growth patterns so that each crop exerts its major demands on resource use at different times in the growing season. Therefore,

Butter *et al* (2011) developed a self-propelled relay seeder with seed-cum-fertilizer attachment. Trials were conducted to evaluate relay planting vis-à-vis conventional sowing of wheat at 4 and 10 locations during 2009-10 and 2010-11, in CW dominated areas of south-western Punjab, India. The wheat planting methods (zero till seeding in standing cotton using self-propelled relay seeder, relay seeding in standing cotton with manual drill without tillage-not included during 2010-11, relay seeding in standing cotton as broadcast with minimum tillage, and conventional sowing of wheat) were evaluated in terms of their effects on yield and profitability of wheat in CW rotation. They reported that planting of wheat under conventional practice got delayed by 20-44 days compared with relay seeding. Yield of wheat sown with self-propelled relay seeder was 41.2% and 11.8% higher compared with conventional practice in 2009-10 and 2010-11, respectively. The increase in wheat yield under relay seeding of wheat was attributed to higher tiller density, longer spikes and more grains per spike. The net returns from the wheat were higher for self-propelled relay-seeder than with conventional sowing, Fig. 2.3.

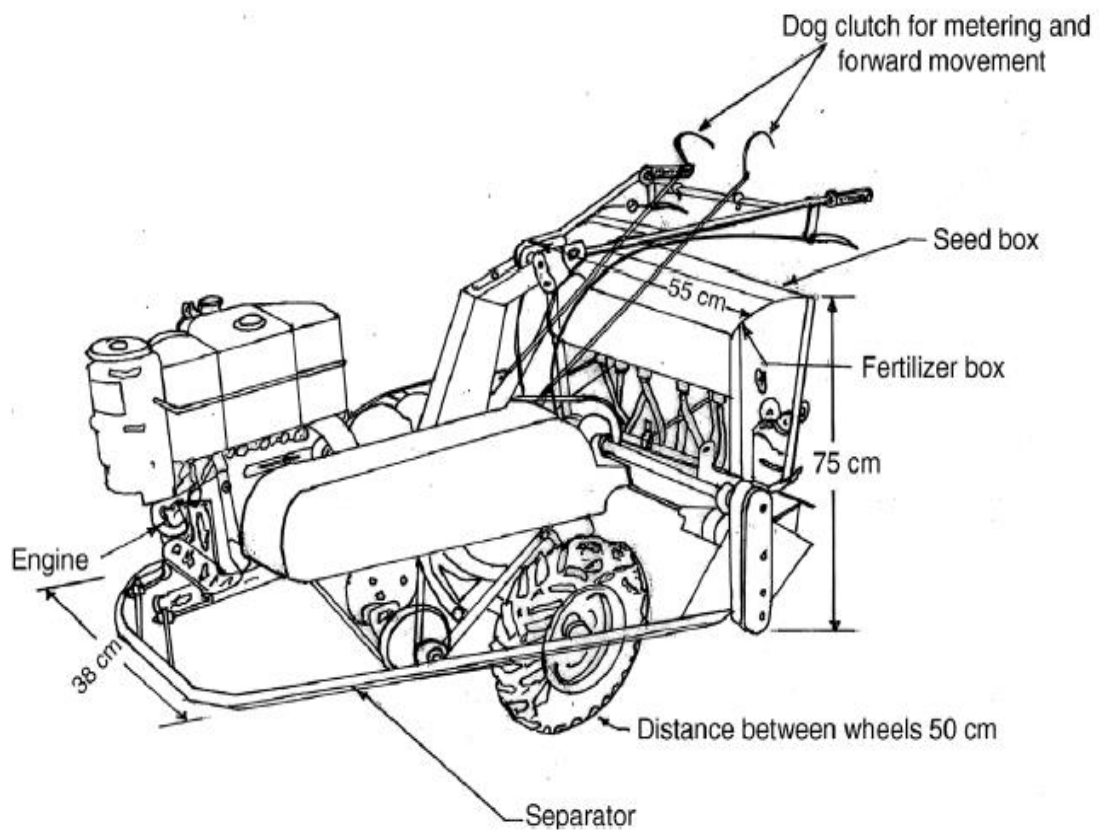


Fig 2.3: Line sketch of self propelled walk behind type relay seeder for seeding 3 rows of wheat in two adjacent rows of cotton

2.4 Tractor stability and steering

Whitaker (1976) studied the steering for adjustable tread width tractors. The increase in the tread width of tractor results in some combination of skid by the front wheels during the turn. The amount of skid can be substantial as shown graphically in Fig. 2.4. Tractor with a track width/wheel base ratio of 0.33 with good steering parameters was selected. When the tread width was increased by a quarter and the tractor is driven through a 90° turn with a 25° turn angle, the wheel with least traction will skid approximately 18 cm. this kind of slippage can hardly help but reduce control and increase tire wear. The steering design on adjustable tread width tractors can, in most of the cases can be improved. This can be accomplished either with an adjustable steering arm angle, the more precise Rey system or some combination.

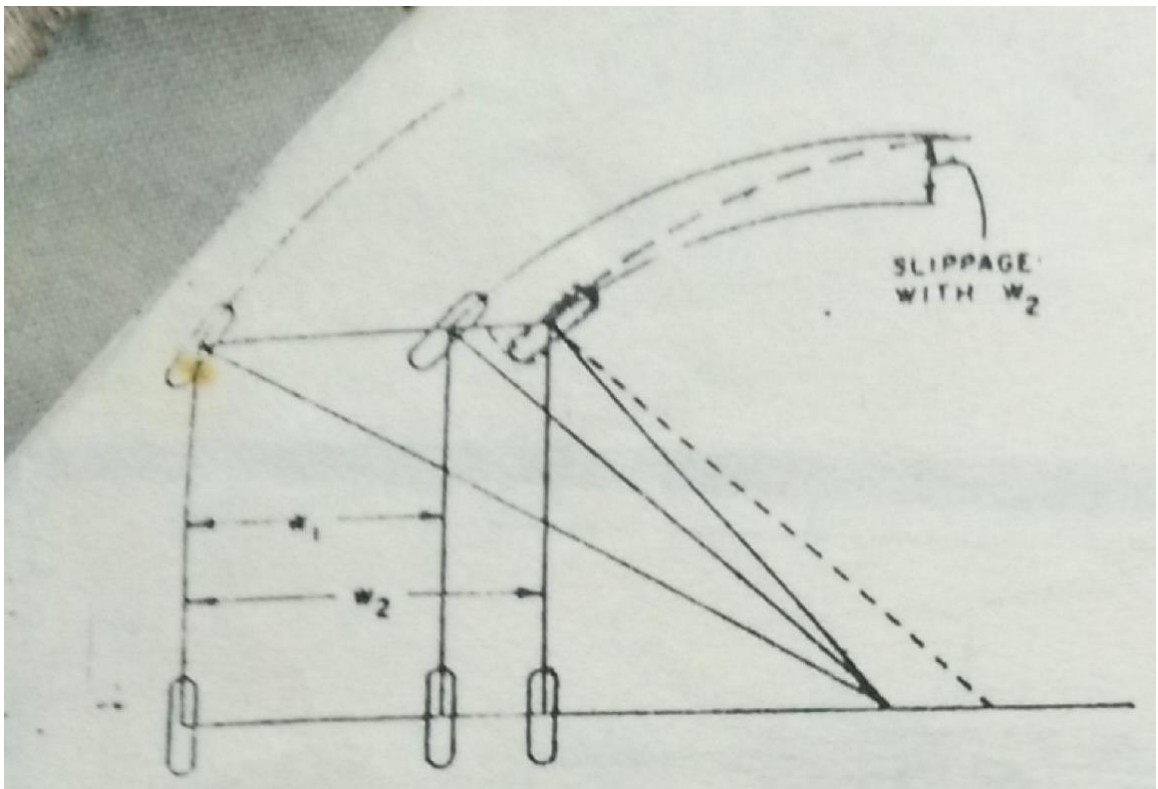


Fig. 2.4: Widening the tread width causes an incorrect turn angle

Ahmadi (2011) investigated the effects of forward speed, ground slope and wheel-ground friction coefficient on lateral stability of tractor at the presence of position disturbances, a tractor dynamic model was developed. In this model two types of instability were considered: instability due to overturn and skid and for each case the stability index was determined, Fig 2.5 and 2.6. Different geometries and mass specifications of tractor

MITSUBISHI-2501D were used to examine the model. According to the results of this model forward speed and ground slope had a reverse effect on all stability indexes. Moreover stability of this tractor was more affected by tractor skidding than overturning. Therefore to improve the overall stability of this tractor, preference should be on increasing the tractor stability index derived from skid dynamics of tractor.

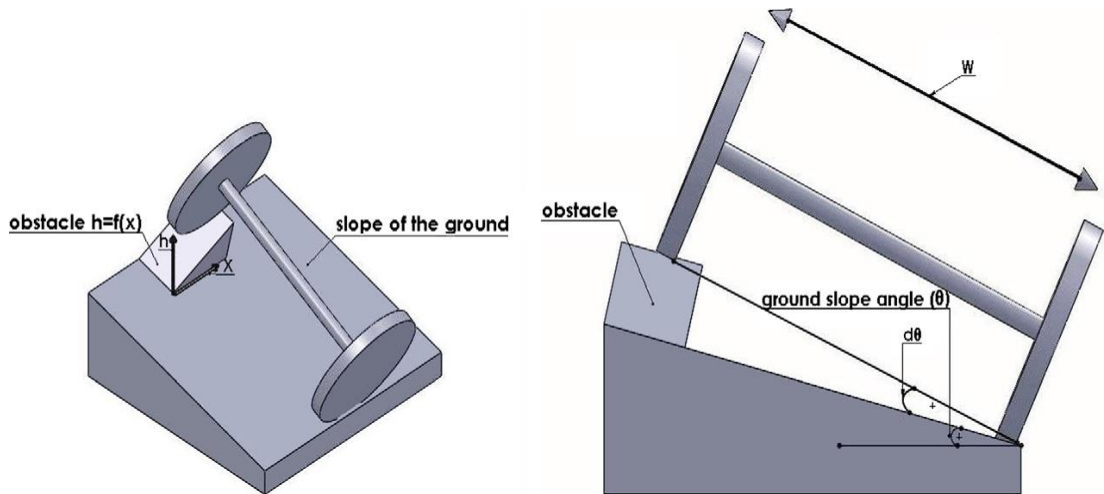


Fig. 2.5: Tractor wheel axel–obstacle geometry (left: 3D view, right: 2D view)

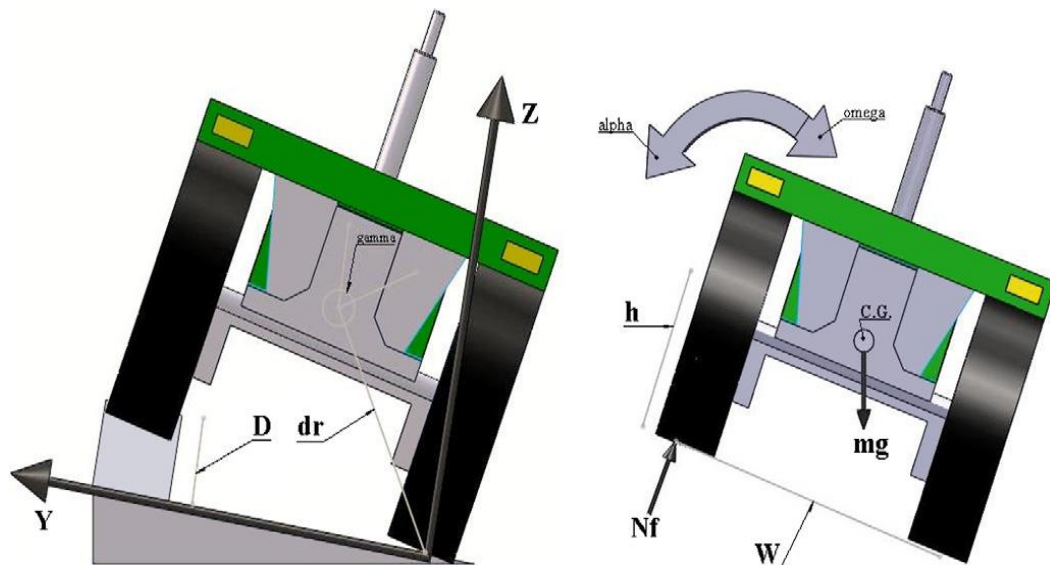


Fig. 2.6: Tractor subjected to position disturbance (left: geometry, right: free body diagram)

Ahmadi (2013) examined the effects of different geometries and mass specifications of a tractor operating across irregular sloping grounds on the lateral stability of this machine, a dynamic model was developed. In the proposed model, overturn and skid instabilities were studied and the tractor stability indexes were formulated, Fig. 2.7 (i.e. *TSI-overturn* and *TSI-skid*). Using a modified Excel spreadsheet package employing the parameters of the model, the *TSIs* were then determined. Finally, the effects of variation in the parameters of the model on *TSIs* were evaluated. The results of the analyses indicate that changing the tractor mass moment of inertias about the x- and y-axes had no influence on *TSI-skid*, whereas increasing the tractor mass moment of inertias about the x-axis by 71% led to a 2.5% reduction of *TSI-overturn* and increasing the tractor mass moment of inertias about the y-axis by 71% led to a 1.8% reduction of *TSI-overturn*. However, increasing the wheel-ground coefficient of friction from 0.34 to 0.84 improved *TSI-skid* by up to 27%. Moreover, the effect of tractor wheel track width and the height of its centre of gravity on *TSI-overturn* were greater than the effect of the tractor wheel base on this stability index. Therefore, the best strategy for stabilizing a tractor against overturn is to lower the tractor's centre of gravity and increase the tractor's wheel track width simultaneously.

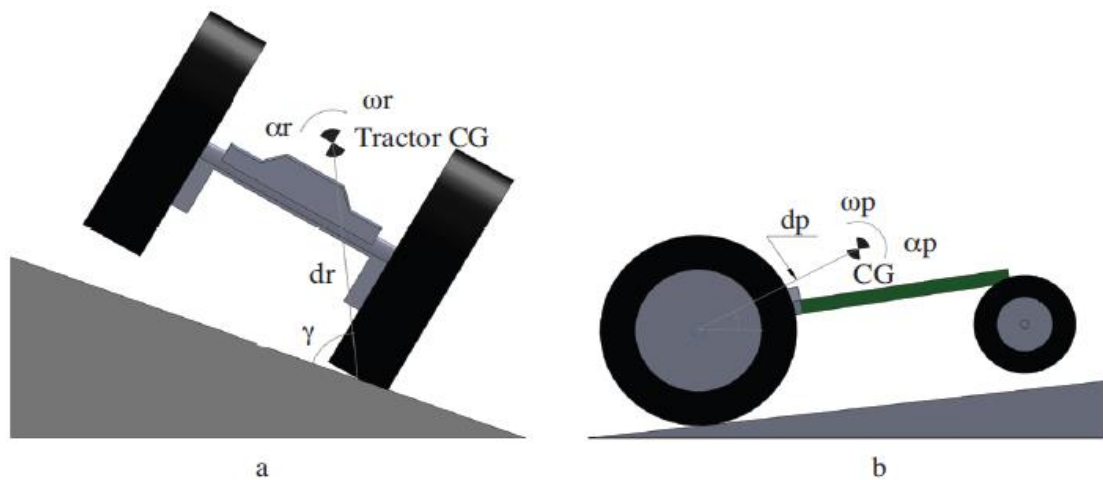


Fig. 2.7: Physical representation of parameters (a) for tractor rolling and (b) pitching situations

Kise and Zhang (2006) proposed the use of “sensor-in-the-loop (SIL)” online tractor attitude and motion simulation to provide rollover warnings based on estimated look-ahead tractor attitude and motion status. A stereovision camera was used as the visual sensor for the SIL system to create a three-dimensional virtual terrain map on which a virtual vehicle travels. This progressively estimates the tractor attitude and motion on the terrain to provide warning of potential rollovers. A series of field tests on various terrains were conducted to

evaluate the dynamic performance of the SIL tractor motion simulator in an actual field environment. The validation test results indicated that the SIL vehicle attitude simulator could predict the attitude and motion status of the vehicle approximately 8.0 m ahead of its actual position with favourable and consistent accuracy at all test sites. Such information can be used as baseline data for a warning signal to prevent rollovers from occurring.

Hamdeh and Al-Jalil (2004) studied the mechanics of a tractor-trailer system moving up and down sloping ground under different operating conditions was theoretically simulated. A computer program was developed to analyze the system to predict the effect of both the trailer loading weight and the slope angle on the tractor stability, traction ability, and drawbar loading. The program was used to analyze a tractor-trailer system moving at uniform motion up and downhill. The results of this analysis showed that the tractor becomes unstable when towing a 3750 kg trailer uphill at 28° slope angle. Insufficient traction occurred at slope angles ranging from 15° to 18° corresponding to trailer weight of 3750 to 750 kg. The parallel component of drawbar pull reached a maximum value of 17318 N when the trailer was pushing the tractor downhill at 30° slope angle. The normal component (normal to the tractive surface) showed similar maximum values for both uphill and downhill motions of the system. The use of computer analysis in this study provided a significant improvement in predicting the effect of different parameters on stability and control of tractor-trailer combination on sloping ground. The following conclusions were drawn for uphill and downhill motions of a tractor-trailer system moving at uniform motion and specific operating conditions based on the computer analysis results obtained from this study:

a) Uphill

1. The higher the slope angle and trailer weight the lower is the stability. The tractor-trailer system considered in this study became unstable at a slope angle of 28° for a trailer mass of 3750 kg.
2. Insufficient rear wheel traction occurred when the maximum traction force developed by the tractor rear wheels was less than the required traction force. This situation happened at slope angles ranging from 15° to 18° at all trailer mass ranging from 3750 to 750 kg.

b) Downhill

1. The stability of the tractor decreased as the weight of the trailer increased, and increased as the slope angle increased. However, the system is always stable for the ranges of trailer loading considered in this work.

- The maximum traction force decreased as the slope angle increased, and increased as the weight on the trailer increased.

Vera *et al* (2015) presented an analytical model, formulated for 3D simulation of the tractor's dynamic stability on inclined terrains, Fig. 2.8. Assuming the constant velocity and curvilinear trajectory of constant radius, it accounted for the gravity force, but also included in analysis the inertial force appeared because of curvilinear motion of the tractor. An appropriate computer code was developed on the base of formulated algorithm (Fig. 2.9), and applied to estimate the stability ranges of three tractors: Fendt Farmer 312, Fendt 926 and John Deer 6400. Tractors were tested for operational velocities in the range between 0 and 50 km/h, and for turning radiuses of 15 m and 60 m. The model represented a suitable tool for preliminary estimations and comparisons of stability areas of the tractors operating at horizontal and especially at sloped terrains at different velocities. Achieved results indicate decreasing the range of allowed terrain slope angles with decreasing radius of curvature of tractor trajectory and with increasing the tractor velocity. In the analysed test conditions, allowed values of longitudinal and transversal angles decrease from about $\pm 40^\circ$ for static conditions to less than about $\pm 20^\circ$ for the highest tested velocities (50 km h⁻¹).

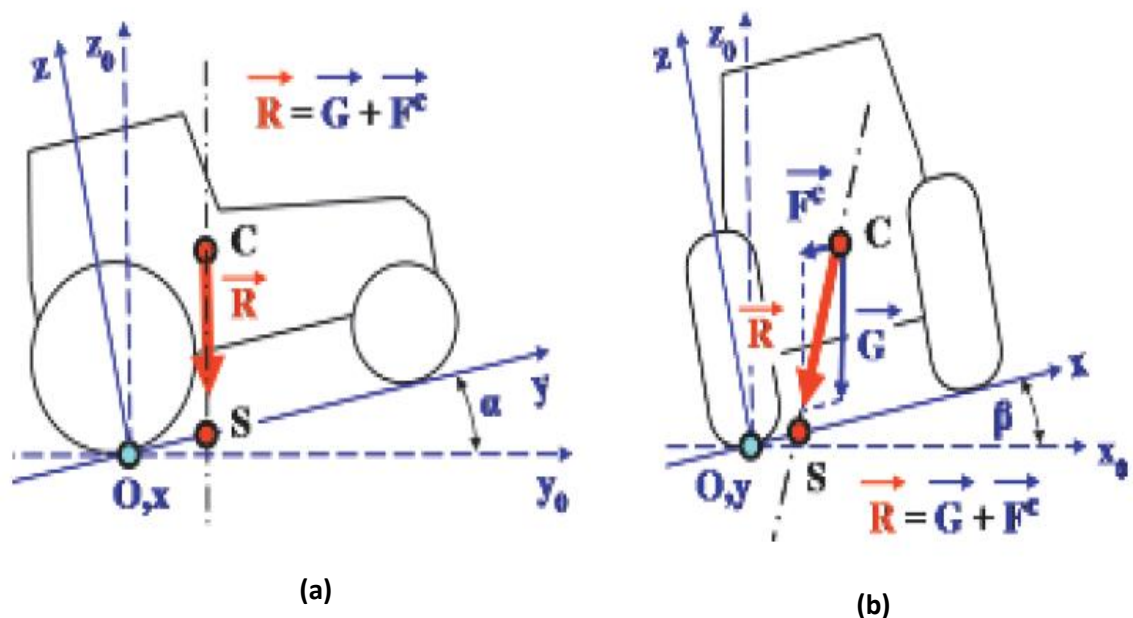


Fig. 2.8: Gravity and centrifugal force of the tractor at uniform curvilinear motion: (a) longitudinal slope and (b) transversal slope. Symbols: R-resulting force; G-weight and FC-centrifugal force

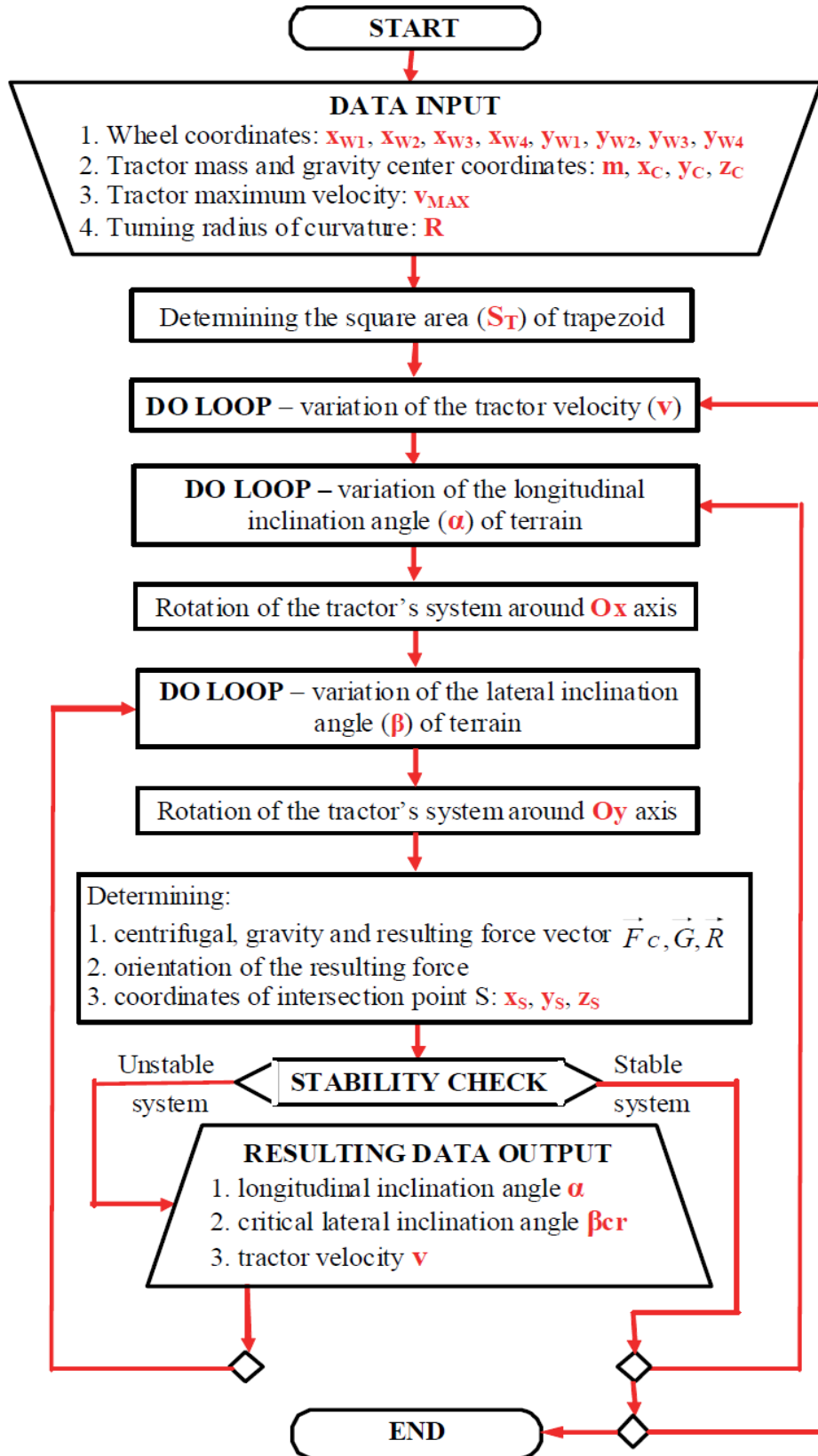


Fig. 2.9: Block diagram of the computer program

2.5 Relay seeding of wheat into cotton

Coolman and Hoyt (1993) studied intercropping for increasing system sustainability and have reported that competition occurs when two plants vie for the same nutritional and after requirements in the same space. One of the plants usually receives less than it requires. Overlapping in space and time, the growth of two or more crops often results in decreased yields of both crops due to competition for limited essential resources. Any development of intercropping systems must evaluate the effects of competition on crop yields. One way to reduce competition for limited water and mineral nutrients is to plant crops at different times of the growing season in a relay-intercropping system. The main way to achieve complementarity, or cooperation, between crop components is to develop crop growth patterns so that each crop exerts its major demands on resource use at different times in the growing season. Therefore, competition can be controlled through adjusting the time when each crop has reached its maximum demand for water and nutrients. The adoption of intercropping systems has a number of potential advantages and disadvantages that are often site and crop-specific. Intercropping can be a more-efficient means of exploiting the resources required for plant growth. Relay-planting crop components so that resource demands occur during different periods of the growing season can be an effective means of minimizing inter specific competition.

Porter and Khalilian (1993) conducted study on wheat response to various row spacing in relay intercropping systems. It involved four planting systems with six replications in a randomized complete block design. Treatment descriptions are; Treatment A involved conventionally planted wheat with row widths equally spaced (15.2 cm). Treatment B utilized the Clemson Inter-seeder and the 11-row planting system (33 and 61 cm alternate). Treatments C & D utilized the Clemson Inter-seeder and the 14-row planting system. A para-plow and French Durou-plow was employed for deep tillage prior to wheat planting for treatments C and D (61, 30.5, 15.2 -4 rows, and 30.5, 15.2 -4 rows, 30.5 and 61 cm) respectively, to compare the effect of these two new conservation tillage implements for wheat production in coastal plain soils, Fig. 2.10. Yield of conventionally planted wheat was not significantly different from yields of skip-row schemes designed to allow for relay intercropping of either soybeans or cotton, Fig. 2.11. For the conventionally planted wheat, tractor traffic on top of certain wheat rows reduced yields of those rows as compared to non-traffic rows. Wheat grown in wider-spaced rows adjacent to the controlled-traffic tire lanes in the schemes designed to allow for relay intercropping compensated yield-wise on an area basis as compared to narrower-spaced rows.

Harvest year	Trt A		Trt B		Trt C		Trt D	
	1992	1993	1992	1993	1992	1993	1992	1993
Planting date	Nov. 21	Dec. 14	Nov. 21	Dec. 14	Nov. 21	Dec. 14	Dec. 3	Dec. 14
Harvest date	June 1	June 7	June 1	June 7	June 1	June 7	June 1	June 7
Number of wheat rows	16	24	11		14		14	
Row width (cm)	19.6	15.2	33.0 & 61.0		15.2, 30.5 & 61.0		15.2, 30.5 & 61.0	
Seeding rate ¹ kg ha ⁻¹	112.1	112.1	112.1		112.1		112.1	
seed (linear m) ⁻¹	64.4	50.3	125.6		93.3		93.3	
Planter ²		Drill	Clemson I.		Clemson I.		Clemson I.	
Fall tillage ¹		Chisel	Paraplow		Paraplow		Duro plow	
Tire spacing (cm)		193	193		244		244	

Fig. 2.10: Description of different treatments of the study

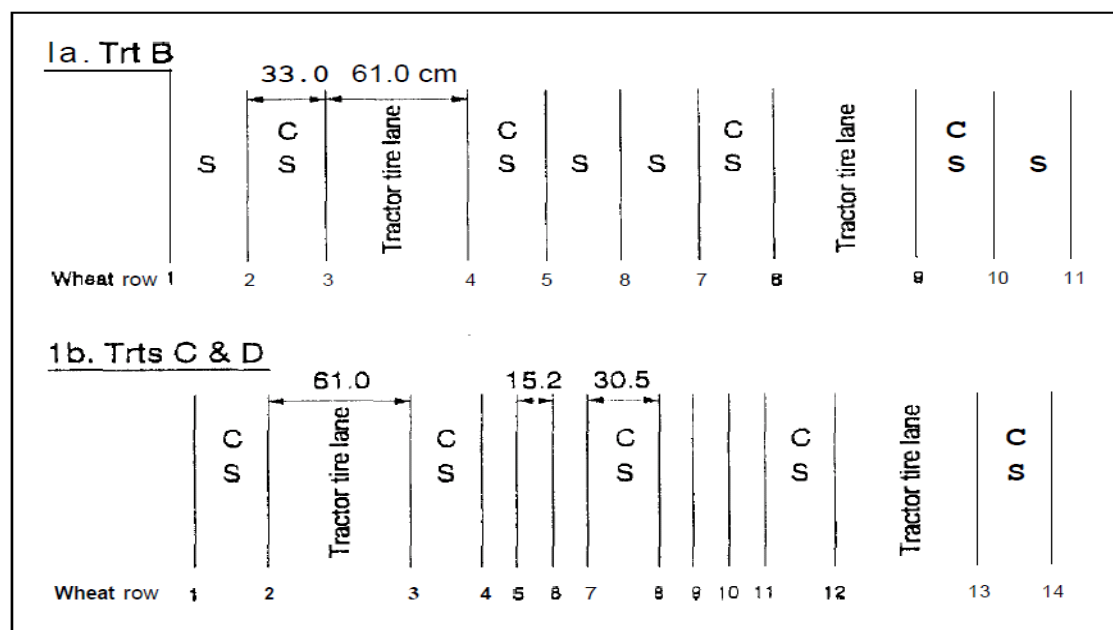


Fig 2.11: Planting pattern for wheat, cotton (C) and soyabeans for a) the 1.93 m tractor wheel spacing, and b) the 2.44 m tractor wheel spacing schemes

Muhammad *et al* (1999) studied agro-economic assessment of different cotton-based inter/relay cropping systems in two geometrical patterns. The planting patterns were 60 cm spaced single rows and 90 cm spaced double rows strips (30/90cm) while intercropping systems included cotton alone, cotton + sesamum, cotton + mungbean, cotton+ mashbean, cotton+ mothbean, cotton+ cowpea, while wheat and lentil were relayed in standing cotton (after the harvest of intercrops) in November. Seed cotton was significantly greater in cotton grown in 90 cm spaced double row strips than in 60 cm spaced single rows. All the intercrops caused almost equal decrease (20-27%) in seed cotton yield compared to cotton alone. Maximum net income of Rs. 48532 per ha was obtained from cotton + mashbean /lentil inter-relay cropping system followed by cotton + mungbean/lentil (Rs. 47415 per ha) and cotton + mungbean/wheat (Rs. 46732 per ha) against Rs. 32348, 32883 and 20552 for cotton/wheat, cotton/lentil and cotton-fallow respectively.

Khan and Khaliq (2005) studied winter cereals as relay crops by surface seeding in cotton based cropping system. This study was conducted for two years i.e. during 1998-99 and 1999-2000. Cotton was sown in 80 cm apart single rows and at the time of relaying each plot was further divided into two: one for relaying in standing cotton and second half for conventional late sowing after cotton harvest for wheat and barley separately. First half of cotton plot pre assigned for relaying was irrigated to the depth of 7.5 cm. Barley (*Hordium vulgare* L.) cv. B.94057 and wheat (*Triticum aestivum*) cv. Inqilab 91 was sown on November, 15 and 18 during 1998 and 1999, respectively on no-tilled soil by a surface seeding technique in the standing cotton. Cotton sticks were cut deep and rabi crops relayed on no-tilled soil were also sown after preparing a fine seedbed conventionally on 31-12-98 and 02-01-99. They reported that wheat relayed in cotton gave a significantly higher grain yield of 2964 kg per ha against 1750 kg per ha grains harvested for wheat sown after the harvest of cotton. Higher grain yield (69.4%) of wheat relayed in cotton was attributed primarily to a 6% higher plant density, 21% more fertile tillers per plant, 18.6% grains per spike and 13.2% higher 1000-grain weight as compared with the wheat crop sown after the harvest of the cotton. The wheat crop relayed into cotton experienced a favourable temperature for germination, crown root development and subsequent developmental stages. The crop sown after harvest of cotton not only faced an unfavourable temperature regime but also a smaller growth duration period of about 1.5 month.

Gupta *et al* (2009) Relay cropping of wheat into a standing cotton crop, a practice common in Uzbekistan, can potentially reduce winter fallows and also provide some green fodder (grazing of winter wheat) for the livestock. Also winter barley and triticale are good

candidates for such cropping practices. In Turkmenistan, farmer trials were directed at adapting resource conserving technologies and validate them under field conditions. Direct drilling was compared to the farmer practices of growing wheat, in areas where cotton and wheat are cropped in rotation. The main emphasis was on evaluating the costs of production. Significant savings, up to 24% of input costs, were achieved by direct drilling of wheat into standing cotton. Furthermore, relay-planting or intercropping systems have shown great potential to significantly increase the system's productivity for various crop combinations including cotton + mung beans and maize + legumes, etc. Furthermore, new equipment introduced for planting winter wheat into standing cotton resulted in a reduction by 20-25% of seed and nitrogen fertilizer application rates.

2.6 Optimum time for wheat sowing

Inamullah *et al* (2007) studied the most suitable time of planting and judge their performance under late sowing in the central agro-ecological zone of NWFP, Pakistan. Five planting dates were used from October 25th to December 5th with 10 days interval in a randomized complete block design with split-plot arrangement replicated thrice. Delay in sowing decreased values of all the parameters. Decrease in days to maturity of various cultivars ranged from 9% (PR-83) to 12% (Saleem-2000), plant height from 10.5% (PR-84) to 26% (PR-85), grains per spike from 14.6% (PR-87) to 33.4 % (Haider-2000), 1000-grain weight from 3.5% (PR-83) to 28.7% (Haider-2000) and rain yield from 45.2% (PR-83) to 59% (PR-86) when sowing was delayed from October 25th to December 5th. Larger decreases in grain yield despite comparatively smaller decreases in grains per spike and 1000-grain weight showed the importance of seed germinability and the number of productive tillers per unit area in late sowing.

Anonymous (2014) reported that wheat must be sown at the optimum time, for securing the best grain yield. Delayed sowing causes a gradual decline in the yield of wheat. A delay of one week in sowing reduces wheat yield by about 150 kg ac⁻¹. Sowing of long duration varieties should commence from the fourth week of October to save these from high temperature near maturity.

Singh *et al* (2011) conducted studies to identify and analyze the physiological aspects of cotton-wheat system with 20 cotton and 6 wheat genotypes in relation to the cropping system productivity. The duration of different cotton genotypes showed large variation and ranged from as early as 130 days to late up to 185 days. Genotypic variations in cotton

genotypes for different morphological (shoot length, number of monopods and sympods), physiological (LAI and biomass) and yield (boll number and boll weight) parameters were significant. Higher vegetative growth (i.e. LAI) at 90 DAS and biomass (175-273 g per plant) at 120 DAS was observed mostly in early genotypes as compared to late genotypes. Many early maturing genotypes also possessed significantly higher number of sympodial branches (33-37 per plant) and significantly higher seed cotton yield (1.93 to 2.34 t ha⁻¹) than the late types (1.81 to 2.04 t ha⁻¹). Variety CNH-36, CNH-120, RS 810, Pusa 8-6, RS- 2013, Vikas, LH-1556, Surbhi and hybrids Ankur 651, Omshanker and LHH-144 appeared physiologically more efficient in terms of photosynthesis (Pn) and photosynthetic water use efficiency (PWUE). In wheat, LAI at 120 DAS and biomass at maturity were significantly reduced in late sown wheat. The study revealed that the grain yield of six wheat genotypes after cotton ranged from 4.7 to 5.2 t ha⁻¹ and was significantly higher in wheat genotypes UP 2338, HD 2687 and PBW 343. Late sowing of wheat due to late harvesting of cotton significantly reduced the wheat yield in all the genotypes. Photosynthesis, transpiration and photosynthetic radiation use efficiency were higher in timely sown wheat genotypes, however photosynthetic water use efficiency was less. Yield of cotton-wheat system in terms of wheat equivalent yield (WEY) and net returns (NR) of cotton-wheat system were also reduced with the late sowing of wheat (8.4 and 6.2%, respectively). Highest WEY (11.1-11.8 t h⁻¹) and NR (45.5-51.3 x 1000 Rs. ha⁻¹) of cotton-wheat system were observed with early maturing cotton genotypes (LRA-5166, LH 1556, Ankur-651, CNH-120, F-1861 and Omshankar) followed by UP2338, HD2687 and PBW343 (wheat). These findings reveal that early maturing genotypes of cotton along with normal sowing of wheat crop can improve the productivity and NR of cotton–wheat system.

Muhammad *et al* (2011) studied the effect of low temperature on yield of wheat cultivars and reported that due to late harvesting of cotton crop in Southern Punjab, wheat sowing is delayed. Consequently, farmers have to face a substantial yield loss. Growers are unable to plant wheat at right time in fall and major factor that seems lacking in case of late sown crop is decreased exposure of the crop to chilling temperature ultimately leading to decrease in crop yield.

Akmal *et al* (2011) Wheat has a determinate growth habit and a delay of each day in sowing from mid-November onward decreases the number of tillers, leaf area, and total dry matter. Moreover, late sowing of wheat also delays anthesis, which ultimately reduces grain yield at a rate of 30-40 kg day⁻¹ ha⁻¹

Khan *et al* (2010) reported that late-sown wheat has to complete its life cycle in a short duration because starch accumulation terminates at the same time in both normal and late-sown plants. Late sowing results in poor germination and delayed emergence due to the prevalence of low temperatures at that time. In consequence, a weak crop stand and less tillering affect grain yields. Moreover, high temperatures at later growth stages enforce shortening of the grain filling period and early maturity.

McDonald *et al* (1983) studied the effect of time of sowing on the yield of 15 wheat cultivars grown under irrigation was examined at Narrabri, N.S.W. Sowing dates, which ranged from mid-April to mid-August, encompassed the period of sowing normally found with commercial crops. The length of the pre-anthesis period was affected by both temperature and photoperiod. Each day's delay in sowing caused a delay of between 0.48 and 0.75 days in anthesis; the delays observed for spring wheat were generally greater than those reported for dryland wheat in eastern Australia. Winter cultivars generally did not show an optimum sowing or anthesis date. For spring cultivars, the optimum time of sowing was early June (range of about 3 weeks), while the optimum anthesis date was the last week of September (range of 1 week). Grain yields of spring cultivars were reduced by 6 and 16% per week's delay in sowing and anthesis respectively. Despite a non-limiting water supply, yields at late plantings were low, which was largely the result of hastened crop development and high temperatures during grain-filling. The environmental factors which determined the optimum sowing and anthesis dates were the incidence of early spring frosts and high spring temperatures.

2.7.1 Performance of furrow openers under laboratory conditions

Baker (1976) investigated the performance of hoe, triple disc and chisel-type furrow openers in a laboratory soil bin containing sandy loam soil under zero tillage conditions. The emergence of wheat seedlings for the chisel opener (77%) was significantly greater than that for the hoe (27%) and triple disc (26%) openers. Measurements of soil cover and the soil moisture content in the grooves created by the opener were analysed and results indicated that the soil moisture retention properties within the groove was the main factor affecting the ability of the seed to emerge. In contrast to triple disc and hoe-type openers, chisel-type openers confined most of the ground disturbance to the subsurface zone, resulting in increased soil moisture availability. The vertical downward force needed to achieve downward penetration was 4 times higher in the case of the triple disc openers as compared to hoe and chisel-type openers.

Ozmeri (1986) evaluated the performance of Suffolk coulter, hoe, single-disc and double-disc furrow openers with respect to seed distribution in the horizontal and vertical planes. Experiments were carried out in a laboratory soil bin containing clay loam soil under conventional tillage systems. The soil moisture was maintained at 18.04% throughout the experiments. The least variation in working depth occurred with the double-disc openers but the least variation in sowing depth was obtained by hoe-type openers. Maximum variation in working depth and depth of sowing occurred with the single-disc openers. In all cases, sowing depth was less than working depth. Variation in the transverse width of the furrow openers was found to be least with single-disc openers. The average seed spacing was closest to the theoretical spacing in the case of the double-disc openers. For hoe-type openers, it was less than the theoretical distance. The seed to seed distances of single-disc and shoe-type openers had large variations. Ozmeri concluded that shoe-type openers were suitable for shallow and deep sowing, single-disc openers for shallow and medium depth of sowing and hoe-type openers for deep sowing only. However, the basis for reaching this conclusion was not clear from the work and supporting data was not presented. Ozmeri did not quantify the terms 'shallow, medium and deep sowing' on the basis of the depth of sowing. However, from results obtained, it is clear that the hoe and double-disc furrow openers gave lesser variation in depth as compared to shoe-type openers both in the horizontal and vertical planes.

Baker and Afzal (1986) developed a winged-type furrow opener having a combined boot for sowing seed and fertilizer in a seed *cum* fertilizer drill for metering rapeseed. Preliminary experiments carried out in a laboratory soil bin showed that rapeseed was sensitive to contact with fertilizer which affected plant emergence. A subsequent experiment showed that plant emergence of rapeseed was better when vertical separation was 20 mm as compared to 10 mm. A horizontal separation of 20 mm or more gave better plant emergence as compared to 20 mm vertical separation under dry soil conditions. However, vertical separation was better under wet soil conditions. Baker and Afzal developed a winged opener consisting of a disc and two winged side blades to provide a horizontal separation of 20 mm and a vertical separation of 75 mm. The opener was evaluated in the laboratory and it was found that effective separation of seed and fertilizer was obtained under zero tillage conditions but not in tilled soil since the separating wall of soil collapsed.

Damora and Pandey (1995) evaluated the performance of seven openers which were basically of the shoe, shovel and hoe designs in laboratory soil bin with sandy clay loam and loamy sand. To evaluate the openers, a performance index was developed which considered variation in depth, amount of soil cover, vertical and horizontal separation of seed and

fertilizer, transverse variation of seed placement from the centre of the row, and soil disturbance as indicated by seed row roughness and specific energy. It was observed that

- More compaction of the furrow bottom and less seed scatter occurred with shoe-type openers as compared to shovel and hoe openers.
- Hoe-type openers placed the seed at the required depth, whereas shoe and shovel-type openers placed the seed shallower than the target depth.
- Under both soil conditions, the shoe-type opener had a minimum variation in depth. Hoe-type openers gave significantly greater lateral and vertical separation of seed and fertilizer as compared to shoe and shovel-type openers.
- Soil disturbance was highest for hoe-type openers due to asymmetric shape of the opener.
- Hoe-type openers had significantly less draught as compared to the other two openers.
- The overall performance index of hoe-type openers was better as compared to the other two openers, both in sandy clay loam and loamy sand soil types.

The above study indicates that although the shoe-type openers had better compaction of the furrow bottom and less variation in depth, the advantages of a compact seedbed at the point of placement of seed could not be obtained since seed was placed at depths shallower than the depth of furrow. Hoe-type openers gave a better performance in sandy clay loam and loamy sand soil types due to better horizontal and vertical separation of seed and fertilizer and its ability to place seed at the compact furrow bottom.

2.7.2 Performance of furrow openers under field conditions

Choudhary and Baker (1988) investigated the ability of a prototype drill using an inverted T opener developed by Baker *et al.* (1979) for sowing fodder radish. Experiments carried out showed that no difference in plant emergence occurred when seed and fertilizer were mixed and sown in comparison to drilling seed and fertilizer separately through the boot of the furrow opener. However, the former gave significantly lower yields. For the fodder radish crop, however, both plant emergence and yields were reduced by mixing seed and fertilizer. The experiments showed that the inverted T opener with a boot section designed for 20 mm horizontal separation of seed and fertilizer could be successfully used for sowing barley and fodder radish crops. Results of this study were in agreement with Baker and Afzal (1986) for dry soil conditions.

Wilkins *et al* (1983) indicated that the effect of variation in soil compaction, soil moisture in seed zone and water potential decrease rate affect plant emergence differently under different soil conditions even for the same type of soil. The furrow openers which brought soil upwards into the seed zone had higher soil moisture around the seed zone, but other factors determined the effect of this higher moisture on plant emergence. A higher soil water loss was caused by deep furrow openers as compared to disc-type openers but this did not affect plant emergence significantly.

Bahri and Bansal (1993) evaluated different combinations of furrow openers and press wheels for zero tillage sowing. They reported that, in relatively moist and loose soils, the double-disc furrow opener was the most suitable, whereas the hoe opener was better suited for hard and dry soil conditions because of its better penetration.

Anonymous (1993b) investigated the performance of inverted T, double-disc and shoe-type furrow openers for sowing the soya bean crop in black soil at soil moisture contents of 16) 89 and 22) 12%. Change in soil cover from the sowing period to the three-leaf stage was largest for the shoe-type furrow openers and smallest in the case of the double-disc openers. No significant differences in plant emergence and yield were observed among the three furrow openers in the first experiment conducted at 16.89% soil moisture content, although average values of plant emergence and yield were highest for double-disc openers. In the second experiment conducted at 22.14% soil moisture content, values of plant emergence were on the whole low but inverted T furrow openers gave significantly higher plant emergence. Sticking of soil on furrow openers was considerably less for the double-disc furrow openers.

In another study, Anonymous (1994), investigated the performance of inverted, double-disc and shoe-type furrow openers with wheat crop under normal (18.59% dry basis) and deficit (14.35% dry basis) soil moisture conditions. Standard deviation of depth of sowing was least for the double-disc furrow openers in both the experiments. However, despite higher values of plant emergence, differences in crop yield were not significant, although the average value of grain yield was highest for the double disc openers.

Tajudin and Balasubramanium (1995) evaluated hoe, shoe, wedge, single-disc and double-disc furrow openers used in bullock drawn seed drills. Field tests were conducted in black soil at a soil moisture content range of 15-20%. A power tiller was used to pull a Gorru (local seed drill) in which the furrow opener was mounted. Each furrow opener was tested with vertical forces of 0, 78.5, 157 and 245 N by adding dead weights. A performance index

was developed to compare the furrow openers. Single-disc furrow openers gave the best performance index mainly due to lower unit draught, *i.e.* draught per unit area of furrow. Wedge-type openers required the maximum power. Double-disc openers had lower unit draught but the performance index of the opener was affected due to poor penetration. In this study, however, only aspects of work output, uniformity of depth and power required were considered. Crop-related variables such as plant emergence and yield were not taken into account. The study therefore does not reflect the actual performance of the furrow openers for sowing of crops.

2.8 Optimum depth for seeding for wheat

Radford (1986) observed the effect of a press wheel and establishment of semi-dwarf depth of sowing on the and tall wheat. The factors were cultivars (tall and semi-dwarf) x depths of sowing x press wheel pressure. The press wheel was a rubber, pneumatic, over-centre pressure type (applying pressure directly over the seed row); it measured 560 mm in diameter by 70 mm wide and had a total loading of 28 kg. Where press wheel pressure was not applied, the seed furrow was closed by dragging a chain harrow behind the opener. The press wheel significantly increased mean wheat establishment ($P < 0.05$) in all sowings except II, III and IV at a site with a much lighter soil. Shallow sowing to within 5.5 cm of the soil surface gave the highest establishment percentage when no rain fell between sowing and emergence. Seed placement at about 3.5 cm appeared too shallow, resulting in significantly lower establishment than placement at 5.5 cm ($P < 0.05$). Sowing at depths below 5.5 cm resulted in significant reductions in establishment in all sowings. It is difficult to define the optimum sowing depth (or range) from these data owing to the limited number of depths tested. However, there was a clearly defined optimum depth of 5.5 cm. The results of this study show that press wheels help overcome these difficulties by increasing the generally poor establishment of deep and shallow-placed seeds. It can be concluded from the review of literature that;

- The farmers have no option rather to wait for cotton crop to mature as cotton crop is of 160 to 170 days duration.
- Planting of wheat after cotton in CW rotation under conventional practice usually gets delayed by 20-44 days as compared to rice wheat rotation.

- The delayed sowing of wheat in cotton wheat rotation reduces the wheat yield by 0.5t ha⁻¹. Relay seeding is not a new concept, work was carried out on wheat broadcasting in standing cotton in early 90's.
- It was also reported that relay seeding of wheat into standing cotton is possible with surface seeding and use of self propelled 3-row wheat seeder. Also, the relay seeding showed significant increase in wheat yield in the studies.
- Due to lack of suitable tractor operated machine for relay seeding, this technology was not adopted. Gupta *et al* (2009) reported relay cropping of wheat into a standing cotton crop, a practice common in Uzbekistan.

Literature reviewed showed that the relay seeding and broadcasting of wheat in cotton has potential to increase the productivity of CW system. Therefore, RS needs to be developed on the basis of minimal damage to cotton and optimal wheat establishment.

MATERIAL AND METHODS

The development of relay seeders for high clearance tractor deals with the design of relay seeders suitable for, popular row geometries of cotton in the region, and to the tractor track width. Apart from the design parameters, the relay seeders were evaluated for seeding wheat in two cotton hybrids. The design parameters, variables studied, equipments and instruments used, experimental procedure and statistical design followed have been discussed in this chapter as under:

3.1 Development of high clearance platform for tractor

The traditional four wheel tractors with ground clearance of around 45 to 50 cm cannot move in the standing cotton field as the plants are about 100 to 130 cm tall. To address this issue, a high clearance platform attachment for a four-wheel tractor was developed in collaboration with International Centre of Maize and Wheat Improvement- Borlaug Institute for South Asia (CIMMYT-BISA), India, and Punjab Agricultural University, (PAU) Ludhiana, India and was got fabricated from a local machinery manufacturer Rajar Agricultural works, Mullanpur, Ludhiana (Punjab), India. The conceptual design view of high clearance platform is shown in Fig. 3.1. This platform increased the ground clearance of the tractor to 115 cm to make the tractor move easily above the standing cotton. The brief specifications of the platform for the high clearance tractor are included in Table 3.1.

Table 3.1: Brief specifications of the normal tractor and tractor mounted on the high clearance platform

Specifications	Normal Tractor	Tractor mounted on high clearance platform
Ground clearance, mm	450	1100
Turning radius, mm	2700	3020
Weight, kg	2005	2550
Speed reduction (over normal)	-	17%
Track width, mm	1350	2020

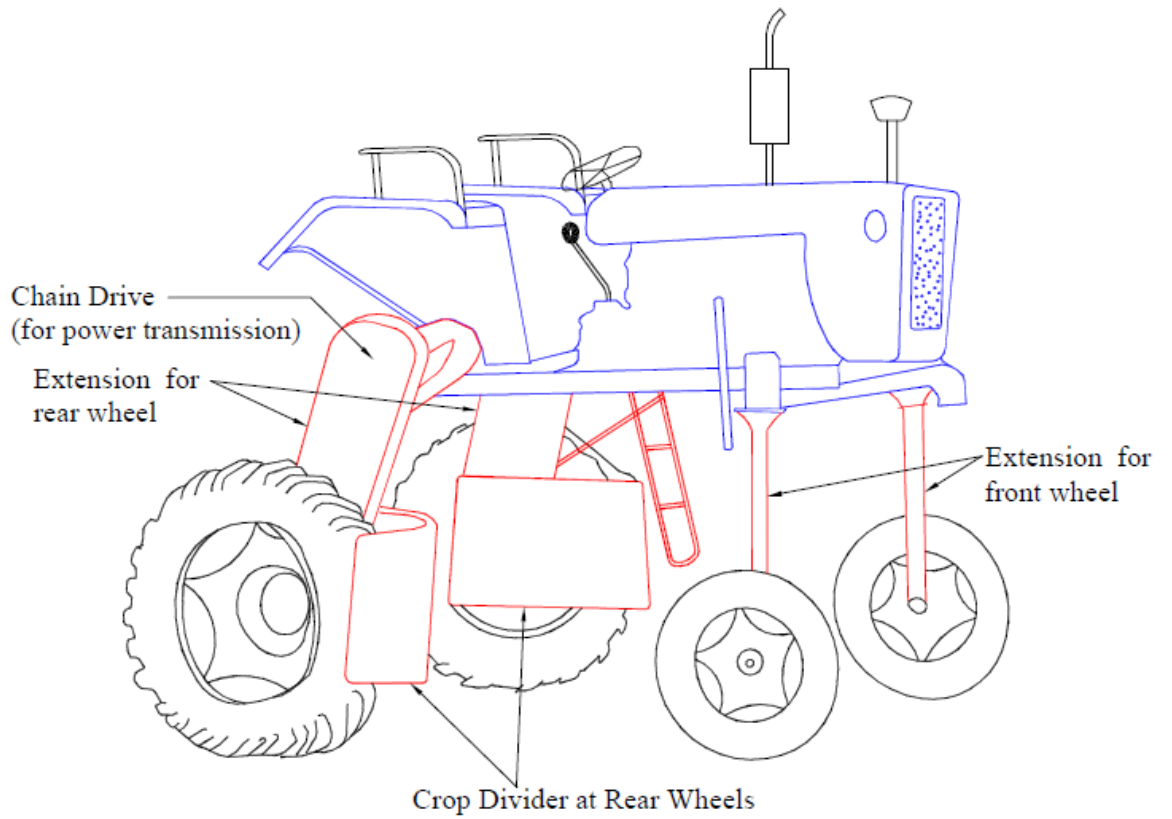


Fig. 3.1: Conceptual design of high clearance platform of the tractor



Fig. 3.2: Tractor (normal) and mounted on high clearance platform

The track width of mounted tractor was increased by 1.5 times the standard one (from 135 cm to 202.5 cm), which enables high clearance tractor to move in both 67.5 and 101.0 cm row geometries of cotton and increase the stability of the tractor. Any traditional tractor (ground clearance ~45 cm) can be converted to high clearance tractor by mounting on high clearance platform in 4 to 6 hours, Fig 3.2.

3.2 Stability of high clearance tractor

To study the stability of the tractor the CG of the normal and high clearance tractor was calculated by standard weighing technique (John *et al* 1989). The location of CG in longitudinal plane (pitching) of normal (G) and high clearance tractor (G') is shown in Fig. 3.3. In this analysis, the following simple assumptions are made:

- (i) Forward motion is uniform; this assumes constant implement forces and no acceleration.
- (ii) Lines of forces on wheels are either tangential or radial or may be resolved as such; wheel sinkage and tyre distortion (but not normal tyre deflection) are neglected.
- (iii) The tractor is symmetrical about the longitudinal vertical plane; all the forces and moments may be considered to act in this plane.
- (iv) Other forces, such as the change in position of the fuel and oil in the tractor on sloping ground, air resistance and other minor forces are neglected.

W and W' are the respective weights of normal and high clearance tractor (HCT), kg

R and R' is the respective soil reaction at front wheel for normal and HCT, kg

P and P' is respective implement pull mounted on to normal and HCT, kg

X_1 and X'_1 is respective distance of CG from rear wheel soil contact point, A in longitudinal direction, m

X_2 is the wheel base of the normal and HCT, m

l and l' is the respective right angle distance between point A and virtual line of pull for normal and HCT, m

θ_1 and θ_2 is the respective angle of pull for normal and HCT, degree

Considering the normal tractor, taking moments at A, we have;

$$R_1 \times X_2 + P \times l = W \times X_1 \quad (\text{Macmillan 2002})$$

Due to effect of weight transfer, the drawbar force P may be large enough to cause R_1 as zero. This gives

$$P = \frac{W \times X_1}{l} \quad \text{--- 3.1}$$

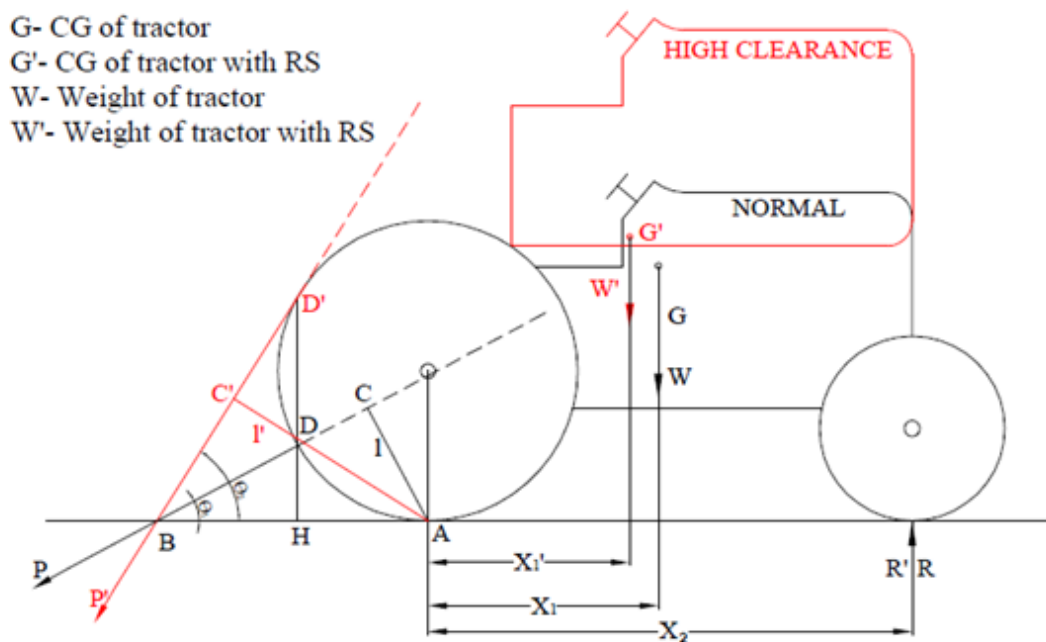


Fig. 3.3: Forces acting on the normal and high clearance tractor while operating on level ground (pitching)

Similarly, for high clearance tractor, taking moments at A, we have;

$$P' = \frac{W' \times X_1}{l'} \quad \text{---3.2}$$

3.3 Stability of high clearance tractor while turning

The location of CG in transverse plane (rolling) of normal (G) and high clearance tractor (G') is shown in Fig. 3.4.

Where, v and v' is the respective speed of travel of normal and HCT, $m s^{-1}$

t and t' is respective track width of normal and HCT, m

r and r' is respective radius of turn of normal and HCT, m

Y_1 and Y'_1 is respective distance of CG from rear wheel soil contact point, A in transverse plane, m

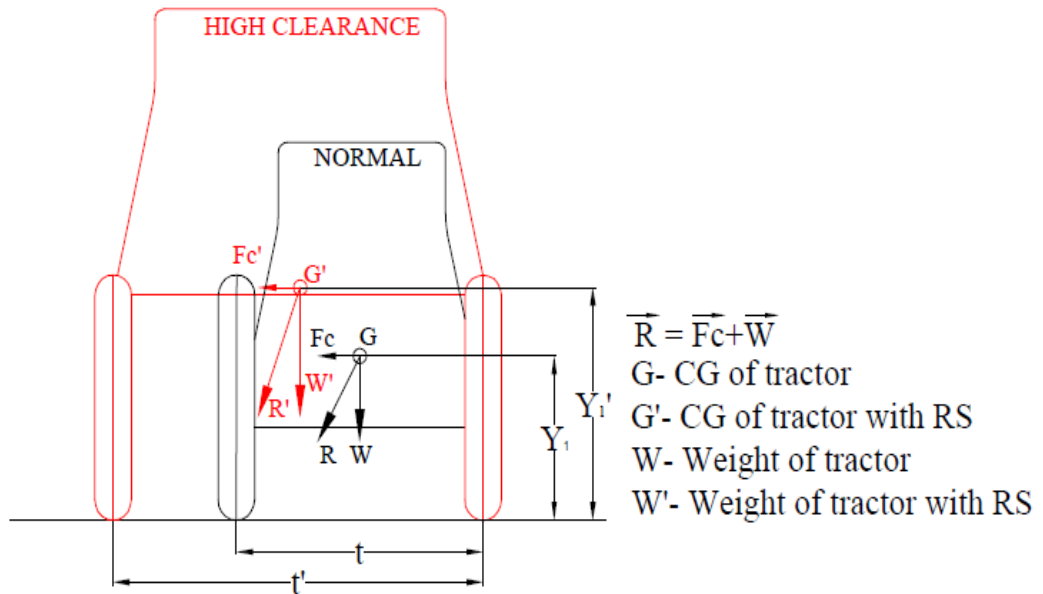


Fig. 3.4: Forces acting on the normal and high clearance tractor while operating on level ground (rolling)

Taking moments about rear wheel contact point, A for normal tractor, we have

$$\frac{W \times v^2}{r} \times Y_1 = \frac{W \times t}{2} \quad \text{----3.3}$$

Similarly for high clearance tractor

$$\frac{W' \times v'^2}{r'} \times Y_1' = \frac{W' \times t'}{2} \quad \text{----3.4}$$

Further, the stability of high clearance tractor and mounted relay seeder, against overturning in transverse plane (pitch) and longitudinal plane (roll) was studied by graphical method and by consideration of static forces acting on the tractor.

3.4 Design concept of Relay seeder

The mechanism was designed on the following consideration: To facilitate the movement of Relay Seeder mounted on high clearance tractor, causing minimal damage to cotton plants and simultaneously, relay planting wheat by opening furrows in between the cotton rows. This can be obtained either placing the RS frame above the plant canopy and designing and arranging furrow openers on to the main frame such that interference among the high clearance tractor and machine is minimal or by placing the machine frame for mounting different furrow openers above the plant canopy (115 cm above ground) for minimal hindrance to cotton. Cotton is relatively bushier at top compared to bottom. In light of this, the set of furrow openers moving among adjacent cotton rows may be arranged on sub frames. These sub frames can be clamped to main frame placed just above the plant canopy with a box section. This arrangement utilizes open space at bottom of cotton plants whereas, on the top side box section cross section moves among the plant canopy. The conceptual design of RS attached to high clearance tractor is shown in Fig. 3.5 and 3.6.

3.4.1 Functional requirements of Relay seeder

The functional requirements of the relay seeder should be:

1. Main frame of the relay seeder should have high clearance so that it can move above the 115- 120 cm high cotton crop.
2. It should be able to drill wheat seed and fertilizer directly among two adjacent rows of cotton.
3. It should cause minimal damage to standing cotton in respect of loss of cotton balls.
4. Its width should be more than the high clearance tractor track width of 202.5 cm.
5. It should be able to sow into 67.5 cm and 101.0 cm row to row spacing of the cotton, which are common among the farmers in the region.

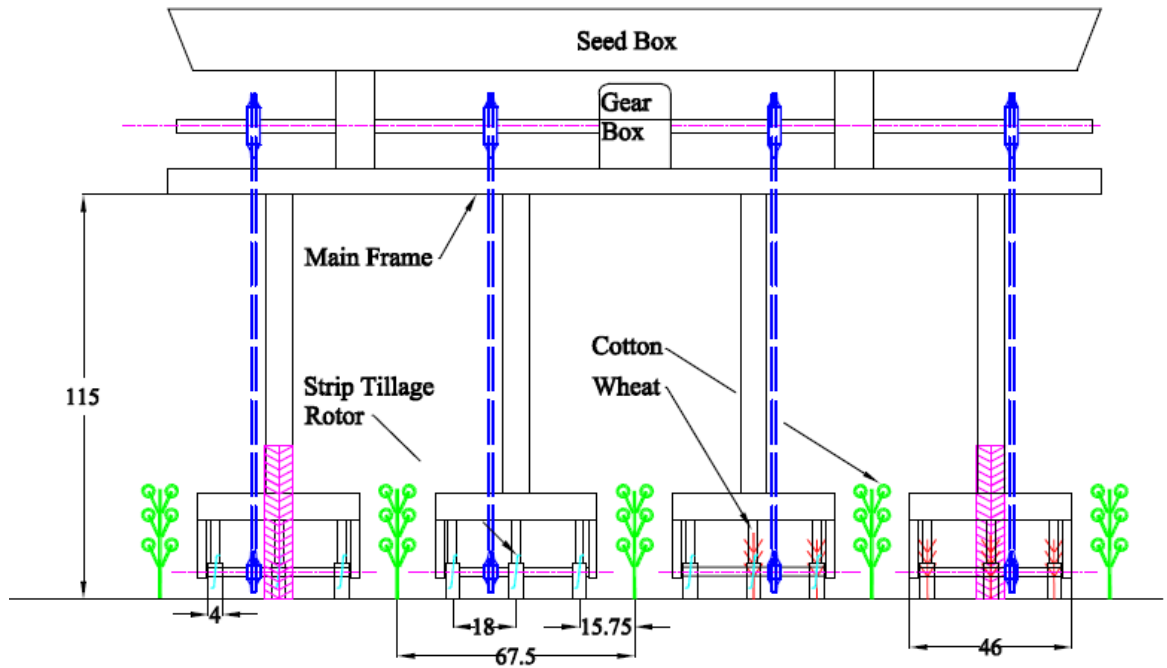


Fig. 3.5: Conceptual design of the 12 row relay seeders driven by the high clearance tractor

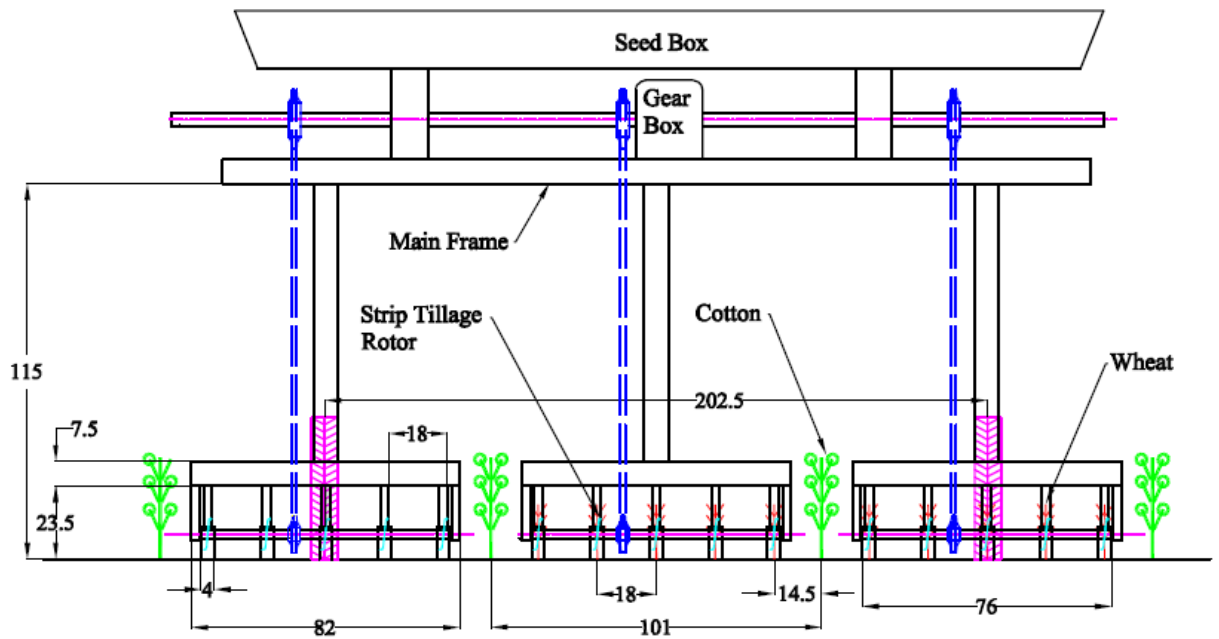


Fig. 3.6: Conceptual design of the 15 row relay seeders driven by the high clearance tractor

3.4.2 Design of different components of Relay Seeder

The design and selection of the various components of Relay Seeder was done on the basic fundamentals of machine design. The main components of straw Relay Seeder are:

- a) Gear box
- b) V-belt and sheaves
- c) Shaft for power transmission
- d) Shafts A and B for chain sprocket assemblies
- e) High clearance frame
- f) Strip tillage rotor shaft

Theoretical design procedure for all the components of RS has been discussed below.

3.4.2.1 Design of gear box

Power required at PTO (kW) for 1 cm of tilling width = 0.3 (Kepnar *et al* 1987).

Power required at shaft A, for 15 row RS having blade width 1 cm = $15 \times 1.0 \times 0.3$ kW

Power required at gear box = $4.5 / S_b \times S_c = 4.89$ kW,

where S_b = power transmission efficiency of V-belt and S_c = power transmission efficiency of chain.

Design power for gear box = $5.09 \times 1.5 = 7.6$ kW (Sharma and Aggarwal 2011)

Rotational speed of the pinion, $N_P = 540$ rpm,

Rotational speed at gear output, $N_G = 270$ rpm

Pressure Angle, $\Phi = 20^\circ$

Number of teeth of the pinion, $T_P = 15$

Number of teeth of the gear, $T_G = 30$

Allowable stress for pinion and gear, $\sigma_{al} = 103 \text{ Mpa}$

Since power is transmitted at a very low pitch line velocity, a gear tooth module $m = 6 \text{ mm}$ may be selected.

Face width (b) = $10 \times m = 60 \text{ mm}$

Outside radius of pitch cone for pinion, $r_{oP} = \frac{m \times T_P}{2} = \frac{6 \times 15}{2} = 45 \text{ mm}$

Outside radius of pitch cone for gear, $r_{oG} = \frac{m \times T_G}{2} = \frac{6 \times 30}{2} = 90 \text{ mm}$

Pitch angle of the pinion, $\alpha_p = \tan^{-1}(45/90) = 26.56^\circ$

Pitch radius at midpoint of face, $r_p = r_{oP} - \frac{b \times \sin \alpha_p}{2} = 31.58 \text{ mm}$

Circular pitch at mid point, $P = \frac{2 \times \pi \times r_{oP}}{T_P} = 18.84 \text{ mm}$

Number of formulate teeth of the pinion, $T_{EP} = \frac{T_P}{\cos \alpha_p} = 16.76$

Tooth form factor for pinion

$$y_P = 0.124 - \frac{0.684}{T_{EP}} = 0.0832$$

Bending capacity, $F_b = \sigma_b \times b \times y_p \times P = 103 \times 60 \times 0.0832 \times 18.84 = 9688.5 \text{ N}$

Velocity, $V = \frac{\pi \times m \times T_P \times N_P}{60 \times 1000} = 2.54 \text{ m s}^{-1}$

Dynamic tooth load, $F_d = \frac{F_t \times C_s}{C_v}$, Where F_t = transmitted or horsepower load,

C_s = Service factor = 1.2 and C_v = Dynamic load factor

$$C_v = \frac{50}{50 + \sqrt{200 \times V}} = 0.689$$

$F_b \geq F_d$, i.e. Bending strength should be greater than or equal to dynamic load.

For safe design, bending strength is taken equal to dynamic tooth load.

$$F_d = F_b = 9688.5\text{N}$$

$$F_t = \frac{F_d \times C_v}{C_s} = 5565 \text{ N}, \text{ Power transmitted by the bevel gears} = \frac{F_t \times V}{1000} = 14.1\text{kW and}$$

FOS for the gear box designed = 1.86

3.4.2.2 Selection of V-belts and sheave

The power required to till the narrow strips ahead of furrow openers may estimated by, Power required at PTO (kW) for 1 cm of tilling width = 0.3 (Kepnar *et al* 1987).

Power required at shaft A, for 15 row RS having blade width 1 cm = 15 x 1 x 0.3 kW

Design power at A $P_d = 4.5 \times 1.2$ (service factor) = 5.4 kW (Sharma and Aggarwal 2011)

Diameter of the sheave mounted on shaft A, $D_1 = 203.2 \text{ mm}$

Diameter of the sheave mounted on shaft B, $D_2 = 304 \text{ mm}$

Shaft A speed, $N_1 = 270 \text{ rpm}$

Center distance between the shafts A and B, $C = 450 \text{ mm}$

Belt speed:

$$V = \frac{\pi D_1 N_1}{60 \times 1000} = 2.87 \text{ m s}^{-1}$$

According to rated power chart, the B section V- Belt was selected

$$\text{Contact angle, } \theta_s = 180 - \frac{60(D_1 - D_2)}{C} = 193.46^\circ$$

Contact Angle 3.37 radians > 2.1 radians is safe for power transmission

$$\text{Theoretical length of belt, } L = 2 \times C + \frac{1}{2} \pi (D_1 + D_2) + \frac{(D_1 - D_2)^2}{4 \times C} = 1703.7 \text{ mm}$$

For C-section, nearest belt length is selected from standard V-belt length tables.

$$\text{Design power, kW } P_d = \frac{V (F_1 - F_2)}{1000} \quad \text{---3.5}$$

$$\text{Also, } \frac{F_1}{F_2} = e^{(\mu_e \times \theta)} \quad \text{---3.6}$$

where $\mu_e = \frac{0.3}{\sin(\beta/2)}$ and $\beta = 38^\circ$ and $\mu = 0.3$ for a cast Iron pulley

By simultaneously solving equation 3.5 and 3.6, we have

$$F_1 = 940.8 \text{ N and } F_2 = 126.4 \text{ N and } F = F_1 + F_2 = 1067.5 \text{ N}$$

Power transmission capacity (Pt) of C-section, V- Belt at faster pulley at 270 rpm is 3.60 hp.

Hence number of V- Belts required, N_b .

$$N_b = \frac{5.4}{k_a \times 0.746 \times k_l \times p_t} = 2.1$$

where, k_a = Angle of contact factor = 0.97 and k_l = Belt length correction factor = 1.0 (Sharma and Aggarwal, 2011).

Three belts were selected for the drive for 15 row relay seeder. The same procedure was followed for 12 row relay seeder was followed and two v-belts with C-section were selected. The V-belt combination acts as safety clutch, in case power required by chain assembly increases, slippage occurs in V-belts.

3.4.2.3 Design of shaft 'A' (Power transmission)

Engine Power at speed of 1400 rpm = 25 hp

Power at PTO = 22.5 hp

Power at Gear box (after Universal joint) = $0.92 \times 22.5 = 20.7$ hp

Power at shaft (after gear box) = $20.7 \times 0.96 = 19.9$ hp

Power at V-belt sheave (after two bearing on the shaft) = $19.9 \times 0.96 = 19.1$ hp

Power in kW = $19.1 \times 0.746 = 14.84$ kW

$\tau_{al} = 50-80$ Mpa (for cold drawn mild steel shafts)

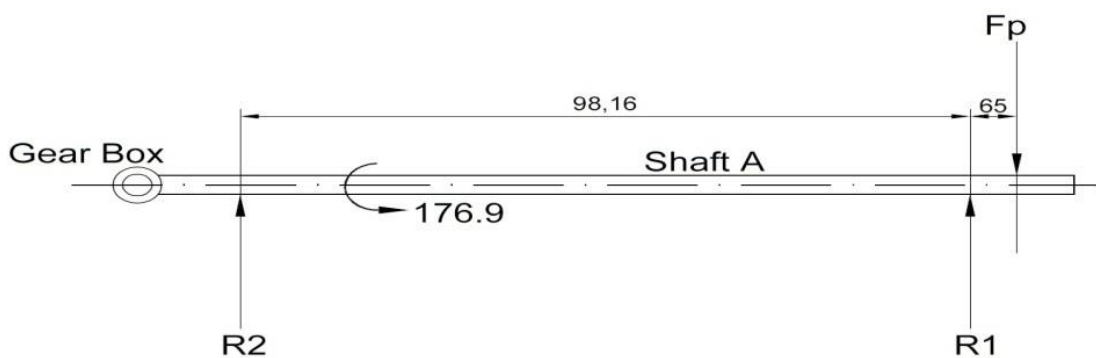


Fig. 3.7: Forces acting on the power transmission shaft 'A'

$$\text{Torque (T)} = \frac{5.0 \times 1000 \times 60}{2 \times \pi \times N_1} = 524.85 \text{ Nm}$$

$$\tau_{\max} = \frac{16}{\pi \times d^3} \sqrt{(k_m \times M)^2 + (k_t \times T)^2}$$

where k_m = Combined shock and fatigue factor for bending, k_t = combined shock and fatigue factor for torsion, M is moment due to bending of the shaft. V-belt sheave was fixed at 8 mm from the bearing due to which bending moment for the shaft was negligible as compared to torque on the shaft, Fig. 3.7. Hence, τ_{\max} is calculated only for torque on the shaft.

$$\tau_{\max} = \frac{16}{\pi \times d^3} \sqrt{(k_t \times T)^2} \text{ Mpa}$$

For safe design of the shaft the value of τ_{\max} should be less than or equal to τ_{al}

$$65 = \frac{16}{\pi \times d^3} \sqrt{(1.2 \times 524875)^2}$$

Diameter of the shaft (d) = 36.67 mm

Standard available shaft size of 50 mm was selected.

3.4.2.4 Selection of chain and sprockets

3.4.2.4.1 Relay seeder of 15 rows

The power required rotate 5 strip till blades, Power required at PTO (kW) for 1 cm of tilling width = 0.3 (Kepnar *et al* 1987).

Power required to rotate 5 row chain assembly = 0.3 x 1 x 5 kW, as thickness of strip till blade is 0.5 cm.

Design power at B, $P_d = 1.5 / 0.9 = 1.67$ kW

Shaft B speed, $N_2 = 180$ rpm

Centre distance between the shafts B and Strip till rotor shaft, $C = 1500$ mm

Design pitch range, $p = \frac{C}{(30 \text{ to } 60)} = 25 \text{ to } 50$ mm

The standard pitch of 25.4 mm was selected, Number of teeth of pinion, $Z_1 = 25$ and minimum factor of safety required is 8.2 (Sharma and Aggarwal 2011).

$$\text{Chain speed, } V = \frac{p Z_1 N_1}{60 \times 1000} = 1.9 \text{ m s}^{-1}$$

Total load, $F_0 = F + F_c + F_f$

$$\text{Where, } F = \text{driving force} = \frac{1.67 \times 1000}{1.9} = 877.2 \text{ N}$$

$$F_c = \frac{w \times V^2}{g} = 9.95 \text{ N}$$

Where w = weight of chain m^{-1} length of chain, = $27 N m^{-1}$ for selected chain

$$F_f = k_f w C = 40.5 N$$

Minimum braking load of selected chain $43.1 N$ (Sharma and Aggarwal 2011)

$$\text{Factor of safety} = \frac{43.1 \times 1000}{927.64} = 46.5, \text{ therefore the selected chain is safe for the}$$

given load. Standard sprockets of $p = 25.7$ were selected for chain.

3.4.2.4.2 Relay seeder of 12 rows

The power required rotate 3 strip till blades, Power required at PTO (kW) for 1 cm of tilling width = 0.3 (Kepnar *et al* 1987).

Power required to rotate 5 row chain assembly = $0.3 \times 0.5 \times 3$ kW, as thickness of strip till blade is 0.5 cm.

$$\text{Design power at A } P_d = 0.45 / 0.9 = 0.5 \text{ kW}$$

Shaft B speed, $N_2 = 180$ rpm

Centre distance between the shafts B and Strip till rotor shaft, $C = 450$ mm

$$\text{Design pitch range, } p = \frac{C}{(30 \text{ to } 60)} = 25 \text{ to } 50 \text{ mm}$$

The standard pitch of 25.4 mm was selected, Number of teeth of pinion, $Z_1 = 25$ and minimum factor of safety required is 8.2 (Sharma and Aggarwal, 2011)

$$\text{Chain speed, } V = \frac{p Z_1 N_1}{60 \times 1000} = 1.9 \text{ m s}^{-1}$$

Total load, $F_0 = F + F_c + F_f$

$$\text{Where, } F = \text{driving force} = \frac{0.5 \times 1000}{1.9} = 263.2 N$$

$$F_c = \frac{w \times V^2}{g} = 9.95 N$$

Where w = weight of chain/m length of chain, = 27 N m^{-1} for selected chain

$$F_f = k_f w C = 40.5 \text{ N}$$

Minimum braking load of selected chain 43.1 N (Sharma and Aggarwal 2011)

$$F_0 = 313.7 \text{ N}$$

Factor of safety = $\frac{43.1 \times 1000}{313.7} = 137$, therefore the selected chain is safe for the given load. Standard sprockets of $p = 25.7$ were selected for chain.

3.4.2.5 Design of main shaft 'B'

3.4.2.5.1 15-row Relay seeder

Load on shaft B due to chain assemblies, $F_{sh} = F + 2 k_f w C = 519.6 \text{ N}$

Also, Power to transmitted by the main shaft in kW = $0.5 \times 0.3 \times 15/0.9 = 2.5 \text{ kW}$

$\tau_{al} = 50\text{-}80 \text{ Mpa}$ (for cold drawn mild steel shafts)

$$\text{Torque (T)} = \frac{2.5 \times 1000 \times 60}{2 \times \pi \times N_2} = 132.63 \text{ Nm}$$

Bending moment in shaft 'B'

$$\tau_{\max} = \frac{16}{\pi \times d^3} \sqrt{(k_m \times M)^2 + (k_t \times T)^2}$$

Where k_m = Combined shock and fatigue factor for bending, k_t = combined shock and fatigue factor for torsion, M is moment due to bending of the shaft, Fig. 3.8.

Load on shaft B due to v-belt pulley $F_p = F_1 + F_2 = 1067.2 \text{ N}$

Load on main shaft due to chain assembly $F_{sh} = F + 2 k_f w C = 519.6 \text{ N}$

Taking moments at R_1

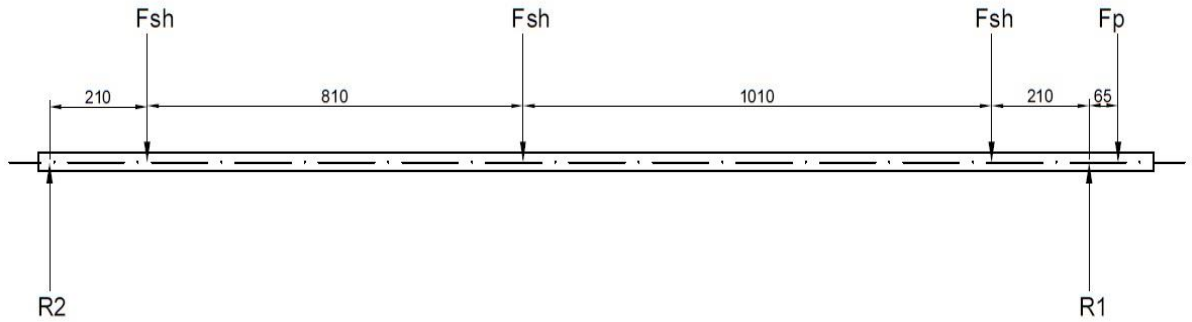


Fig. 3.8: Forces acting on the power transmission shaft 'B' used for 15-row relay seeder

$$519.6 \times 0.21 + 519.6 \times 1.22 + 519.6 \times 2.03 = R_2 \times 2.24 + 1067.7 \times 0.065, R_2 = 771.6 \text{ N}$$

Similarly $R_1 = 1854.4 \text{ N}$

The critical section for the shaft is at R_1 , Moment at this section = 69.4 N m

For safe design of the shaft the value of τ_{\max} should be less than or equal to τ_{al}

$$65 = \frac{16}{\pi \times d^3} \sqrt{(1.2 \times 69.4)^2 + (1.3 \times 132.63)^2}$$

Diameter of the shaft (d) = 24.7 mm

Standard available shaft size of 35 mm was selected for 15 row relay seeder.

3.4.2.5.2 12-row Relay seeder

Load on shaft B due to chain assemblies, $F_{\text{sh}} = F + 2 k_f w C = 394.6 \text{ N}$

Also, Power to transmitted by the main shaft in kW = $0.5 \times 0.3 \times 12/0.9 = 2 \text{ kW}$

$\tau_{\text{al}} = 50\text{-}80 \text{ M Pa}$ (for cold drawn mild steel shafts)

$$\text{Torque (T)} = \frac{2 \times 1000 \times 60}{2 \times \pi \times N_2} = 106.1 \text{ Nm}$$

Bending moment in shaft B

$$\tau_{\max} = \frac{16}{\pi \times d^3} \sqrt{(k_m \times M)^2 + (k_t \times T)^2}$$

where k_m = Combined shock and fatigue factor for bending, k_t = combined shock and fatigue factor for torsion, M is moment due to bending of the shaft, Fig. 3.9.

Load on shaft B due to v-belt pulley $F_p = F_1 + F_2 = 783 \text{ N}$

Load on main shaft due to chain assembly $F_{sh} = F + 2 k_f w C = 394.6 \text{ N}$

Taking moments at R_1

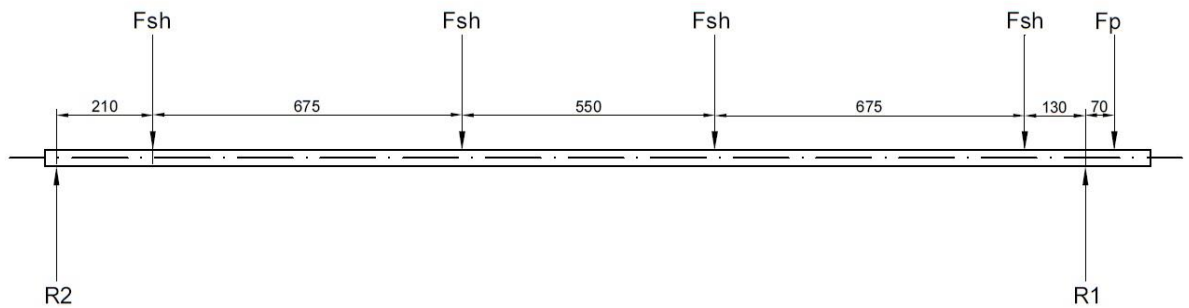


Fig. 3.9: Forces acting on the power transmission shaft 'B' used for 12-row relay seeder

$$394.6 (0.13 + 0.805 + 1.355 + 2.03) = R_2 \times 2.24 + 783 \times 0.07, R_2 = 736.5 \text{ N}$$

Similarly $R_1 = 1624.9 \text{ N}$

The critical section for the shaft is at R_1 , Moment at this section = 54.8 N m

For safe design of the shaft the value of τ_{\max} should be less than or equal to τ_{al}

$$65 = \frac{16}{\pi \times d^3} \sqrt{(1.2 \times 54.8)^2 + (1.3 \times 106.1)^2}$$

Diameter of the shaft (d) = 22.9 mm

Standard available shaft size of 35 mm was selected for 12 row relay seeder.

3.4.2.6 Design of tine for Relay seeder

Draft of zero till tine = 15 kgf = 147 N (Sharma and Mukesh, 2008, Kepnar *et al* 1987)

Distance of draft application on furrow opener tine, $a = h/3$, where h is the total length of furrow opener and tine.

Moment arm length = $h-a = (200-66.6) = 133.4$ mm

Bending moment in tine, $M_b = 147 \times 133.4 = 19609.9$ N mm

Section modulus of tine (Z) = $(M_b/f_b) \times \text{FOS}$, where $f_b = 65$ N mm⁻² and FOS = 2

$$Z = \frac{t \times b^2}{6} = \frac{19609.9}{65} \times 2, t = 9.1 \text{ mm (Assuming } b = 20 \text{ mm)}$$

Hence, MS flat section of 20x10 mm was selected for the tine of relay seeder

3.4.2.7 Design of sub frame of Relay seeder

3.4.2.7.1 15-row Relay seeder

Draft force on set of 5 tines = 5×147 N = 735 N

Torque on the square section due to draft = $735 \times 133.4 = 98049$ N mm

Bending moment in sub frame due to draft = $147 (0.09+0.27+0.45) = 11907$ N mm

$$T_{eq} = \sqrt{(1.0 \times 11907)^2 + (1.0 \times 98049)^2} = 98769.3 \text{ N mm}$$

$$\frac{Z}{Y} = \frac{\tau_{eq}}{f_b} \times 2$$

Where. Z = section modulus for square section = $\frac{a^4 - b^4}{12}$, $Y = \frac{a}{\sqrt{2}}$, a = other dimension

of square section and b is inner dimension of section, Also assume $a=1.2b$, we have

$$\frac{(a^4 - b^4)}{a} = 25787.3, b = 30.66, a = 36.79 \text{ mm}$$

Therefore, box section with a = 45 mm and b = 40 mm was selected

3.4.2.7.2 12-row Relay Seeder

Draft force on set of 3 tines = 3 x 147 N = 441 N

Torque on the square section due to draft = 441 x 133.4 = 58829.4 N mm

Bending moment in sub frame due to draft = 147 (0.18) = 26.46 N mm

$$T_{eq} = \sqrt{(1.0 \times 26.46)^2 + (1.0 \times 58829.4)^2} = 58829.4 \text{ N mm}$$

$$\frac{Z}{Y} = \frac{\tau_{eq}}{f_b} \times 2$$

Where, Z = section modulus for square section = $\frac{a^4 - b^4}{12}$, $Y = \frac{a}{\sqrt{2}}$, a = outer dimension of square section and b is inner dimension of section, Also assume a = 1.2b, we have

$$\frac{(a^4 - b^4)}{a} = 15359.5, b = 25.79, a = 30.96 \text{ mm}$$

Therefore, box section with a = 45 mm and b = 40 mm was selected

3.4.2.8 Design of main frame of Relay seeder

3.4.2.8.1 15-row Relay seeder

Draft force on set of 5 tines = 5 x 147 N = 735 N (as two sub frames will attached to one frame and central sub frame of 5 furrow openers be attached with other box section)

Torque on the square section due to draft = 735 x 1140 = 0.84 x 10⁶ N mm

τ_{eq} = torque on main frame as bending moment on main frame is negligible compared to torsion stress = 0.84 x 10⁶ N mm

Twin square boxes were used to attach the sub-frame to main frame, this reduce the equivalent torque by 50%. Also, FOS = 2

$$\frac{Z}{Y} = \frac{\tau_{eq}}{2 \times f_b} \times 2$$

where Z = section modulus for square section = $\frac{a^4 - b^4}{12}$, $Y = \frac{a}{\sqrt{2}}$ a = other dimension of square section and b is inner dimension of section, Also assume $a = 1.2b$, we have

$$\frac{(a^4 - b^4)}{a} = 109655.9, \quad b = 46.74, \quad a = 56.1 \text{ mm}$$

Therefore, box section of with $a = 60$ mm and $b = 50$ mm was selected

3.4.2.8.2 12-row Relay seeder

Draft force on set of 3 tines = $3 \times 147 \text{ N} = 441 \text{ N}$ (as two sub frames will attached to one frame and central sub frame of 5 furrow openers be attached with other box section)

Torque on the square section due to draft = $441 \times 1140 = 0.503 \times 10^6 \text{ N mm}$

τ_{eq} = torque on main frame as bending moment on main frame is negligible compared to torsion stress = $0.503 \times 10^6 \text{ N mm}$

Twin square boxes were used to attach the sub-frame to main frame, this reduce the equivalent torque by 50%. Also, FOS = 2

$$\frac{Z}{Y} = \frac{\tau_{eq}}{2 f_b} \times 2$$

Where, Z = section modulus for square section = $\frac{a^4 - b^4}{12}$, $Y = \frac{a}{\sqrt{2}}$, a = other dimension of square section and b is inner dimension of section, Also assume $a = 1.2b$, we

have,

$$\frac{(a^4 - b^4)}{a} = 65629.1, \quad b = 39.4, \quad a = 47.3 \text{ mm}$$

Therefore, box section of with $a = 60$ mm and $b = 50$ mm was selected. Standard bearings have been selected for the designed sizes for shafts.

3.4.3 Fabrication of the Relay seeders

Relay seeders with 12 and 15 rows for seeding wheat into 67.5 cm and 101.0 cm row spacing of cotton were developed in collaboration with BISA CIMMYT India, and department of Farm Machinery and Power Engineering, PAU, Ludhiana and was got fabricated from M/s Jagajit Industries, Cheema Mandi, Mansa (Punjab), India, based on the specification of different components designed in pervious section, Table 3.2. The RS attached to high clearance tractor was developed at Borlaug Institute for South Asia (BISA), Lodowal, Ludhiana. Testing and field evaluation were conducted on the BISA Farm during 2013-14. Three types of furrow openers (zero-till inverted T-type furrow opener (ZTT), double disc furrow openers (ZTDD) and strip till rotor furrow openers (STR) were fabricated and evaluated for seeding of wheat, Fig. 3.10. In strip tillage, furrow openers make a narrow strip (2.5–3.5 cm) using steel blades mounted on a rotor in front of each zero till furrow opener to facilitate placement of seed and fertilizer. A ZTT opener is a zero till furrow opener which opens the furrow and places seed and fertilizer in the soil. The ZTDD furrow opener has two spring mounted discs to open furrow, for placement of seed and fertilizer. The depth of seeding is controlled by the spring tension whereas, in case of SRT and ZTT openers separate depth control wheels were mounted on the frame of RS. The main frame of relay seeders has a ground clearance of 120 cm enabling its movement above the standing cotton with minimal interference with the plants. Two separate boxes for seed and fertilizer with fluted roller seed-metering mechanism were mounted onto the main frame. The 12-row RS consists of 4 seeding units (36 cm wide) having 3 metering units mounted on each unit and thus covering 4 rows of cotton crop in a single pass, Fig. 3.11.

Similarly, 15- row RS consists of 3 seeding units (72 cm wide) having 5 metering units and it covers 3 rows of cotton crop in a single pass, Fig. 3.11. The seeding units consist of tool bar for mounting of furrow openers, strip tillage rotor assembly and crop dividers. The tool bar carrying the furrow openers was welded onto two box section of size 5 cm x5 cm x90 cm. These box sections were clamped to main frame of the RS. Double box section was used to reduce the bending moment on the machine frame, as the length of box section was more compared to traditional drills. A gear box was mounted on the main frame of both relay seeders to transmit the power from the tractor PTO to the different strip tillage rotors of the machine. Brief specifications of 12- row and 15-row RSs are included in Table 3.3.

Table 3.2: Summary of design considerations and selected specifications for 15-row and 12-row Relay Seeder

Component of Relay Seeder	Designed specifications		Selected specifications	
	12-row RS	15-row RS	12-row RS	15-row RS
V-belt for power transmission from shaft 'A' to shaft 'B'	-	2.1 belts of C-section	3 belts of C-section	3 belts of C-section
Chain and sprocket assembly	-	Chain with pitch 25.4 mm and teeth of pinion as 25	Chain with pitch 25.4 mm and teeth of pinion as 25	Chain with pitch 25.4 mm and teeth of pinion as 25
Diameter of shaft 'A', mm	-	36.67	50	50
Diameter of shaft 'B', mm	22.9	24.7	35	35
Tine (MS flat), mm ²	-	20x9.1	20x10	20x10
Sub frame (hollow box cross section) (a, b), mm	31.0, 25.8	36.8, 30.7	45, 40	45, 40
Sub frame (hollow box cross section) (a, b), mm	47.3, 39.4	56.1, 46.7	60, 50	60, 50

RS-Relay seeder, a-outer cross section of hollow box section, b-inner cross section of hollow box section

3.4.3.1 Seeding unit for 12- row relay seeder

It consists of a tool bar for mounting three furrow openers each at 18 cm apart and rotary shaft mounted ahead of furrow openers. Four tool bars containing three furrow openers are clamped to the main frame by welding two square box sections of 50x50 mm, Fig. 3.12. A chain for transmitting power to strip till rotor shaft is housed inside these box sections to avoid the direct contact of chain with the cotton plants. Since cotton plants are bushy at middle and top, compared to its bottom, the seeding units were designed broader at bottom and narrow at the top for smooth movement/passage of unit through the cotton crop. The width of unit for 12-row RS is 450 mm from the bottom and 50 mm from the top. The main frame of relay seeder moves above the cotton plant and seeding assemblies' moves between

Table 3.3: Brief specifications of the 12 rows relay seeder and 15 rows relay seeder

SNO	Description or component	12 row relay seeder	15 row relay seeder
1	Type of implement	Tractor mounted (Three point hitch)	Tractor mounted (Three point hitch)
2	Power required (horse power)	35 or above	35 or above
3	Ground clearance of machine (mm)	1100	1100
4	Working width (mm)	2700	3030
5	Gear box	Bevel crown wheel and pinion	Bevel crown wheel and pinion
6	Capacity (ha h ⁻¹)	0.24	0.27
7	Weight (kg)	400	450
8	Fuel consumption (L ha ⁻¹)	16.67	14.81
Strip-till rotor			
9	Type of rotor drive	Chain drive	Chain drive
10	Number of blades	4	4
11	Type of blade	Knife	Knife
12	Number of flanges	12	15
Furrow openers			
13	Number of tool bars and mounting on main frame	4 ; Alternate on front and back bar of main frame	3 ; Alternate on front and back bar of main frame
14	Number of furrow openers	12 ; 3 on each tool bar	15; 5 on the each tool bar
15	Type of furrow openers	STR, ZTT,ZTDD	STR, ZTT,ZTDD
16	Number of crop dividers	4	3
17	Row spacing (mm)	18 cm between 3 openers of tool bar and 32 cm between adjacent set of openers of adjacent tool bar	18 between 5 openers of tool bar and 29 cm between adjacent set of openers of adjacent tool bar
18	Seed metering device	Fluted feed rollers	Fluted feed rollers
19	Fertiliser metering device	Fluted feed rollers	Fluted feed rollers

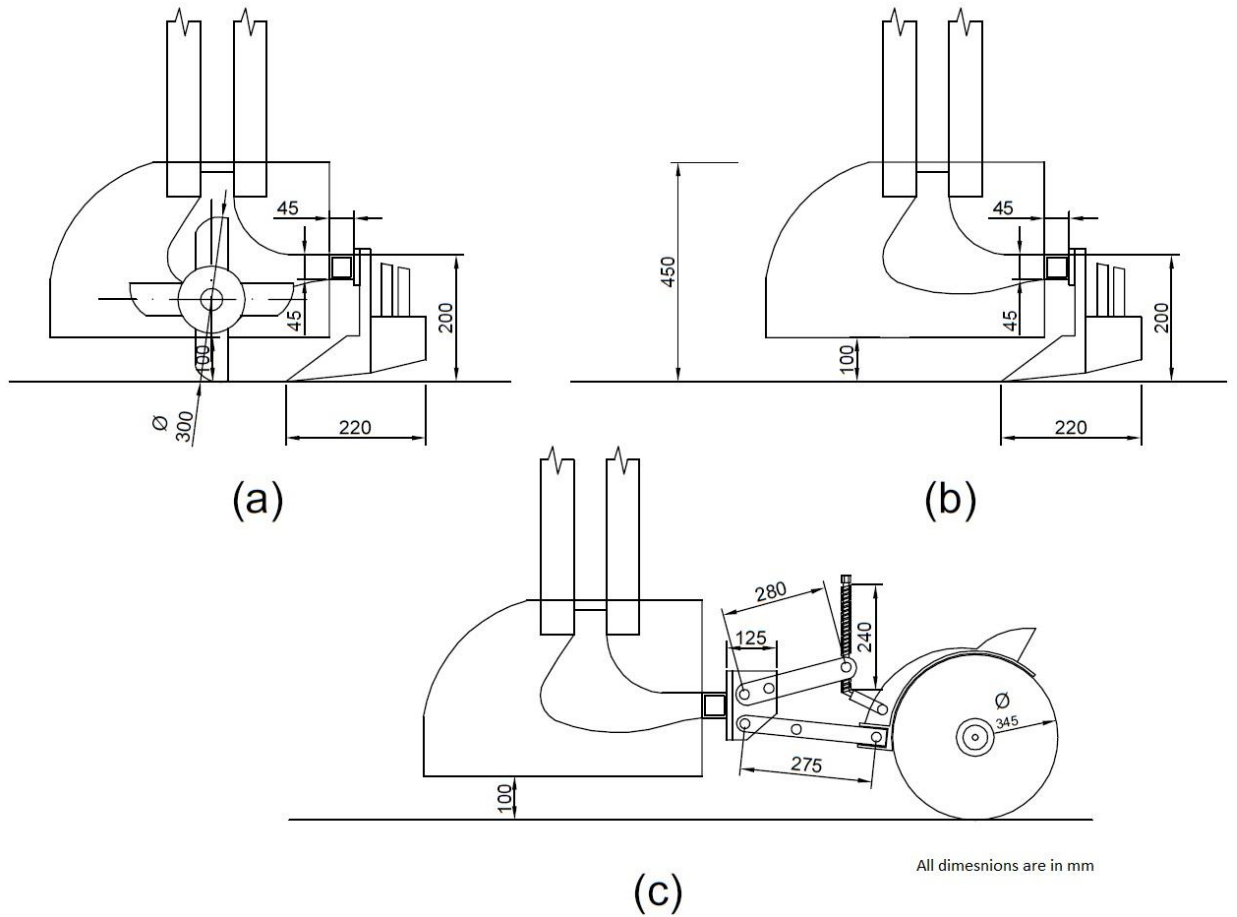


Fig. 3.10: Different type of furrow openers tested with RS a) STR b) ZTT and c) ZTDD

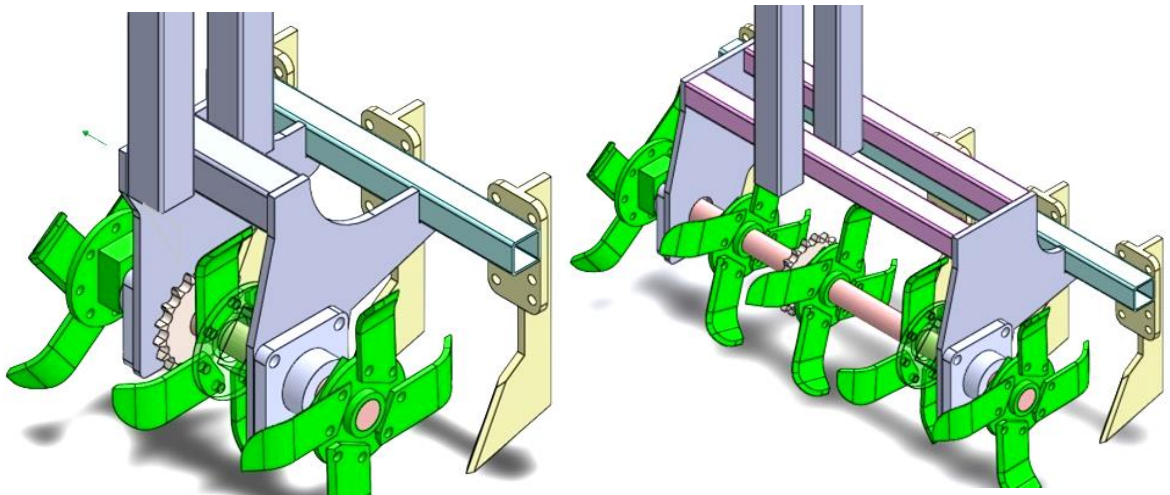


Fig. 3.11: Arrangement of tines and STR on seeding assemblies for a) 67.5 cm row to row spacing of cotton and b) 101.0 cm row to row spacing of cotton

the rows of cotton. 4 seeding units were staggered on to main frame of relay seeder (Alternate 2 on front tool bar and remaining 2 on rear tool bar of the machine) to provide more open space to cotton plant during machine operation, Fig 3.13.

3.4.3.2 Seeding units for 15 rows relay seeder

It has five furrow openers each at 18 cm apart and rotary shaft mounted ahead of furrow openers. Three tool bars containing 5 furrow openers are clamped to the main frame by welding two square box sections of 50 x 50 mm, Fig. 3.14. Two square box sections were attached to tool bar containing furrow openers to check the machine failure against bending force acting at bottom of seeding unit assembly. A chain for transmitting power to strip till rotor shaft is housed inside these box sections to avoid the direct contact of chain with the cotton plants and to keep the width of seeding assembly minimum at the top. Since cotton plant canopy is bushy at middle and top compared to its bottom section, the seeding units were designed broader at bottom and narrow from the top for smooth movement/passage of unit through the crop. The bottom width of unit for 15- row RS is 800 mm and top width is 50 mm. The main frame of relay seeder moves above the cotton plant and seeding assembly's moves between the rows of cotton. The 3 seeding units (2 on front tool bar and one in centre of rear tool bar of the machine) were clamped alternately to the both bars of the main frame of relay seeder to provide more open space to cotton plant during machine operation, Fig. 3.15.

3.4.3.3 Power transmission wheel for seed and fertilizer metering unit

The traditional ground wheel for metering the seed and fertilizer was modified for taking power from the tractor rear wheel. The spokes welded on to the circumference of ground wheel were replaced with rectangular bars (10x10x100 mm) to mesh with lugs of the rear wheel of tractor. The weight of the ground wheel was develops sufficient friction among the power wheel and tractor rear wheel, Fig. 3.16. This friction force rotates the power wheel and it transmits power to seed and fertilizer metering mechanisms. The power wheel is hinged to main frame of the RS and it engages with rear wheel of tractor. A chain is attached with the ground wheel and machine frame and its length is so adjusted that the power wheel got disengaged from the rear wheel of tractor as and when the relay seeder is lifted on turns by the operator. This arrangement checks the unnecessary dropping seed and fertilizer from the relay seeder while sowing in the field.

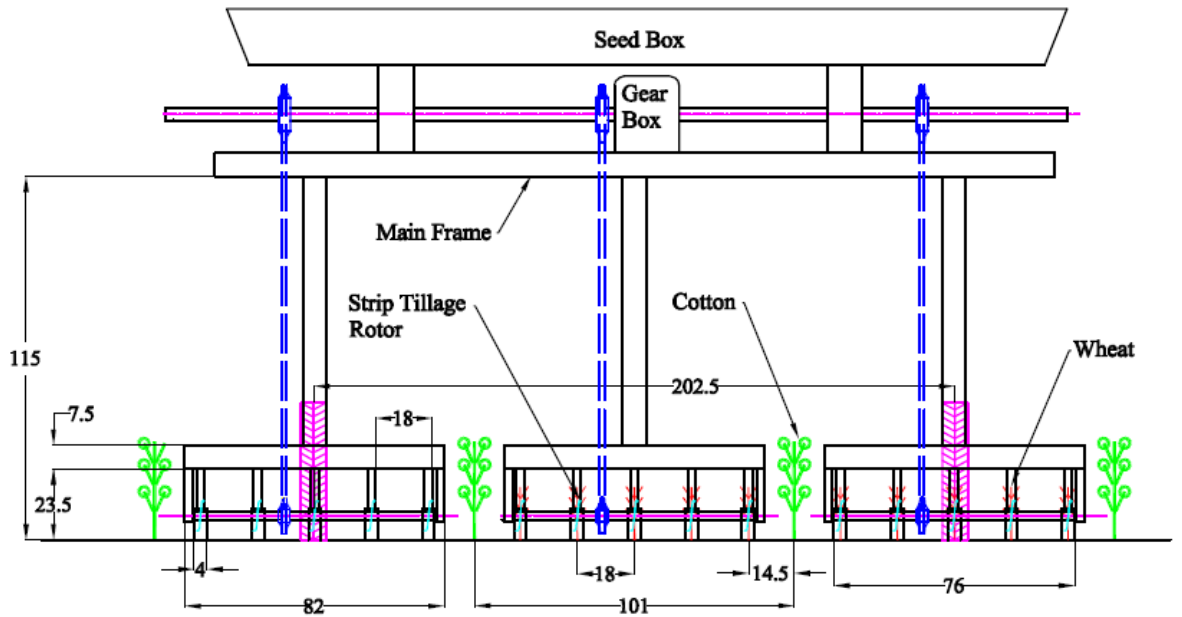


Fig. 3.14: Front and side view of 101.0 cm row spacing relay seeder

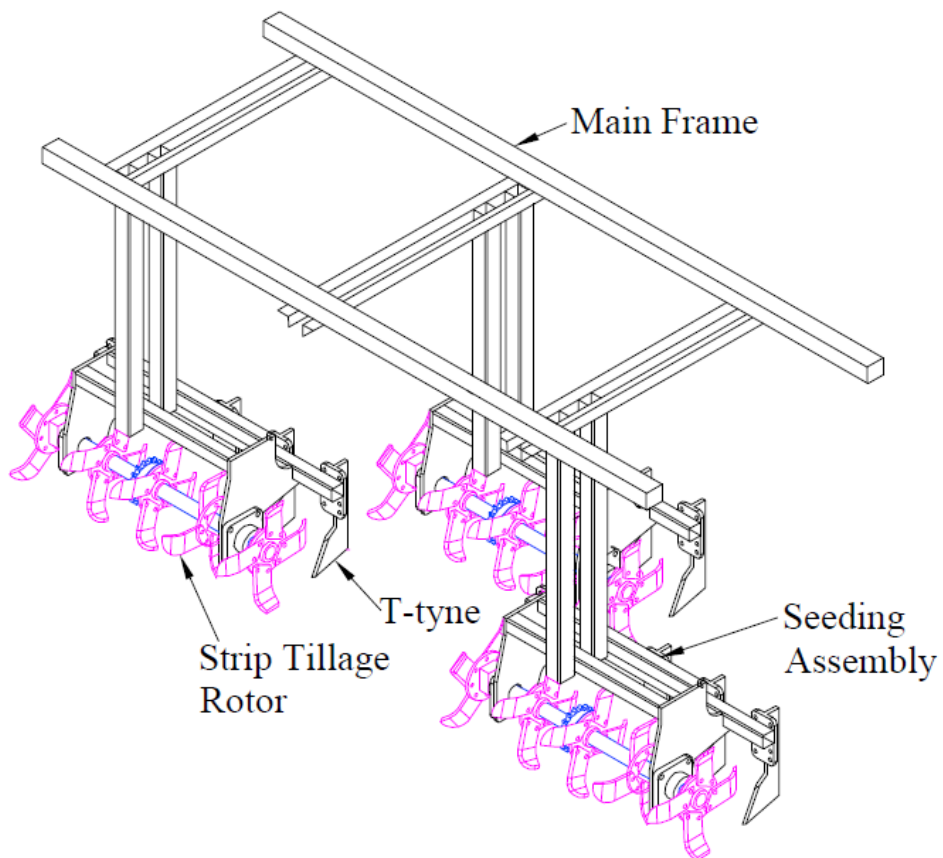


Fig. 3.15: Staggered placement of three seeding assemblies for 101.0 cm row to row cotton on the main frame of relay seeder



Fig. 3.16: Powering of driving wheel for seed and fertilizer metering mechanism from the rear tyre of tractor

3.4.3.4 Power Transmission system

The power transmission system consists of Universal shaft, gear box, power transmission shafts and pulleys and V-belts, Fig. 3.17. Universal shaft was used to transmit power from tractor PTO to RS gear box. Pulleys and V-belts transmit power to main shaft from the gear box. Chain and sprockets system was used to transmit power from main shaft to different seeding assemblies. The box section for attaching the seeding assemblies onto main frame was used as a housing of chains to avoid the direct contact of moving chains with cotton crop during machine operation in the field.

3.4.3.5 Depth wheels

Two adjustable depth wheels were mounted on the main frame to adjust the working depth of machine while seeding wheat into standing cotton, in case of strip and zero tillage conditions. The depth of double disc openers is adjusted by the spring tension.

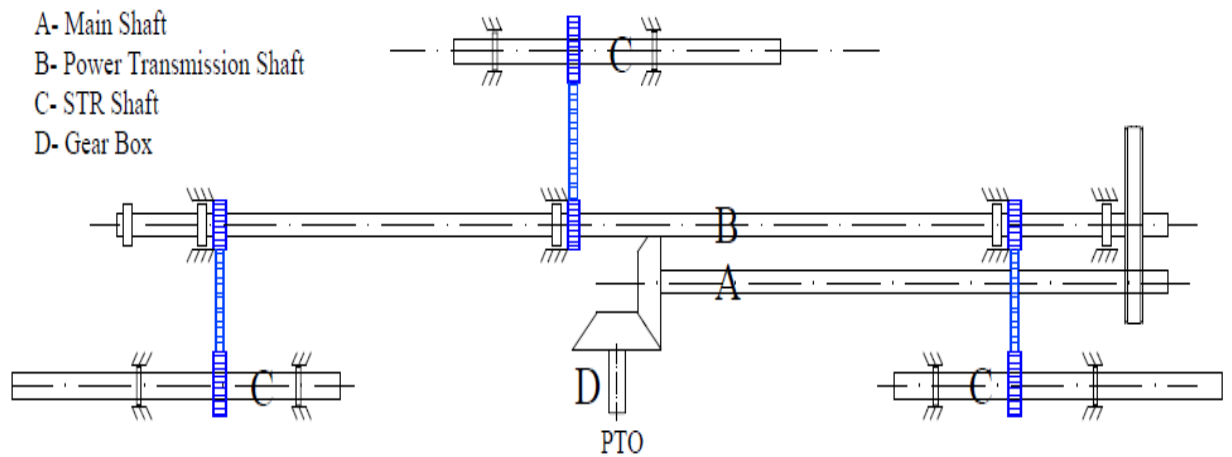


Fig. 3.17: Schematic diagram of power transmission system of RS for driving the strip till rotors (STR)

3.4.3.6 Crop dividers relay seeder and high clearance tractor

Crop dividers were attached in front of seeding units and front wheel of tractor to avoid damage to cotton plants during relay seeding wheat into standing cotton. Shoe type crop divider/lifters were fabricated and placed in front of wheels of the tractor. Crop dividers lift the logged branches of cotton and place it above the tractor wheels. This reduces the damage caused to the plants by high clearance tractor. Four dividers with 450 mm bottom width were fabricated and attached to the 4 seeding units for a 12- row RS. Similarly, 3 dividers with 850 mm bottom width were fabricated and attached to the 3 seeding units for a 15- row RS.

3.5 Evaluation of Relay Seeders for planting wheat in cotton

One on-station and five on-farm participatory field experiments were conducted during 2013-14 in Punjab India to evaluate and validate the relay seeders, Fig. 3.18 and 3.19.

3.5.1 Experiment-I. On-station evaluation of relay seeder

3.5.1.1 Site characteristics

A replicated field experiment was conducted on a sandy loam soil during 2013–2014 at the research farm of the Borlaug Institute for South Asia (BISA) at Ladhowal (30° 59' N and 75° 44' E), Ludhiana (Punjab), India. The soil in the 0–15 cm layer was non-saline



Fig 3.18: First prototype of 12 row relay seeder with ZTDD openers attached with the high clearance tractor



Fig 3.19: First prototype of 15 row relay seeder with ZTT openers attached with the high clearance tractor

(electrical conductivity 0.26 dS m⁻¹) with pH ranging from 8.07 with 5.7 g kg⁻¹ organic carbon (Walkley & Black, 1934), 10.8 mg ha⁻¹ Olsen P and 69.2 mg ha⁻¹ NH₄OAc-extractable K. The climate of the region is subtropical, semi-arid. Under average climatic conditions, the area receives about 699 mm of rainfall during the cotton season (May–November) and 237 mm during the wheat season (November– May). Temperature data during May 2013 to April 2014 were recorded from the automatic weather station installed at the BISA farm

3.5.1.2 Experimental layout and treatments

Field trial was laid out in a strip-plot design with three replications. Treatments included two *Bt*-cotton genotypes (RCH 776 and MRC 7017) having different canopy cover and vigor in the main plots. For ease in the movement of tractor and relay seeders, cotton genotypes were planted in vertical strips. The layout of the experimental fields is shown in Fig. 3.20. The allocation of the treatments to the various plots was done with suitable random number generation technique. The horizontal strips included eight combinations of two types of relay seeders (suitable for cotton with either 67.5 cm or 101.0 cm row spacing), four types of relay seeding methods (manual broadcast, STR-RS, ZTDD-RS, ZTT-RS) and conventional till wheat (CTW). Plot size was 219 and 252 m² for 67.5 and 101.0 cm row to row spacing in cotton, respectively (13 rows for 67.5 cm and 10 rows for 101.0 cm spacing). An alley way of 10 m was kept between the two replications as well as at head lands to facilitate movement of the tractor and implement.

FIELD LAYOUT OF COTTON FOR RELAY SEEDING OF WHEAT INTO STANDING COTTON, DOS 20-22/05/2013									
REP 1			PATH	REP 2			REP 3		
STRIP NO.	RCH 776	MRC 7017		STRIP NO.	RCH 776	MRC 7017	STRIP NO.	RCH 776	MRC 7017
9	67.5, C	67.5, C	18	101, M4	101, M4	27	101, M2	101, M2	
8	101, M1	101, M1	17	67.5, M3	67.5, M3	26	67.5, M4	67.5, M4	
7	67.5, M2	67.5, M2	16	101, M2	101, M2	25	101, M1	101, M1	
6	101, M3	101, M3	15	67.5, M1	67.5, M1	24	67.5, M2	67.5, M2	
5	67.5, M4	67.5, M4	14	67.5, C	67.5, C	23	67.5, M3	67.5, M3	
4	101, M2	101, M2	13	101, M3	101, M3	22	101, M4	101, M4	
3	67.5, M1	67.5, M1	12	67.5, M4	67.5, M4	21	67.5, M1	67.5, M1	
2	101, M4	101, M4	11	101, M1	101, M1	20	101, M3	101, M3	
1	67.5, M3	67.5, M3	10	67.5, M2	67.5, M2	19	67.5, C	67.5, C	

M1	ZREO TILL WHEAT (INVERTED T-TYPE)
M2	ZREO TILL WHEAT (DISC OPENER)
M3	STRIP TILL WHEAT
M4	MANUAL BROADCASTING
C	FARMER PRACTICE

Fig. 3.20: Layout of the replicated experiment for evaluation of relay seeders

3.5.1.3 Crop management

3.5.1.3.1 Cotton

After the harvest of general crop of well-fertilized wheat in mid-April, two Bt cotton genotypes (MRC 7017 and RCH 776) were planted on 22 April, 2013 under two geometries (67.5 cm row by 75 cm plant spacing and 101.0 cm row by 50 cm plant spacing). Cotton was planted with tractor operated inclined plate cotton planter using a seed rate of 3 kg ha⁻¹. The crop management practices except the method of seeding were common for all the treatments. A uniform recommended dose of 150 kg N ha⁻¹ as urea, 30 kg ha⁻¹ of P as diammonium phosphate (DAP) and 25 kg K ha⁻¹ as muriate of potash (MOP) was applied to the cotton crop. While whole of the P and K was applied at seeding, fertilizer N was applied in equal split doses; 50 % N top dressed after thinning in the fourth week after sowing and the remaining 50 % N applied at flowering stage. Two percent solution of potassium nitrate (13:0:45) was sprayed four times at weekly interval starting from the initiation of flowering in the cotton. The first irrigation to cotton crop was applied at 35 days after sowing and remaining 4 irrigations were applied at 2-3 weeks interval.

The sucking pests (aphids) of cotton were controlled by spraying *Imidacloprid* 200 SL (100 ml ha⁻¹). Four sprays of *Ethion* 50 EC (2 L ha⁻¹) were made to protect cotton against whitefly attack. After the first picking of cotton on 04 November, 2013, flood irrigation (75-80 mm) was applied on 07 November, 2013. Wheat was sown into the residual moisture using the relay seeder on 15 November, 2013. The third picking of cotton was done at 25 days after relay seeding. In the relay seeded plots cotton stalks were manually pulled out after applying first post-sowing irrigation at 25 days after planting. In the conventional wheat (T1), pre-sowing irrigation was applied in standing cotton 4 days before stalk pulling and the wheat was sown after conventional tillage using seed-cum-fertilizer drill on 13 December 2013. In relay seeding treatments, one additional picking of cotton was made at the time of manual uprooting of cotton stalks when majority of immature bolls were fully opened.

3.5.1.3.2 Wheat

Wheat (HD-2967) was sown using a seed rate of 100 kg ha⁻¹. Crop management practices except the method of seeding were similar for all the treatments. A uniform dose of fertilizer nutrients (120 kg N, 26 kg P and 25 kg K ha⁻¹) was applied to the wheat. Whole of the P and K, and 50% of N was applied at seeding. Remaining 50% of fertilizer N was top dressed before the first post-sowing irrigation applied at 3 weeks after sowing. The broad leaf

weeds and *phalaris minor* were controlled by applying Algrip 20 WP (*metsulfuron*) at 25 g ha⁻¹ and *clodinafop* (15 WP) at 400 g ha⁻¹. Four irrigations of 7.5 cm each were applied to the crop. Rogor 30 EC (*dimethoate*) was sprayed at 375 ml dissolved in 250 L ha⁻¹ water for control of aphids.

3.5.1.4 Independent parameters

3.5.1.4.1 Horizontal strips: Bt. cotton hybrids

- 1) RCH 776
- 2) MRC 7017

3.5.1.4.2 Vertical strips: 8 treatment combinations of cotton geometry and 4 method of sowing + one farmer practice

- 1) Cotton geometries; 67.5 x 75 cm² and 101.0 x 50 cm², Fig. 3.21.
- 2) Method of sowing wheat; Relay seeder with Strip tillage rotor (STR) openers, Relay seeder with Zero till tine (ZTT) openers, Relay seeder with Zero till double disc (ZTDD) openers and Relay manual broadcasting (MB).
- 3) Farmer practice; Conventional practice of seeding wheat after harvesting the cotton stalks.

The details of the treatments are provided in the Table 3.4.

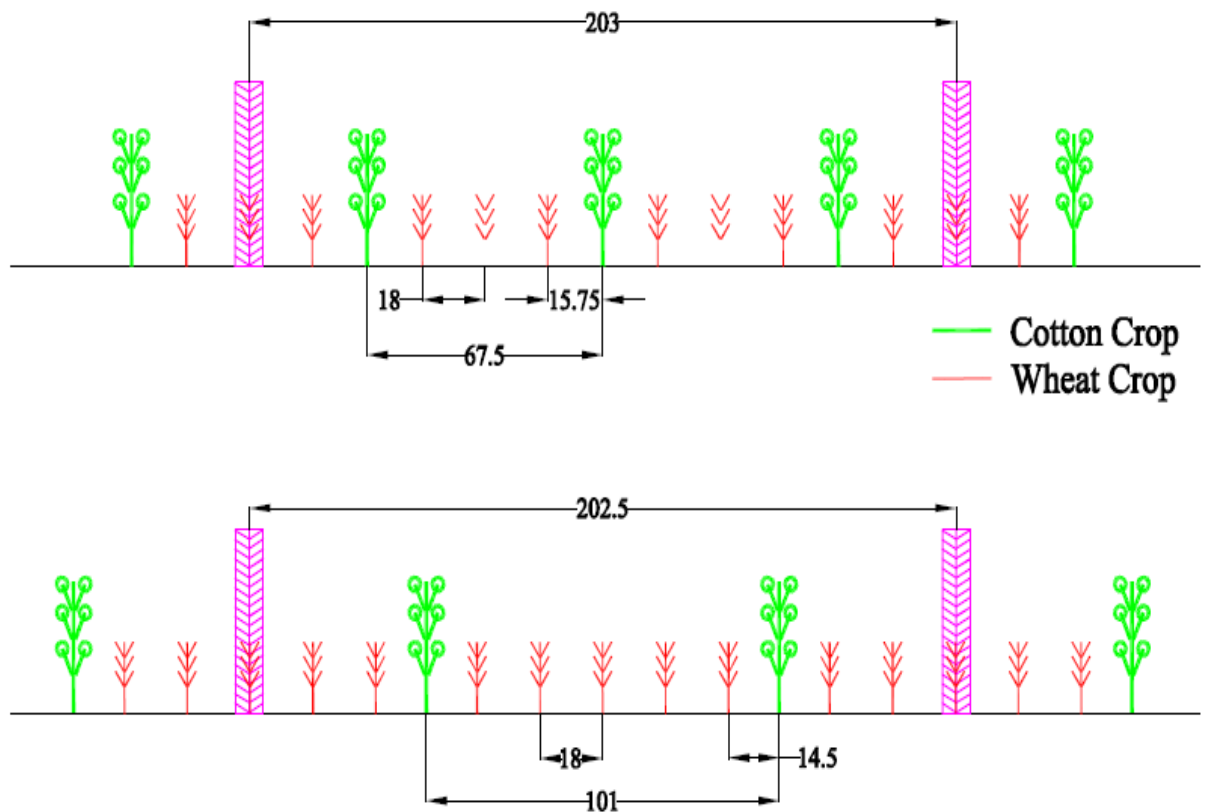


Fig. 3.21: Relay planting of wheat into two geometries of standing cotton (67.5 and 101.0 cm) row spacing

3.5.1.5 Measurement of dependent parameters

3.5.1.5.1 Speed of operation

The speed of operation, field capacity and fuel consumption of RS for different types of furrow openers was measured after 25 m run of the tractor while relay seeding wheat into standing cotton. The speed of operation was calculated by measuring time taken by relay seeder to sow 25 m length of field.

Table 3.4: Sub-plot treatment details for experiment-I

Treatment no.	Treatment abbreviation	Treatment details
T1	12-row STR RS	12-row relay seeding with strip tillage. Relay seeding was done after 1 st picking of cotton on 14 th November, 2013, using strip tillage with no prior tillage. Three rows of wheat at 18-cm apart were sown in 67.5 cm row spacing covering 4 rows of cotton.
T2	12-row ZTT RS	Same as for T1, except zero till tine opener relay seeder used for seeding wheat.
T3	12-row ZTDD RS	Same as for T1, except zero till double disc opener relay seeder used for seeding wheat.
T4	15-row STR RS	15-row relay seeding with strip tillage in 101.0 cm row spacing. Five rows of wheat at 18-cm apart were seeded in between two rows of cotton and covering three rows of cotton. Other details are the same as in T1.
T5	15-row ZTT RS	Same as for T4, except relay seeder with zero-till tine openers was used for seeding wheat,
T6	15-row ZTDD RS	Same as for T4, except relay seeder with zero-till double disc openers was used for seeding wheat,
T7	MB-67.5 cm	Manual broadcast under 67.5 row spacing. Wheat seed was manually broadcasted in standing irrigation water after 1 st picking of cotton with 67.5 cm row spacing.
T8	MB-101.0 cm	Same as in T7, except broadcasted under 101.0 cm row spaced cotton
T9	CTW	Conventional till wheat after cotton harvest. Irrigation was applied to standing cotton 4 days before stalk pulling. Seedbed preparation involved one discing followed by two comb harrowings and two plankings. Wheat was sown at a row-to-row distance of 20 cm, using a conventional four-wheel tractor drawn seed-cum fertilizer drill.

3.5.1.5.2 Fuel Consumption

Fuel flow meter was installed in the fuel line of the tractor to measure the volume of fuel consumed in 25 m length of travel. The unused fuel is not fed back to the tank through a separate line, but is fed back into the fuel line after the pump and before the fine filter in order to filter out any mechanical impurities, Fig. 3.22. The least count of the flow meter was 1 ml. This version of fuel flow meter works satisfactory for -25°C to $+70^{\circ}\text{C}$ ambient temperature with flow pressure in the pipe < 25 bars. Filter mesh size of 0.080 mm should be attached with Flow meter to guard it against impurities.

Fuel flow meter reading was noted at the start and end of each test run and the difference between the two readings is volume of fuel consumed per test run, Fig. 3.23.

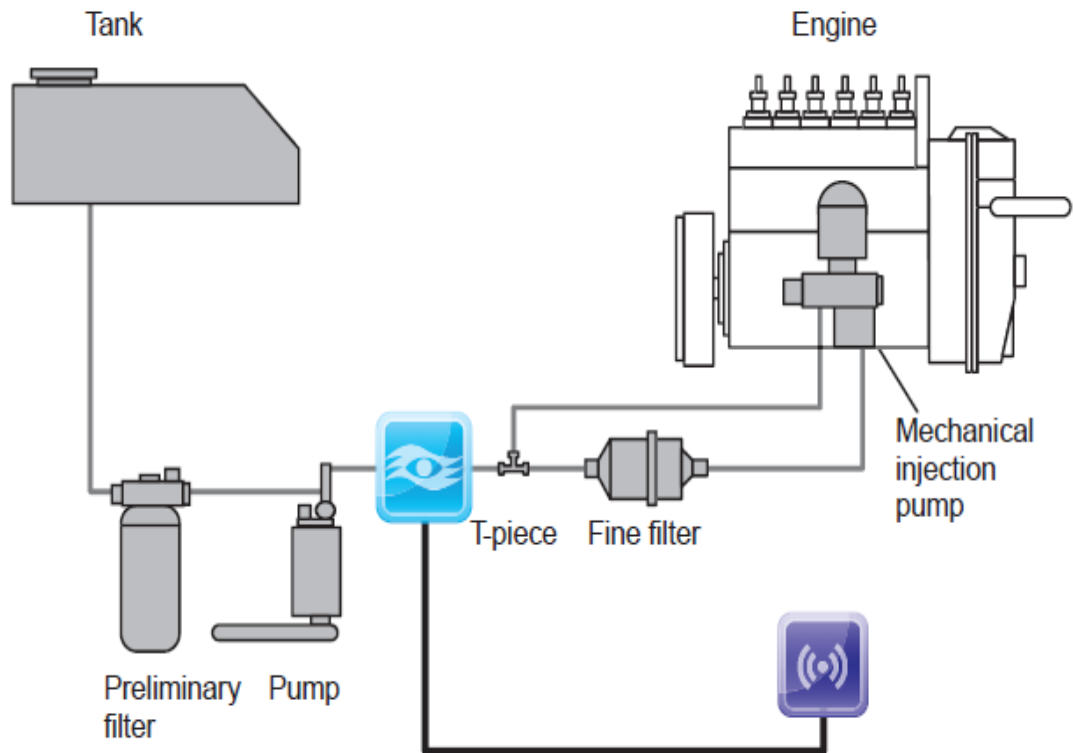


Fig. 3.22: Installation of fuel flow meter in the fuel line of tractor



Fig. 3.23: Fuel flow meter installed in the fuel supply of tractor

3.5.1.5.3 Power required by Relay seeder

Power required by the different furrow openers and relay seeders was estimated in laboratory. A tractor PTO operated alternator was loaded with the help of constant load of heating coil of 18 kW for estimation of power consumed by different furrow openers. The load was distributed equally on three phases by using 3 coils of 6 kW. The alternator was operated at various engine rpm (1000 to 2000 rpm with an increase of 100 rpm each time) and the corresponding power consumed by heating elements and fuel consumption of the tractor was measured, Fig. 3.24. The actual electric load was measured by digital electronic clamp meter (model 3510PHW) and the corresponding fuel consumption was measured with fuel flow meter installed in the diesel supply of the tractor. The accuracy, resolution, range and procedure for power measurement are given in appendix A

The power consumed by the RS for various types of furrow openers was predicted using simple linear regression analysis using SAS 9.2 software. The actual power produced by the tractor at a particular fuel consumption rate was calculated by dividing the power produced by alternator efficiency.



Fig. 3.24: Setup for measuring obtaining the power curve v/s fuel consumption

3.5.1.5.4 Cotton yield

The monopods and sympods were counted from 20 randomly selected cotton plants within each replication. The height of 20 tagged plants was also measured using steel rule. The number of cotton bolls picked of all tag plants were counted at each picking. Seed cotton yield was recorded after every picking from 20 randomly selected and tagged plants within each plot. The total yield is the sum of the three pickings from conventional CW system (T9) and four pickings from the relay-seeded CW (T1-T3, T7 and T4-T6, T8). The cotton with the relay seeding remained in the main field for 30 days more than conventional CW system.

3.5.1.5.5 Loss of cotton by RS and high clearance Tractor movement

The damage to standing cotton while relay seeding of wheat was measured in terms of number of cotton bolls and seed cotton yield lost due to the movement of RS and tractor.

3.5.1.5.6 Loss of cotton bolls

The damage to cotton crop was measured by counting the number of broken bolls after each pass of relay seeder in the standing cotton. Percent loss of cotton bolls is ratio of number of cotton bolls damaged by RS to the total number of bolls in the whole plot before operation of RS.

3.5.1.5.7 Loss of seed cotton yield

Seed cotton was collected and weighed after sun drying the cotton bolls damaged by RS and data reported as loss of seed cotton.

3.5.1.5.8 Ease of operation of Relay Seeder

Clogging of cotton residues and weeds into RS openers was determined to examine the ease of RS operation in standing cotton. Grassy weeds usually emerge between the rows of cotton crop and which may entangle the sowing tines of RS. The accumulated residues on the machine openers were collected after each pass of RS and weighed.

3.5.1.5.9 Wheat emergence count

Crop emergence count (plants that had emerged through the soil) at 20 days after seeding. Emergence count was recorded in three randomly selected locations within each plot from 1-m long three adjacent rows in case of 67.5 cm and 1-m long five adjacent rows (101.0 cm) and 1 m × 1 m area in MB and CTW. The number of wheat plants that had emerged through the soil was counted at 20 days after seeding and was converted to number of plants per square meter area for all the treatments.

3.5.1.5.10 Harvesting parameters

Grain yield components (spike density, number of grains per spike and grain weight) were measured at harvest. Spike density was measured in three randomly selected locations within each plot as in case of emergence count. The number of grains per spike was recorded from 15 randomly selected spikes in each plot at maturity. Grain yield was determined on two randomly selected locations within each plot from 5-m long 9 adjacent rows of wheat (10.125 m² area) in T1-T3 and 5-m long 10 adjacent rows (10.1 m²) in T4-T6, 2 m x 5 m area in T7-T9. Wheat was manually harvested and threshed using small plot power thresher and grain

yield was reported on air dry weight basis. Average test weight was determined on 1000 grains.

3.5.2 On-farm evaluation of relay seeder in wheat

Five on-farm single replicated trials were conducted in 2013-14 to evaluate the performance of tractor operated relay seeder with double disc furrow openers for the sowing wheat in standing cotton vis-à-vis CTW during 2013-14 in district Bathinda representing CW belt of Punjab, India. The locations of the experimental sites along with sowing date of wheat are provided in Table 3.5. The climate of the region (district Bathinda) is subtropical, semi-arid. Under average climatic conditions, the area receives about 460 mm of rainfall during the cotton season (April–November) and 75 mm during the wheat season (November– April). The 12- row relay seeder with double disc furrow openers was used for seeding wheat into standing *Bt*-cotton (Super 6488) planted at 67.5 row spacing and compared with CT wheat establishment. Relay seeding of wheat was done before the third picking of cotton. Relay seeding of wheat in on-farm trials was delayed due to non-availability of relay seeder on time as only one prototype of relay seeder was available and the machine could only be spared after the completion of wheat planting in on-station experiment. Plot size varied from 400 to 500 m². All locations were sown with the same variety of wheat (PAU 621) at a rate of 100 kg ha⁻¹.

Table 3.5: Details of on-farm trials conducted at different location in district Bhatinda in Punjab (India) during 2013-14

Location	Longitude (degree)	Latitude (degree)	DOS	
			RS	CT
Machhana	30° 3' N	74° 51' E	25-11-2013	30-11-2013
SangatMandi	30° 9' N	74° 58' E	30-11-2013	11-12-2013
Malwala	30° 3' N	74° 54' E	1-12-2013	10-12-2013
Bhagwanghar	30° 4' N	74° 55' E	3-12-2013	9-12-2013
Jodhpur Romana	30° 9' N	74° 54' E	3-12-2013	8-12-2013

Farmers managed their cotton and wheat crops and followed the crop management practices as described under on-station experiment, which were the same for both the treatments. Wheat yield at maturity was measured by harvesting 4.05 m² for relay seeded wheat and 3 m² for CT wheat from two random locations within each plot.

3.6 Economic analysis

The variable cost of growing wheat in each treatment was calculated by taking into account the costs of inputs (seed, fertilizers and pesticides), tillage (discing, cultivator and planking), seeding under different treatments (seed-cum-fertilizer drill, broadcast seeding and tractor operated relay seeder), hiring of manual labour, custom hire for machinery operations, transport and marketing. Hiring charges for combine harvester and straw chopper/trolley were included for calculating harvesting and threshing costs. Electricity for pumping water is supplied free of cost to the farmers, the cost of irrigation included the cost of labour involved in applying irrigation water. The cost of a 50-kg bag of urea, DAP and muriate of potash was taken as Indian Rs. 270, 1210 and 840 (1 Rs = US\$ 0.0161), respectively. The charges for human labour hiring were taken as Rs. 35 h⁻¹. The cost of labour for fertilizer application, pesticide spray and irrigation was included for each of these operations. The charges for discing, cultivators and planking were Rs. 1438, 1313 and 500 ha⁻¹ respectively. The cost of seeding was considered as Rs. 1438 ha⁻¹ for conventional sowing (T1), Rs. 3386 ha⁻¹ for relay seeding and Rs. 560 ha⁻¹ for MB. The cost of relay seeder was taken as Rs. 100,000 and its fuel consumption is 4.0 l h⁻¹. The relay seeder can seed wheat at 0.18 ha h⁻¹ with a working window period of 20 days in a year and its life was taken as 10 years. The market price of wheat grain as fixed by Govt of India was Rs. 14000 t⁻¹ and prevailing market price of straw was Rs. 2.25 kg⁻¹. The market price of seed cotton was taken as Rs. 39 kg⁻¹. Straw yield of wheat was calculated on the basis of straw–grain ratio of 1:1. The data on variable cost for the cultivation of cotton and wheat for the year 2013–2014 were obtained from the Department of Economics and Sociology, Punjab Agricultural University, Ludhiana, India. The interest on variable cost was considered as 9% for the half crop season. The variable cost used for cotton was similar under different relay seeder treatments, except the additional cost for 4th picking of cotton under relay planting treatments. The value of increased cotton yield in relay planting treatments (T1–T8) was included for calculating gross returns. The gross and net returns were calculated by subtracting total variable costs from the gross return.

3.7 Statistical analysis

Data collected for all the dependent variables were subjected to analysis of variance in factorial strip plot design using SAS 9.2 software package. Before analysis, the Levene's test was performed to test the homogeneity of variances using the proc GLM procedure with the HOVTEST option in the MEANS statement. Differences between treatment means were compared using a LSD test at $P < 0.05$ (Gomez and Gomez 1984). Student's T-test using

SAS 9.2 software package was performed for comparing grain yield between two treatments in experiment 2. The economic analysis was also done by Student's T-test using SAS 9.2 software package.

RESULTS AND DISCUSSION

This chapter includes stability of high clearance tractor, effect of relay seeding treatments/cotton spacing on cotton yield, performance of RS for seeding wheat into standing cotton and effect of relay seeding on wheat yield and yield contributing parameters.

The location of CG of normal and tractor mounted on the high clearance platform are shown in Table 4.1. As expected the high clearance platform shifts the CG towards the rear wheel of tractor and moves away from the ground. Therefore, the stability of tractor in pitching and rolling condition was studied.

Table 4.1: Location of CG of normal and high clearance tractor

Specifications	Normal tractor	High clearance tractor	High clearance tractor with RS mounted
Weight with operator, kg	2005	2545	3045
CG (X, Y, Z), mm	924, 802.5, 675	808.7, 1137, 1001	553, 1076, 1001

4.1 Stability of high clearance tractor while hitching

Dividing the equation 3.1 by 3.2, we have

$$\frac{P}{P'} = \frac{W \times 0.924 \times l'}{W' \times 0.809 \times l}$$

Where $W = 2005$ kg and $W' = 2550$ kg and $X_1 = 0.924$ and $X'_1 = 0.809$ m

From geometry of ΔABC and $\Delta ABC'$ in Figure 3.3, we have,

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{l}{l'}$$

As the tractor hitch points were lifted from D to D' which means $\theta_2 > \theta_1$. The angle of pull is generally low, $0 < \theta_1 < 30^\circ$ Therefore, the value of $\frac{l}{l'}$ is a fraction, Fig. 3.3.

Case 1: Assuming $\theta_2 = 2\theta_1$ and $\theta_1 = 15^\circ$ then we have $P' = 0.58 P$

Case 2: Assuming $\theta_2 = 1.5\theta_1$ and $\theta_1 = 15^\circ$ then we have $P' = 0.61 P$

Case 3: Assuming $\theta_2 = \theta_1$, then we have $P' = 0.90 P$

Therefore, maximum draw bar pull in case of high clearance tractor is reduced compared with the normal tractor and it is further dependent on angle of pull. Higher pull can be achieved by keeping angle of pull as low as possible.

4.2 Stability of high clearance tractor while turning

Considering the Figure 3.4 in chapter III and dividing equation 3.3 by 3.4, we have

$$\frac{v'}{v} = \sqrt{\frac{Y_1 \times t' \times r'}{t \times Y_1' \times r}} = 1.03 \sqrt{\frac{r'}{r}}$$

Where the $t = 135 \text{ cm}$ and $t' = 202.5 \text{ cm}$ and $Y_1 = 0.803$ and $Y_1' = 1.137 \text{ m}$

The steering system was adjusted to increase the turning radius so $r' > r$, for critical case if $r' = r$, therefore, the safe turning velocity for the high clearance tractor was higher by 1.03 as compared to normal tractor. Therefore, the high clearance tractor is safer than the normal tractor while taking a turn of similar radius as track width of high clearance tractor is increased by 50 percent of the normal tractor. This is consistent with Ahamdi (2013), who has developed a computer program on tractor stability concluded that the best strategy for stabilizing a tractor against overturn is to lower the tractor's center of gravity and increase the tractor's wheel track width simultaneously.

4.3 Shift in CG of high clearance tractor while moving up on slope in longitudinal plane (graphical method)

Graphical analysis showed the position of CG (pitching) of the tractor alone and tractor with relay seeder while moving on ground slopes of 0° , 30° and 45° , Fig. 4.1. The analysis showed that the tractor alone or with relay seeder mounted at rear, moving on 30° ground slope was safe against overturn as the weight acting at G and G' was inside of rear

wheel reaction and tractor wheel base, Fig. 4.1b. The high clearance tractor (without relay seeder) might not overturn while moving on 45° ground slope, as weight of the tractor acting at CG (G) was between tractor and the rear wheel reaction (R), Fig. 4.1c. Whereas, the tractor with relay seeder moving on a ground slope of 45° might overturn as the combined CG (G') of tractor and machine was shifted rearward, and nearly overlaps with the rear wheel reaction (R). Hamdeh and Al-Jalil (2004) reported that the higher the slope angle and implement weight the reduced the stability of tractor while moving uphill.

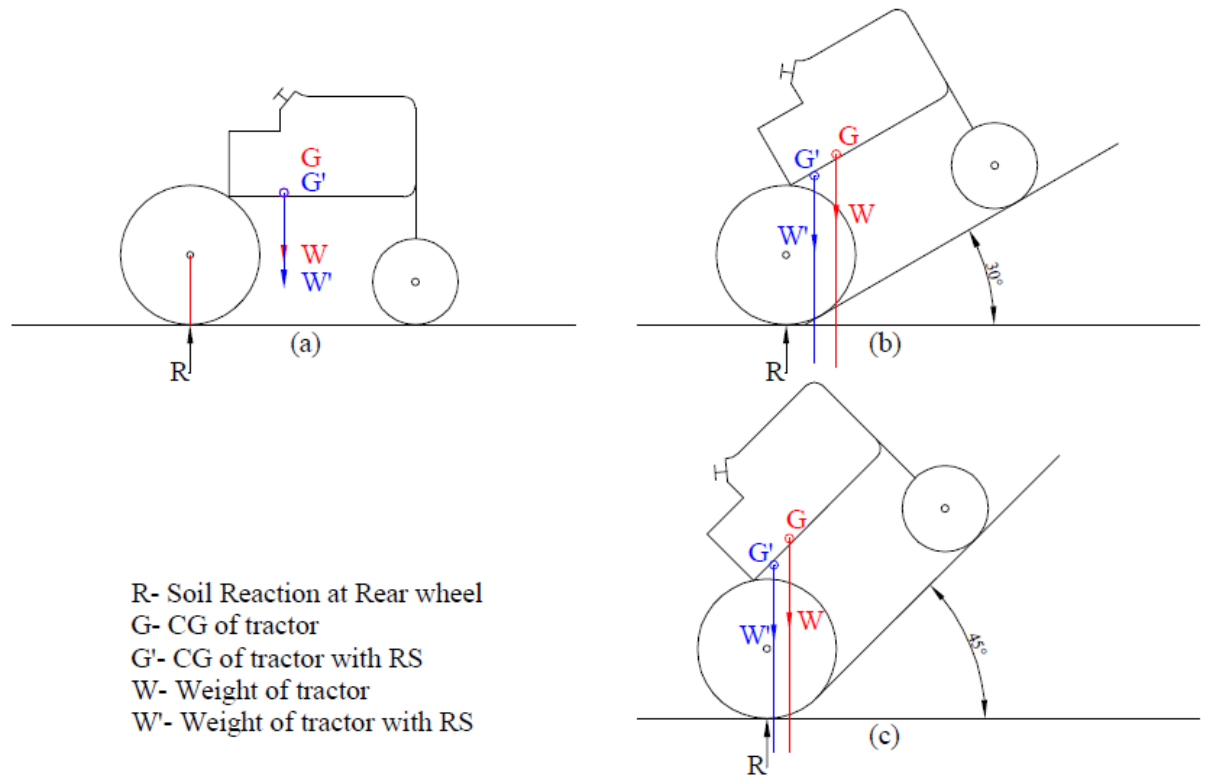


Fig. 4.1: Shift in CG of high clearance tractor while moving on slope with and without mounted implement (Pitch)

4.4 Shift in CG of high clearance tractor while moving up on slope in transverse plane (graphical method)

Graphical analysis showed the position of CG (rolling) of the tractor and tractor with relay seeder while moving on ground slopes of 0° , 30° and 40° , Fig. 4.2. The analysis showed that the tractor alone or with relay seeder mounted at rear, moving on 30° ground slope was

safe against roll as resultant force (F) was inside the rear wheel reaction (R) and tractor track, Fig. 4.2b. The analysis showed that the high clearance tractor might roll for tractor moving on ground with 40° slope, as resultant force F acting on CG (G) moves outside of tractor and the rear wheel reaction (R), Fig 4.2c. However, the tractor with mounted relay seeder moving on a ground slope of 40° might not roll as the resultant force F acting on combined CG (G') of tractor and Relay Seeder was inside of rear wheel reaction point and tractor, Fig. 4.2. Relay Seeder mounted at tractor lowered the combined CG, and this increased the stability of tractor.

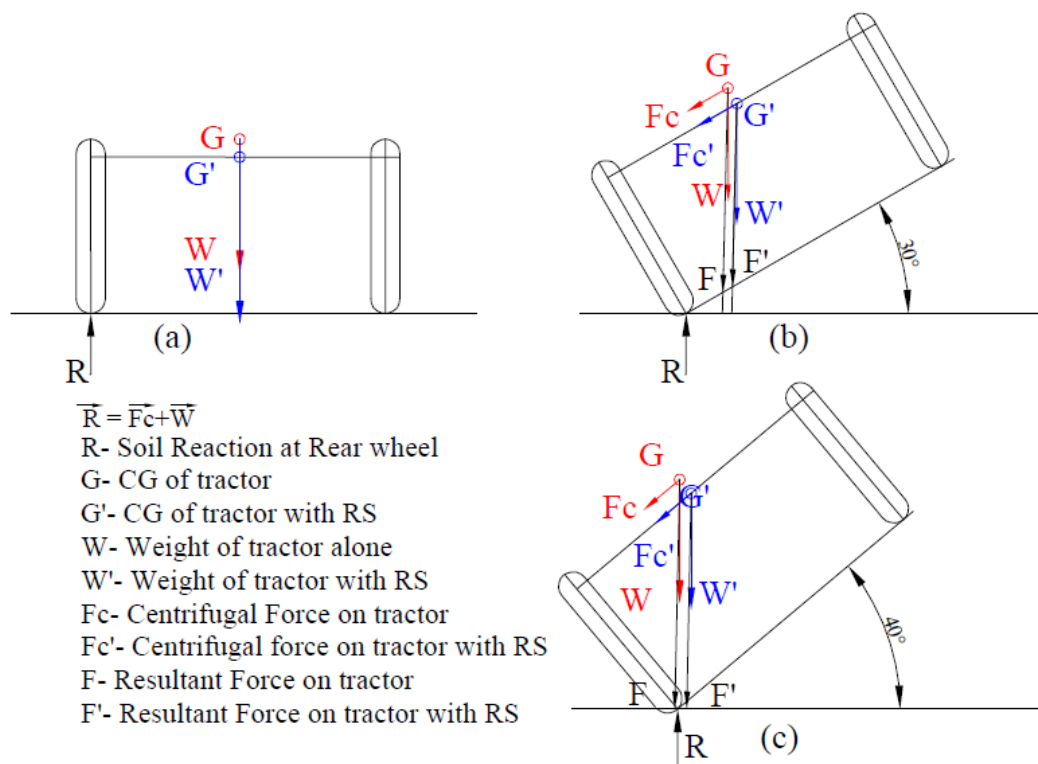


Fig. 4.2: Shift in CG of high clearance tractor while moving on slope with and without mounted implement (Roll)

4.5 Effect of relay seeding treatments and cotton-spacing on cotton

The mean daily minimum and maximum temperatures during the cotton season ranged from 6.0 to 27.4°C and 27.9 to 45.9°C respectively, and the corresponding values during the wheat season were 2.4 to 20.9 °C and 14.5 to 39.0°C, Fig. 4.3.

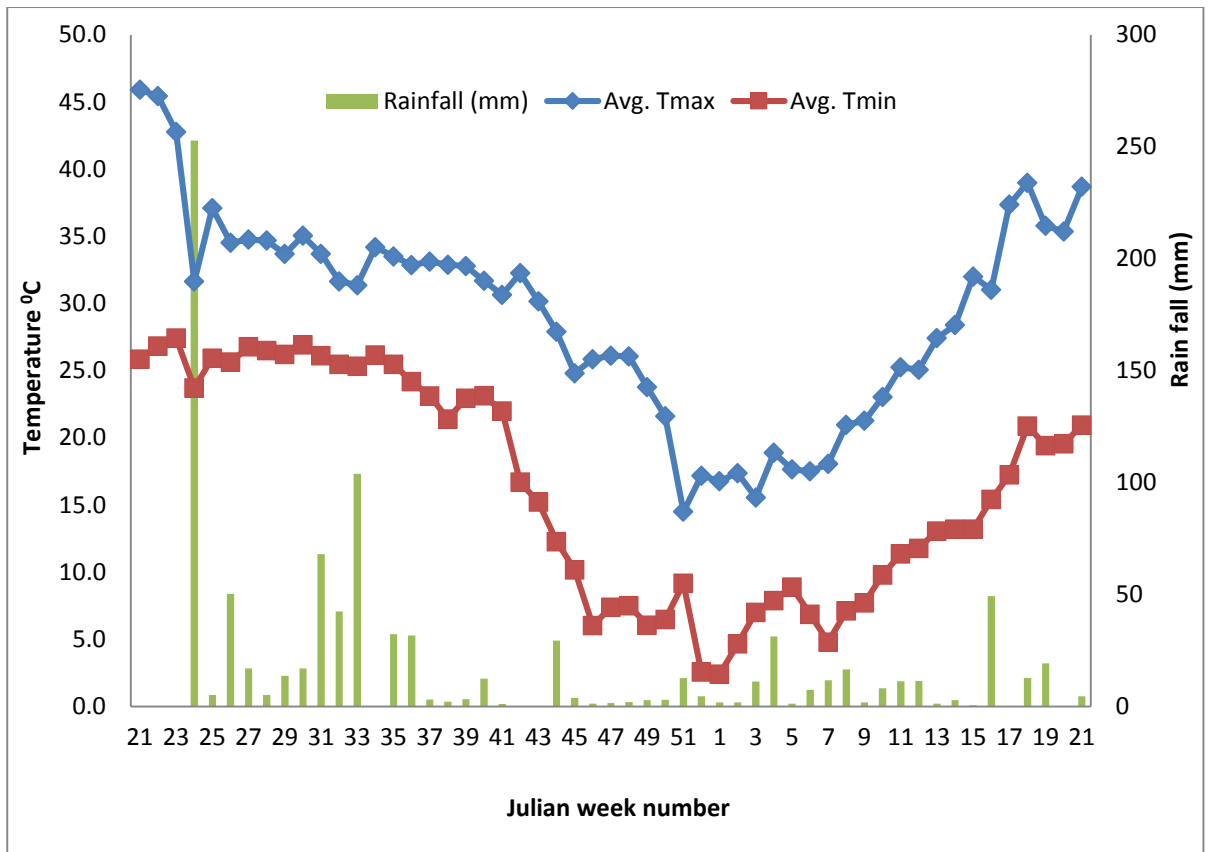


Fig. 4.3: Weekly average minimum, maximum temperatures and rainfall recorded in the year 2013-2014

4.5.1 Effect of relay seeding treatments and cotton-spacing on cotton growth

The cotton hybrid, RCH 776 had significantly more number of monopods compared to MRC 7017 but the sympods are nearly same for both the hybrids, Table 4.2. The cotton geometry did not show any significant effect on the number of monopods and sympods of cotton (Table B1 and Table B2 of Appendix-B). RCH 776 had 1 more monopod compared to the MRC 7017. More monopods made the plants bushy and plant had wider canopy. However, the average height of cotton plant height was similar for the two hybrids, Table 4.2.

4.5.2 Effect of relay seeding treatments and cotton-spacing on seed cotton yield

Cotton genotypes (MRC 7017 and RCH 776) and row spacing (67.5 cm and 101.0 cm) showed no significant effect on number of mature bolls in all the four pickings, Table

Table 4.2: Effect of geometry and hybrid on mean (\pm Standard error, SE) plant height, number of monopods and sympods for cotton plant

Treatments	Monopods (plant ⁻¹)	Sympods (plant ⁻¹)	Plant height, cm
	Mean \pm SE	Mean \pm SE	Mean \pm SE
RCH 776	3.05 \pm 0.2	27.5 \pm 0.8	128.6 \pm 0.5
MRC 7017	2.20 \pm 0.2	27.3 \pm 1.5	128.3 \pm 0.3
F-test (p-value)	<.0001	0.88	0.89
Cotton Row spacing (67.5)	2.45 \pm 0.2	26.9 \pm 1.2	129.6 \pm 0.8
Cotton Row spacing 101	2.80 \pm 0.1	28.0 \pm 1.3	128.5 \pm 1.4
F-test(p-value)	0.07	0.4	0.32

4.3. Average number of mature bolls at fourth picking was 4 per plant in the entire relay seeded treatments. Total number of mature bolls/plant was significantly higher (10%) for cotton genotypes in relay seeded treatments compared to CTW(T9). Cotton genotypes and their interaction with crop establishment methods had no significant effect on seed cotton yield. Mean seed cotton yield for 67.5 and 101.0 cm row spacing under relay seeding was 11-14% higher as compared with conventional crop. Cotton genotypes (MRC 17017 and RCH 776) and row spacing (67.5 cm and 101.0 cm) showed no significant effect on number of mature bolls in all the four pickings, Table 4.3. Average number of mature bolls at fourth picking was 4 per plant in all the relay seeded treatments. Total number of mature bolls per plant was significantly higher (10%) for cotton genotypes in relay seeded treatments as compared to CTW(T9), (Table B3 to B8 of Appendix-B). Cotton genotypes and their interaction with crop establishment methods had no significant effect on seed cotton yield. Mean seed cotton yield for 67.5 and 101.0 cm row spacing under relay seeding was 11-14% higher compared with conventional crop.

4.6 Operational Parameters of Relay Seeders

Type of furrow opener significantly affected the forward speed of travel and field capacity of different relay seeders, Fig. 4.4 and 4.5. Cotton hybrids had no significant effect

Table 4.3: Yield attributing characters of cotton and seed yield as influenced by different planting methods in cotton–wheat system

Cotton–wheat system	Number of mature bolls plant ⁻¹				Total bolls plant ⁻¹	Seed cotton yield (t ha ⁻¹)
	1 st picking	2 nd picking	3 rd picking	4 th picking		
A. Cotton Hybrids						
RCH 776	9.8	16.1	8.0	2.5	36.4	2.17
MRC 7017	9.8	16.1	8.0	2.5	36.4	2.17
F-test (p-value)	0.98	0.99	0.98	0.74	0.99	0.98
B. Crop establishment methods						
Cotton at 67.5 cm + relay wheat	9.7	16.0	7.8	3.7a	37.3a	2.23a
Cotton at 101 cm + relay wheat	9.9	16.4	8.0	3.8a	37.8a	2.29a
Cotton at 67.5 cm + Conventional wheat	9.8	16.0	8.2	0.0b	34.2b	2.01b
F-test (p-value)	0.59	0.48	0.24	0.0001	0.0008	0.0003

The values with in a column with different letter are significantly different at $P \leq 0.05$

on forward speed and field capacity of RSs, Table 4.4 (Table B9 in Appendix B). The speed of operation and field capacity was lowest (1.49-1.53 km h⁻¹ and 0.20-0.23 ha h⁻¹) for the ZTT openers due to frequent clogging of the openers with cotton and weed residues. Strip tillage rotor furrow opener helps to reduce the clogging of openers by cutting the weeds and plant residues ahead of tine openers. Field capacity of RS with ZTDD furrow openers was significantly higher compared with both ZTT and STR furrow openers. As expected, field capacity was significantly more for 15-row RS than for 12-row RS because of the higher swath width 3.03 m in comparison to 2.7 m swath width in case of 12-row machine.

Fuel consumption was significantly higher for 15-row RS (10.53 L ha⁻¹) compared with 12-row RS (9.52 L ha⁻¹) as the average row to row spacing wheat is 20.2 cm for 15-row and 22.5 cm for the 15-row RS, respectively (Table B11 in Appendix B). Thus, the 12-row RS will have lesser number of seeded rows per unit width as compared with 15-row RS. The STR openers had significantly higher fuel consumption (12.36 L ha⁻¹) than ZTT (8.57 L ha⁻¹) and ZTDD furrow openers



Fig. 4.4: 12-row relay seeder with ZTT openers relay seeding wheat into standing cotton



Fig. 4.5: 15-row relay seeder with ZTDD openers relay seeding wheat into standing cotton

Table 4.4: Effect of cotton hybrids and different type of furrow openers on operational parameters of relay seeders (RS) for seeding wheat into standing cotton

Treatments	Fuel consumption (L ha⁻¹)	Average forward speed (km h⁻¹)	Field capacity (ha h⁻¹)
A. Cotton hybrids			
RCH 776	10.09	1.63	0.23
MRC 7017	9.96	1.62	0.23
F-test (p-value)	0.58	0.30	0.29
B. Crop establishment methods			
T1 (12-row STR RS)	12.00a	1.61b	0.22d
T2 (12-row ZTT RS)	7.95d	1.49c	0.20e
T3 (12-row ZTDD RS)	8.62cd	1.78a	0.24bc
T4 (15-row STR RS)	12.72a	1.61b	0.24b
T5 (15-row ZTT RS)	9.20bc	1.53c	0.23c
T6 (15-row ZTDD RS)	9.68b	1.74a	0.26a
F-test (p-value)	<0.0001	<0.0001	<0.0001
Interaction AxB	0.94	0.49	0.53

The values with in a column with different letter are significantly different at $p \leq 0.05$

(9.15 L ha⁻¹). The higher fuel consumption in STR openers was due to rotary tilling of narrow strip ahead of tine openers for achieving better soil-seed contact.

A calibration curve was produced by using the laboratory test data (Table 4.5) for predicating the engine power from fuel consumed by the tractor at different engine speeds. As expected, the regression model for predicting the power required for the operating relay seeder from the fuel consumption of the tractor was highly significant ($p < 0.0001$), (Table B12 in Appendix B). Regression coefficient for predicting the tractor power form fuel consumed was significant for the regression equation

$$\text{Power, hp} = -2.014 + 4.01 * (\text{Fuel consumed, L h}^{-1})$$

The power required for 15-row RS was 31.8 % higher than for 12-row RS, irrespective of type of furrow opener used. Power consumption was significantly more for STR openers as compared with ZTT and ZTDD furrow openers, (Table B13 in Appendix B).

Table 4.5: Fuel consumption of tractor for different engine RPM of the tractor and corresponding power produced by alternator attached at tractor PTO

Engine speed, RPM	Average fuel consumption, L h ⁻¹	Average power, hp
1000	1.74	4.25
1100	2.08	5.83
1200	2.52	7.78
1300	2.96	9.83
1400	3.50	11.97
1500	4.08	14.29
1600	4.74	16.51
1700	5.31	18.37
1800	5.88	20.19
1900	6.48	21.34
2000	6.96	22.39

Table 4.6: Effect of cotton hybrids and different type of furrow openers on power required for relay seeders (RS)

Treatments	Power required (hp)
A. Cotton hybrids	
RCH 776	7.49
MRC 7017	7.25
F-test (p-value)	0.25
B. Crop establishment methods	
T1 (12-row STR RS)	8.42b
T2 (12-row ZTT RS)	4.39d
T3 (12-row ZTDD RS)	6.25c
T4 (15-row STR RS)	10.41a
T5 (15-row ZTT RS)	6.53c
T6 (15-row ZTDD RS)	8.21b
F-test (p-value)	<0.0001
Interaction AxB	0.85

The values with in a column with different letter are significantly different at $p \leq 0.05$

The Power consumption for STR openers was 72% and 30% higher as compared with ZTT and ZTDD furrow openers, respectively. Also, Power consumption for ZTT openers was 32% lower as compared with ZTDD furrow openers, Table 4.6. Chaudhuri (2001) has reported among the different type of furrow openers, disc-type openers are generally popular for conventional tillage due to their lower draught, less soil disturbance and lesser variation in depth. The forward speed of travel for ZTDD furrow openers was 9.3% and 16.6% higher as compared with STR and ZTT openers, respectively. The predicted power requirement on per unit time basis was higher for ZTDD openers than for the tine openers. This trend may be reversed if power is predicted by fuel consumed per unit area basis. The interaction effects of cotton genotypes and crop establishment methods of power requirement was non-significant.

The contrast analysis showed that the average operational speed was significantly higher (1.76 km h^{-1}) for the ZTDD openers as compared with for STR opener (1.61 km h^{-1}) and ZTT furrow openers (1.51 km h^{-1}), respectively, Fig. 4.6. This might be due to better cutting of weeds and lesser force required for opening the furrow compared with STR and ZTT furrow openers. The fuel consumption was significantly higher for STR openers as compared with ZTDD and ZTT openers whereas; fuel consumption was significantly lower for 12-row relay seeder as compared with 15-row RS due to lesser machine width, Fig. 4.7. Similarly, the power required was significantly higher for STR openers as compared with ZTDD and ZTT openers. Therefore, contrast analysis showed that ZTDD openers performed better as compared with STR and ZTT openers in terms of high speed of operation, field capacity and low fuel consumption.

4.7 Effect of Relay Seeding on Standing Cotton

4.7.1 Effect of Relay seeding on cotton bolls detached from cotton plants

Number of cotton bolls detached per plot from plants due to the movement of RS and high clearance tractor was significantly lower (112) for 15-row RS as compared with for 12-row RS (187), Table 4.7. This was due to 25% reduction in the number of passes of the tractor in the field due to wider machine swath of 15-row RS as compared to 12-row RS. Furthermore, wider row to row spacing (101.0 cm) for the movement of tractor and the seeding units for 15-row as compared to 12-row RS, reduced the contact of machine parts with cotton-plant and, thereby, reduced the crop damage.

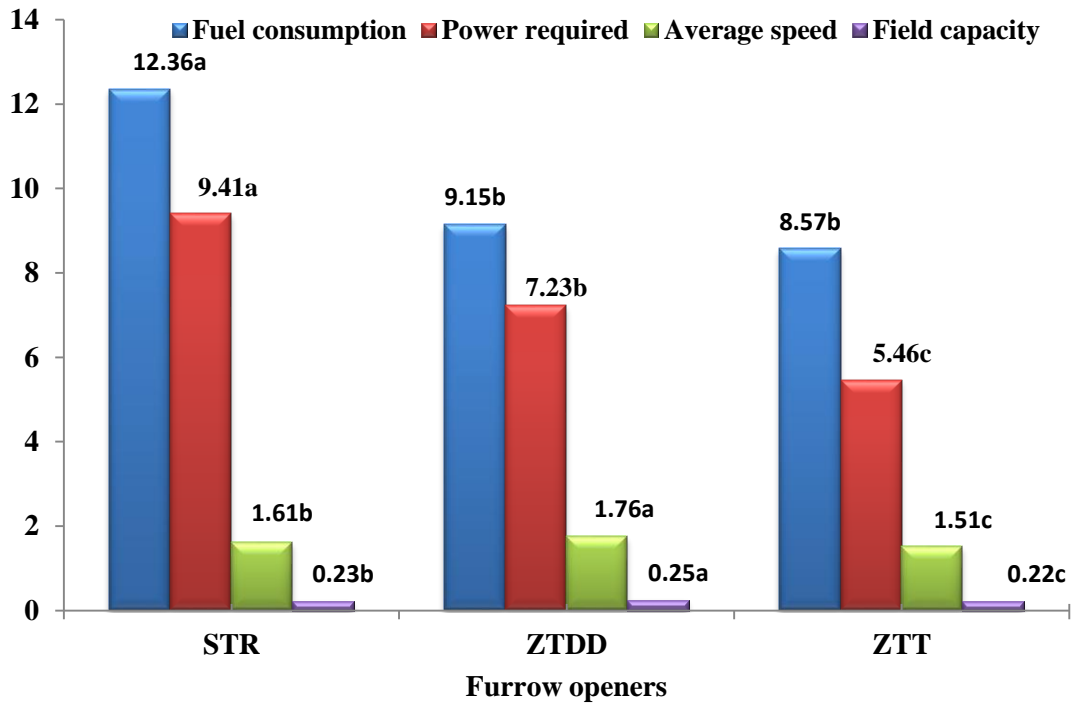


Fig. 4.6: Effect of type of furrow openers on operational parameters

Note: Unit for fuel consumption is L ha⁻¹, Power required is in hp, Speed of operation are in km h⁻¹, and field capacity is in ha h⁻¹. STR-strip till rotor, ZTDD-zero till double disc, ZTT-zero till tine openers. Values with for a dependent parameter with different letter are significantly different at $p \leq 0.05$

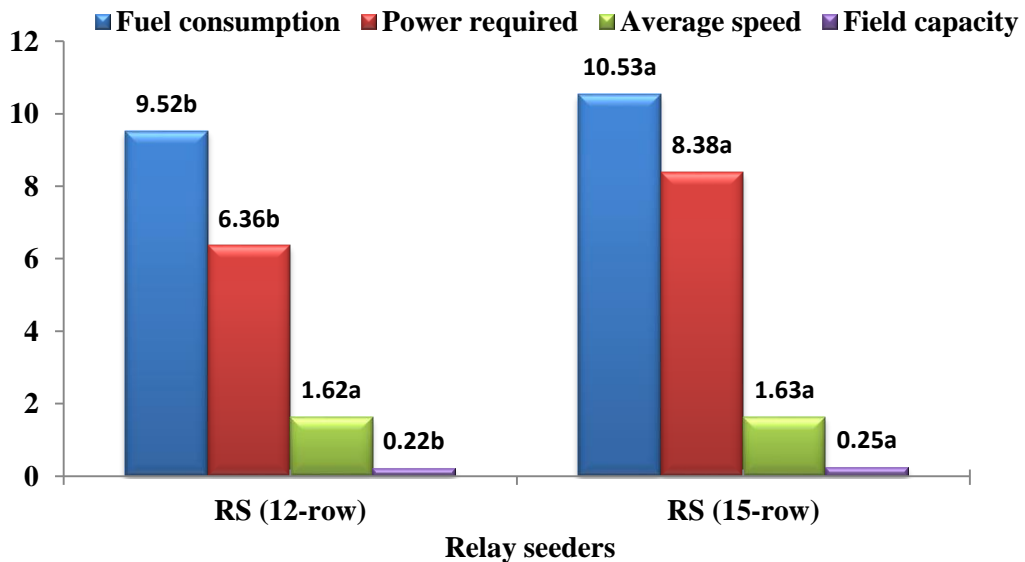


Fig. 4.7: Effect of type of Relay seeders on operational parameters

Note: Unit for fuel consumption is L ha⁻¹, Power required is in hp, Speed of operation are in km h⁻¹, and field capacity is in ha h⁻¹. Values with for a dependent parameter with different letter are significantly different at $p \leq 0.05$

Table 4.7: Effect of different cotton hybrids, CW systems and different type of furrow openers on performance of RS for seeding wheat into standing cotton

Treatments	Cotton Bolls Damaged (Count/plot*)	Percent Bolls Damaged (%)	Seed Cotton Lost (kg ha ⁻¹)	Fresh weight of weeds/plant residue accumulated (g m ⁻²)
A. Cotton hybrids				
RCH 776	154	1.22	8.46	21.2
MRC 7017	146	1.17	9.46	20.0
F-test (p-value)	0.59	0.62	0.42	0.57
B. Crop establishment methods				
T1 (12-row STR RS)	214a	1.77a	11.84ab	31.6a
T2 (12-row ZTT RS)	192ab	1.56ab	15.56a	28.3ab
T3 (12-row ZTDD RS)	156bc	1.28bc	6.72c	23.1bc
T4 (15-row STR RS)	116cd	0.88cd	6.84c	14.0cd
T5 (15-row ZTT RS)	141bc	1.07c	8.07bc	16.9de
T6 (15-row ZTDD RS)	79d	0.62d	4.72c	9.5e
F-test (p-value)	0.0003	<0.0001	0.0004	<0.0001
Interaction AxB	0.42	0.86	0.87	0.86

The values with in a column with different letter are significantly different at $p \leq 0.05$
 * Plot size of 250 m²

There was no significant effect of cotton hybrids on the cotton bolls damaged by movement of relay seeder and high clearance tractor (Table B14 in Appendix B).

4.7.2 Effect of Relay seeding on percent cotton bolls lost

The mean percent number of bolls lost was about 28% lower for ZTDD openers as compared with STR and ZTT furrow openers (Table B15 in Appendix B). RS with ZTDD openers does not require depth control wheels for machine as the depth of seeding is maintained by the spring tension, whereas, depth wheels are required for ZTT openers to stabilize the RS. Cotton plants obstruct the movement of depth wheels due to less space between cotton plants thus resulting in increase in damage of cotton bolls/plant. Also, the ZTDD openers cut the lodged cotton braches and residue that comes in front of the openers whereas these branches and residues entangle in the furrow openers (STR and ZTT) and in some cases it may even uproot the whole cotton plant. The loss of cotton bolls by the RS and

the tractor was less than 2%. This loss in cotton balls was compensated by the 4th picking of cotton in the relayed seeded crop. Buttar *et al* (2013) had recorded 11% higher seed cotton yield under relay seeding of wheat as compared with conventional practice. Fourth picking in relay seeded plots was made possible as the crop was allowed to grow after the third picking, which provided additional seed cotton yield.

4.7.3 Effect of Relay seeding on seed cotton yield

There was no significant difference between cotton hybrids on seed cotton loss due to movement of relay seeder and high clearance tractor (Table B16 in Appendix B). The mean loss of seed cotton due to relay seeding was 43% more for 12-row RS (for 67.5 cm row spacing of cotton) as compared with for 15-row RS (for 101.0 cm row spacing of cotton), Table 4.7. The loss of seed cotton was significantly lower by 63% and 106% for ZTDD openers as compared with STR and ZTT openers, respectively.

The results indicated that the RS for wider row spacing (101.0 cm) of cotton using ZTDD openers is causing lesser damage to cotton plants as compared to RS suitable for narrow row spacing (67.5 cm) of cotton using ZTT and STR openers, Fig. 4.8.

4.7.4 Effect on Weed/Plant residue accumulation

RS type (12-row and 15-row) and type of furrow openers showed significant effect on the amount of accumulation of weed/cotton residues (Table B17 in Appendix B). Both cotton hybrids had similar effect on residue accumulation, Table 4.7. The residue accumulation was significantly lower with ZTDD openers as compared to STR furrow openers for 12-row RS. ZTDD openers cut the cotton residues coming in front of it and move over it without dragging the residues, ZTT and STR furrow openers drag the fallen branches of cotton and weeds causing accumulation of the residues, Fig. 4.9. The residue accumulation was significantly lower for RS in 101.0 cm cotton row spacing as compared with RS suitable for 67.5 cm row spacing. The contrast analysis showed that the ZTDD openers performs better in terms of cotton bolls damaged, wheat establishment and residue/weeds accumulation as compared with ZTT and STR openers. Similarly, the 15-row RS (for 101 cm cotton row spacing) performed better in terms of wheat establishment and residue/weeds accumulation as compared with 12-row RS (for 67.5 cm cotton row spacing), Fig. 4.10. Therefore, 15-row RS with ZTDD openers performed better than all other combinations of the furrow openers and the type of RS.

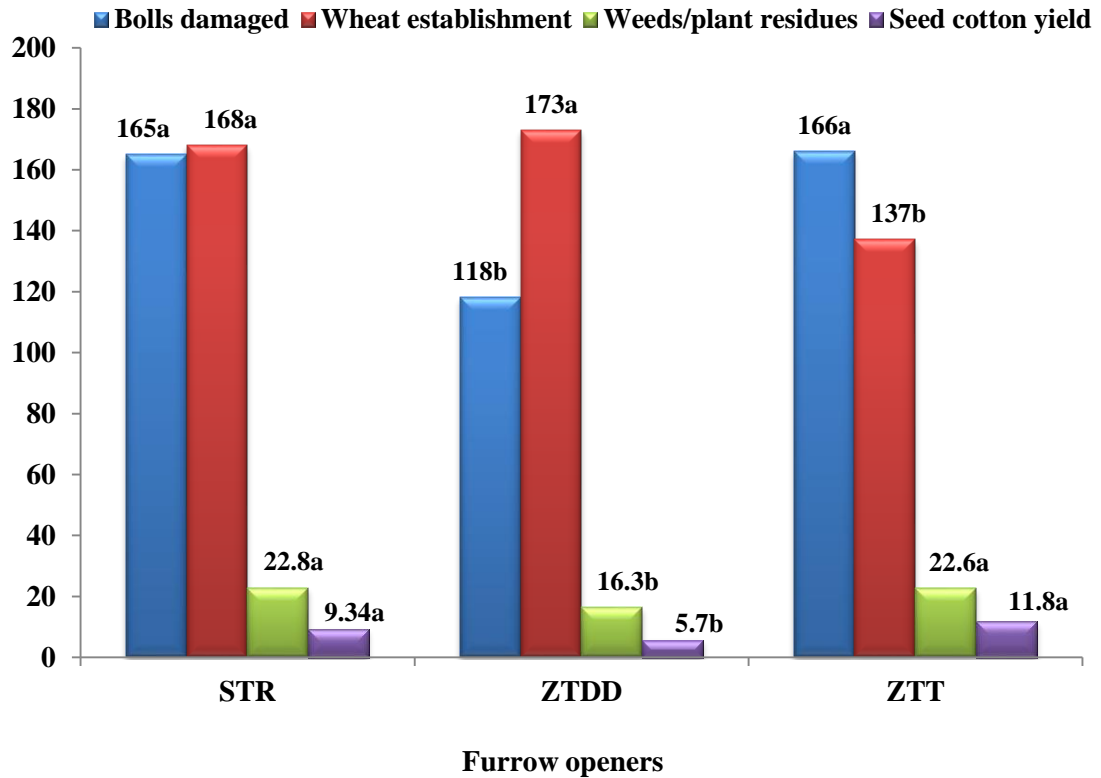


Figure 4.8: Effect of three types of furrow openers and two row geometries in cotton on performance of relay seeders

Note: Unit for cotton bolls damage is number per plant, wheat establishment is in number of plant m^{-2} , Weed/cotton leaves accumulated are in gm^{-2} (fresh weight basis), and seed cotton yield loss is in $kg ha^{-1}$. STR-strip till rotor, ZTDD-zero till double disc, ZTT-zero till tine openers. Values with for a dependent parameter with different letter are significantly different at $p \leq 0.05$



Fig. 4.9: Accumulation of weeds/plant residues on RS furrow openers and uneven sowing depth due to accumulation (from left to right)

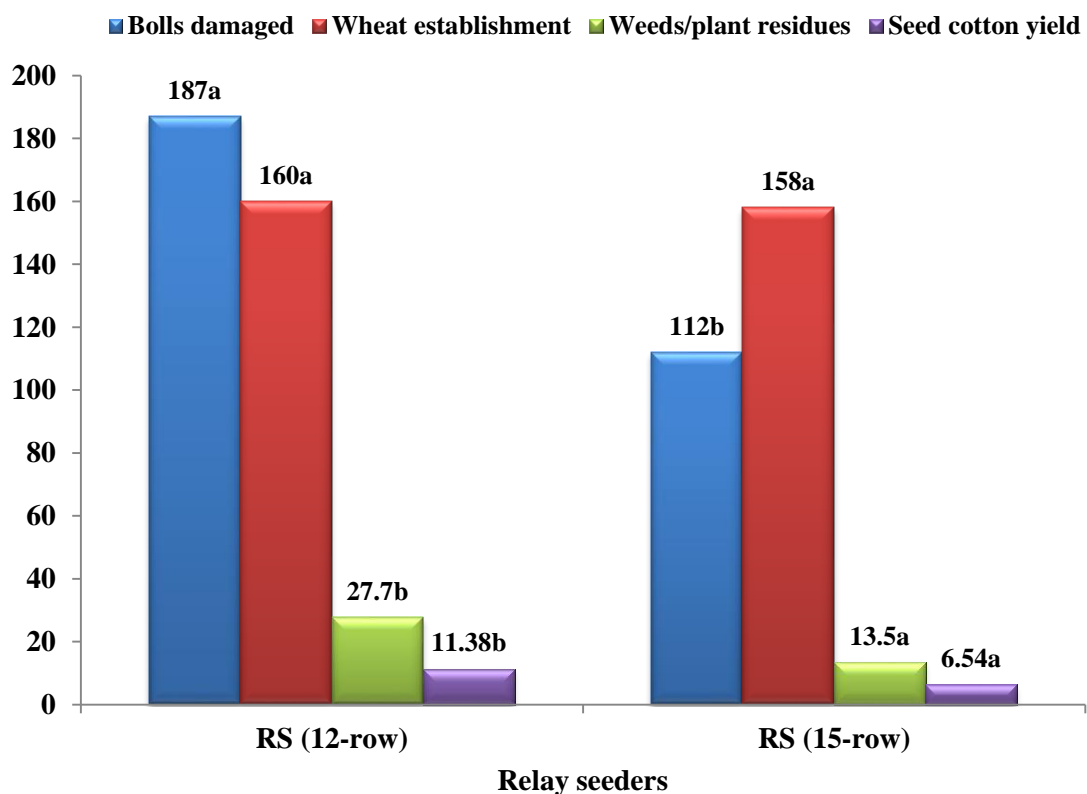


Figure 4.10: Effect of three types of Relay Seeder and two row geometries in cotton on performance of relay seeders

Note: Unit for cotton bolls damage is number per plant, wheat establishment is in number of plant m^{-2} , Weed/cotton leaves accumulated are in $g m^{-2}$ (fresh weight basis), and seed cotton yield loss is in $kg ha^{-1}$. Values with for a dependent parameter with different letter are significantly different at $p \leq 0.05$

4.8 Effect of relay seeding and cotton-spacing on wheat

4.8.1 Effect on wheat establishment

There was no significant interaction effect of type of cotton genotypes, relay seeders (or row spacing) and type of furrow openers on wheat emergence at 20 days, after sowing, Fig. 4.11. Relay seeders (for 67.5 cm and 101.0 cm cotton row spacing) and cotton genotypes had no significant effect on emergence count of wheat, Table 4.8. Furrow openers (STR, ZTT, ZTDD) and MB significantly influenced the emergence count, Fig. 4.12. Wheat seeded with STR and ZTDD furrow openers, and CT (T9) resulted in significantly higher emergence count as compared with ZTT furrow openers (Table B18 in Appendix B). Emergence count was markedly lower for MB as compared to relay seeded wheat due to poor soil-seed contact. The lower wheat emergence count in ZTT compared to STR and ZTDD furrow openers was mainly due to the uneven depth of seeding caused by significantly higher weeds/plant

residues accumulation in front of furrow openers. Emergence count was higher for the STR as compared with ZTT openers because of the better seed-soil contact. The double-disc openers gave most evenness of drilling in soils having crop residue as compared to other openers (Ozmeri 1986, Wilkins *et al* 1983). Anon (1994), investigated the performance of inverted, double-disc and shoe-type furrow openers with wheat crop under normal (18.59 %) and deficit (14.35 %) soil moisture conditions on dry basis and reported that standard deviation of depth of sowing was least for the double-disc furrow openers in both the experiments.



Fig. 4.11: Establishment of relay wheat in standing cotton on 67.5 and 101 cm row to row cotton (from left to right)

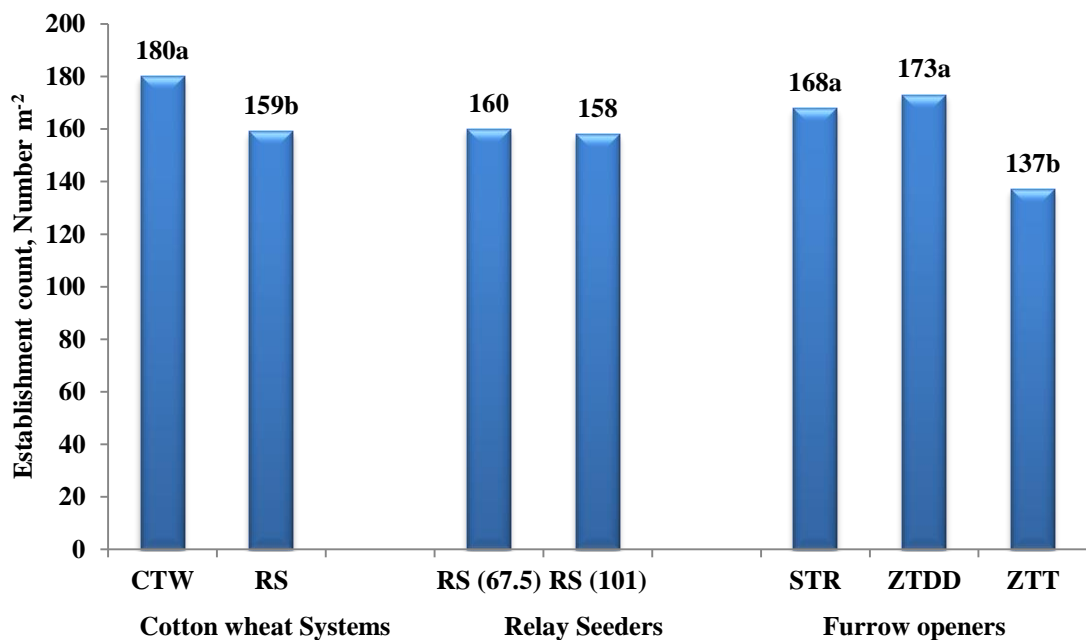


Fig. 4.12: Contrast analysis of establishment count for different cotton wheat systems, Relay seeders and type of furrow openers used

Emergence count in wheat was markedly lower for the MB due to poor soil and seed contact as compared with drill sowing with relay seeders, Fig. 12. Better wheat emergence under drill sowing as compared to MB has been reported by many researchers (Shaalán *et al* 1997, Tanveer *et al* 2003, Ali *et al* 2012) due to the placement of seed at optimum and uniform depth under drill sowing. However, Fischer *et al* (1976) found a wide range in optimum plant density (80–200 plants m⁻², provided that plant density was even) for maximum yield for a range of irrigated spring wheat varieties grown under climatic conditions fairly similar to those of northwest India, suggesting adequate plant population in all crop establishment methods in our experiment.

4.8.2 Time saving under relay planting of wheat

The crop duration (sowing to maturity) of wheat was 165 days and 134 days for relay and conventional sown wheat, respectively. The relay seeding advanced the sowing of wheat by 31 days as compared with conventional sowing of wheat after cotton harvest. But wheat crop matured at the same time under both of the planting methods. It may be due to the fact that higher temperatures near maturity may “force” the late sown crop (conventional) to complete the degree-days quickly. Several researchers (Khan and Khaliq 2005, Inamullah *et al* 2007, Subhan *et al* 2004) have reported a decrease in the days to maturity due to delay in sowing of wheat.

4.8.3 Effect on yield contributing parameters in wheat

Relay seeded treatments had 27.3% more spike density as compared with conventional sown wheat and manual broadcast, Table 4.8 and Fig. 4.13 and 4.14. Reduction in spike density sown after cotton harvest might be attributed to adverse effect of prevailing low temperature coinciding with the tillering stage of wheat. Each stage of development was progressively reduced with delay in sowing, which reduced spike density, Buttar *et al* (2013). The poor crop establishment in MB was, however, the main reason for significantly lower spike density as compared with the other treatments. Khan and Khaliq (2005), reported a similar negative effect of late sowing on spike density in wheat.

Number of grains/spike was significantly higher in relay seeded as compared to CTW wheat, Table 4.8. Fewer number of grains/spike in the conventional sown wheat could be attributed to higher temperature at anthesis and grain development stages under late sowing as



Fig. 4.13: Wheat establishment in 67.5 and 101.0 cm row spacing of cotton (from left to right)

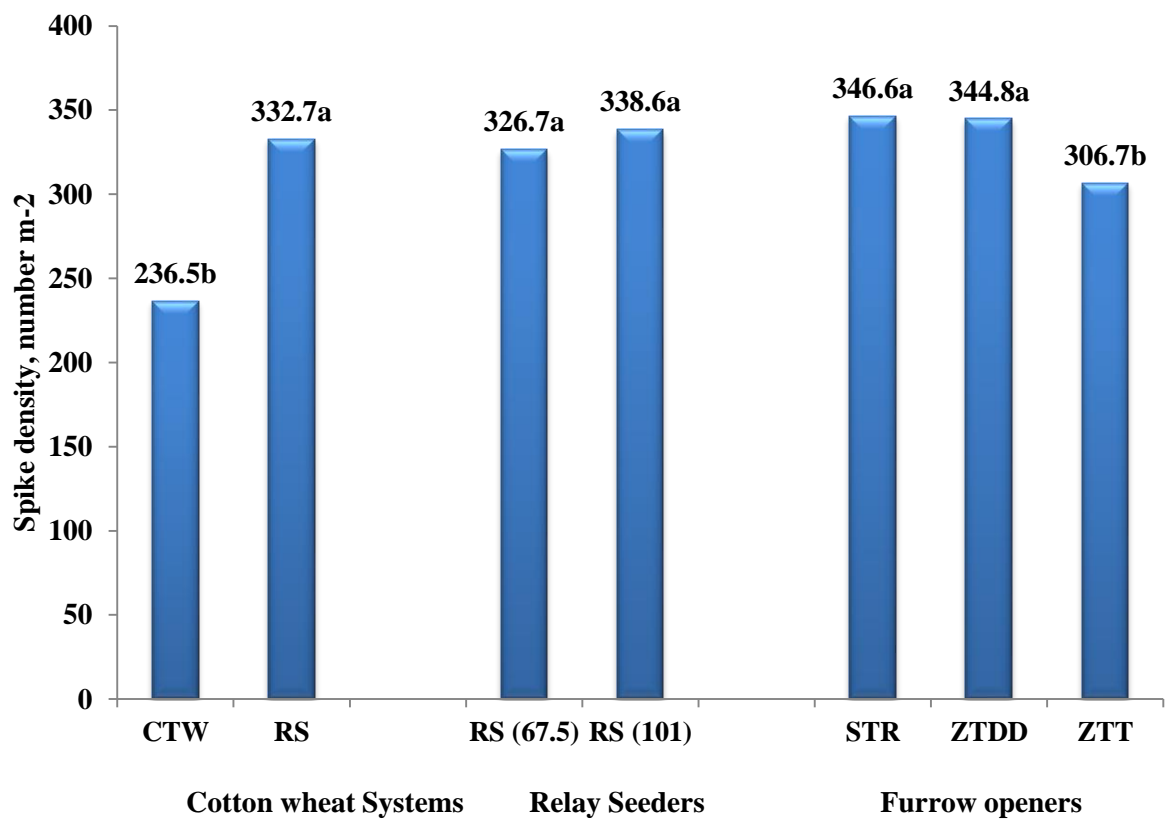


Fig. 4.14: Contrast analysis of spike density for different cotton wheat systems, Relay seeders and type of furrow openers used

Table 4.8: Wheat emergence, grain yield and yield attributing characters as influenced by different planting methods in cotton-wheat system

Treatments	Emergence (count m⁻²)	Spike density (m⁻²)	Number of grains spike⁻¹	Test weight (mg)	Wheat Yield (t ha⁻¹)
A. Cotton hybrids					
RCH 776	146	286.9	51.0	44.7	4.61
MRC 7017	147	300.7	51.6	44.7	4.60
F-test (p-value)	0.74	0.12	0.21	0.94	0.97
B. Cotton wheat system					
T1 (12-row STR RS)	169ab	338.5a	49.9b	44.9bcd	5.16a
T2 (12-row ZTT RS)	137c	292.9b	51.7ab	45.6abcd	4.65bc
T3 (12-row ZTDD RS)	174ab	348.9a	52.9a	44.4d	4.93ab
T4 (15-row STR RS)	167b	354.7a	52.0ab	45.7abc	5.35a
T5 (15-row ZTT RS)	136c	320.5ab	51.4ab	45.2abcd	5.14a
T6 (15-row ZTDD RS)	172ab	340.7a	52.8a	44.7cd	5.08ab
T7 (MB-67.5 cm)	98d	235.1c	52.1ab	46.0ab	3.50d
T8 (MB-101.0 cm)	87d	176.9d	52.3a	46.2a	3.36d
T9 (CTW)	180a	236.5c	46.7c	39.9e	4.25c
F-test (p-value)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Interaction AxB	0.58	0.59	0.20	0.70	0.93

The values with in a column with different letter are significantly different at $P \leq 0.05$

compared with relay seeded wheat, Fig. 4.15. Delayed sowing of wheat commonly has a negative influence on the number of grains/spike (Jan *et al* 2000, Buttar *et al* 2013).

Mean test weight under conventional tillage was significantly lower (13 %) as compared with relay seeding in standing cotton, Fig. 4.16. This can be attributed to a longer grain filling period available to the early sown crop. These results are in accordance with those of Green *et al* (1985) and Jan *et al* (2000) who reported that grain weight decreased significantly with delay in sowing. Khan and Khaliq (2005) reported that the relay seeded wheat produced 13.2% higher grain weight as compared to conventional sowing. The contrast analysis showed that all relay seeding treatments have significantly more spike density, number of grains per spike test weight as compared to CTW. Spike density for RS (67.5 cm)

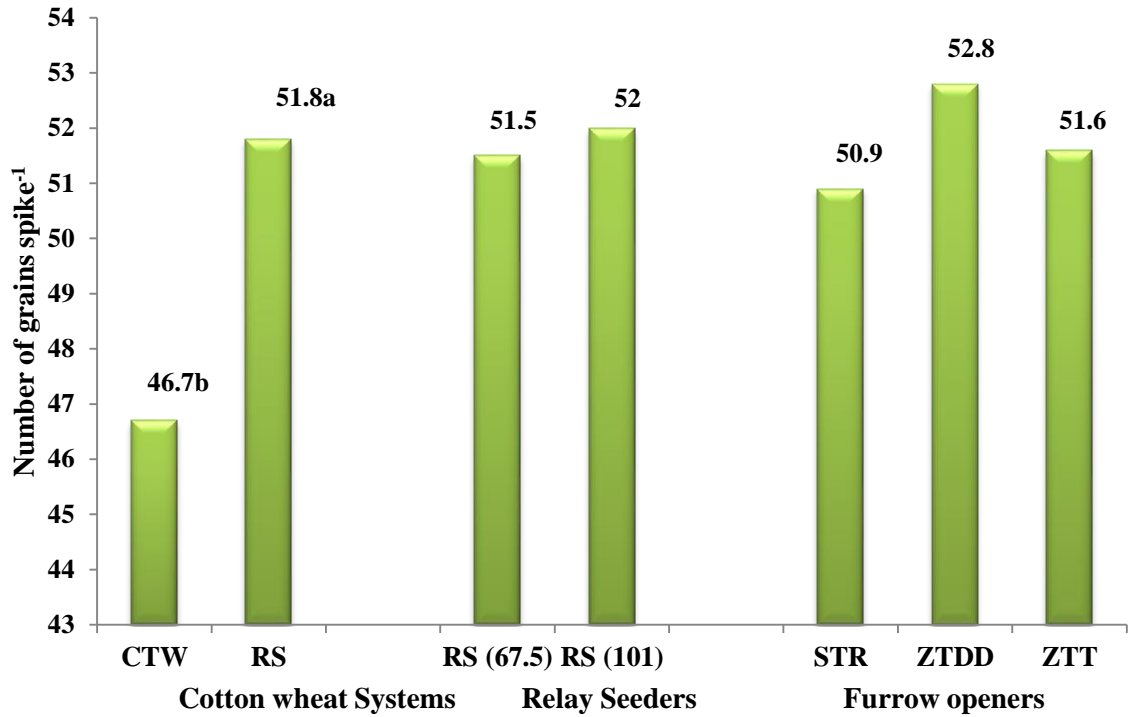


Fig. 4.15: Contrast analysis of number of grains per spike for different cotton wheat systems, Relay seeders and type of furrow openers used

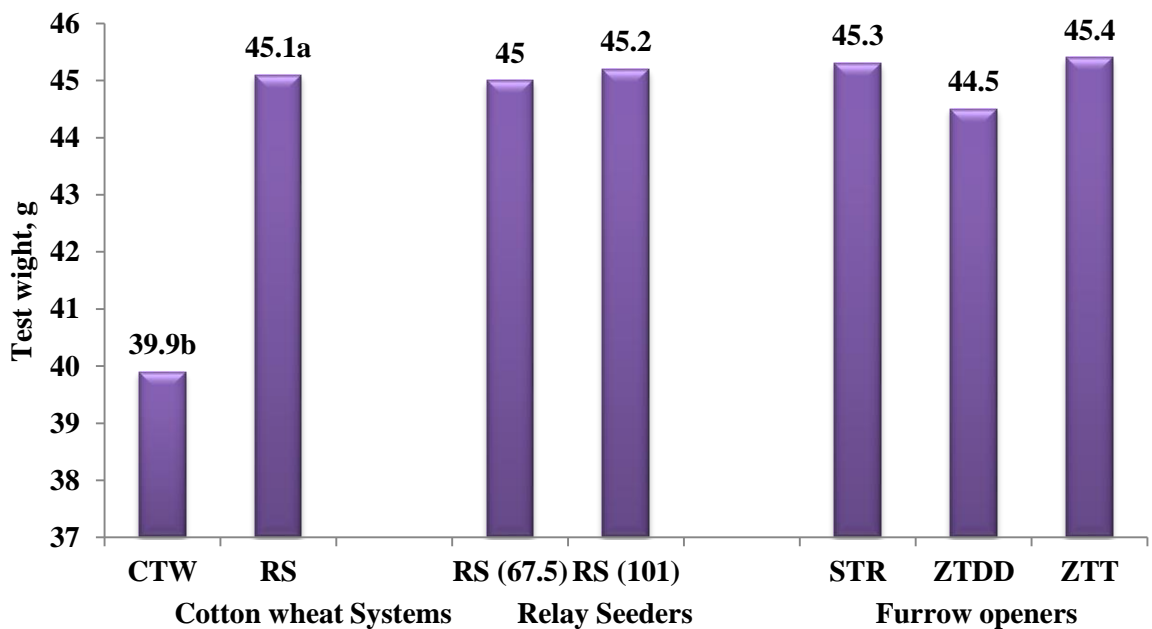


Fig. 4.16: Contrast analysis of test weight for different cotton wheat systems, Relay seeders and type of furrow openers used

and RS (101.0 cm) have statistically similar, whereas; the STR and ZTDD openers have significantly higher spike density as compared with ZTT openers.

4.8.4 Effect on wheat yield

All the relay seeder treatments except ZTT furrow openers (T2) produced significantly higher wheat yield as compared with CTW (T9) and MB (T7 and T9), Table 4.8. The early sowing of wheat by 31 days under relay seeding increased the spike density and the number of grains per spikes as compared with T9 leading to higher grain yield. This is consistent with the observation made by Buttar *et al* (2013) who reported 25% higher grain yield of wheat sown with relay seeder compared to CT wheat. The short duration of CTW and unfavorable temperature regime during grain development phase experienced by the crop adversely affected the yield. The low grain yield recorded in T2 (ZTT furrow opener in 67.5 cm row spacing of cotton) was mainly due to poor crop establishment caused by uneven seeding depth. Wheat yield was significantly lower for the MB treatments as compared with drill sowing using relay seeder and CTW (Table B22 in Appendix B). The main reason for the lower grain yield in MB was due to poor crop establishment because of poor soil-seed contact and lack of uniformity in crop establishment. Earlier, Dawelbeit and Babiker (1997) and Mann *et al* (2008) reported that seed broadcasting resulted in significantly lower wheat yields than drill sowing and or earth ridging after broadcasting. Other workers (Shaalán *et al* 1997, Khan *et al* 2007, Soomro *et al* 2009) reported that number of grains per spike, grain weight and grain yield were higher for drill than broadcast sown wheat.

The grain yield was statistically similar for ZTDD, STR and ZTT openers, whereas, the yield was significantly higher for STR opener as compared with ZTT. The poor crop establishment due to uneven depth of seeding in ZTT openers was responsible for lower wheat yield. There was no effect of different row spacing in cotton and relay seeding of wheat (3 rows in 67.5 row spacing and 5 rows in 101.0 cm row spacing in cotton) on wheat yield.

Porter and Khalilian (2005) reported that yield of conventional tillage wheat was not affected by skip-row geometry designed to allow for relay intercropping of either soybean or cotton. The contrast analysis showed that wheat yield is significantly lower for CTW wheat as compared to relay seeding of wheat. The different sizes of RS (suitable for 67.5 cm and 101.0 cm cotton row spacing) had similar wheat yield. ZTT openers had significantly lower wheat yield as compared with STR openers, whereas, the grain yield was statistically at par for ZTDD and STR openers, Fig. 4.17.

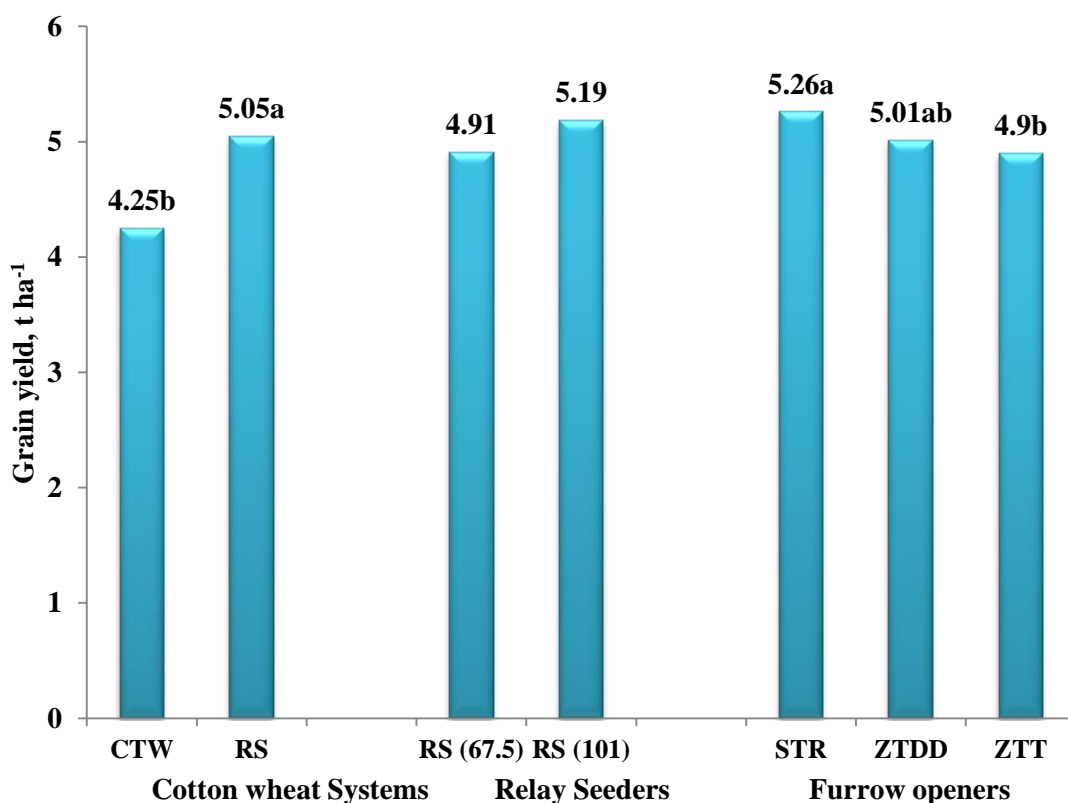


Fig. 4.17: Contrast analysis of grain yield for different cotton wheat systems, Relay seeders and type of furrow openers used

4.9 Performance of relay seeded wheat on farmers' fields

Relay sowing of wheat advanced the sowing of wheat by 5 to 11 days as compared with CT wheat cultivation after cotton harvest, Table 4.9. The advancement in relay seeding was lower than that recorded in experiment-I, due to non availability of relay seeder at the right time as single prototype of relay seeder was available (Fig. 4.18), which could be made available only after the completion of seeding of wheat in experiment-I and time involved in transport the machine as well as the high clearance tractor to the farmers locations in Bathinda, Punjab, India that was about 250 km from BISA site at Ludhiana, where the experiment-I was laid. Student's t-test analysis showed significantly lower yields for CT as compared with relay seeding (Table B23 in Appendix B). On average 6.4% higher grain yield was recorded for relay seeding as compared with CT wheat. The greater increase in gain yield from relay seeding as compared to CT wheat can be expected when relay seeding of wheat is accomplished in the first fortnight of November in this region.



Fig. 4.18: 12-row Relay seeder with ZTDD furrow openers seeding wheat in cotton at Farmers field at Batinda, Punjab

Table 4.9: Saving in time of planting and effect on wheat yield from 12 -row tractor operated RS with disc openers in on-farm trials conducted in district Bhatinda in Punjab (India) in 2013-14

Location	Saving in days	Wheat Yield (t ha ⁻¹)		% Yield gain over CT
		RS	CT	
Machhana	5	4.85	4.53	7.2
SangatMandi	11	4.43	3.98	11.3
Malwala	9	4.85	4.75	2.1
Bhagwanghar	6	4.63	4.50	2.8
Jodhpur Romana	5	4.03	3.70	8.8
Mean	-	4.56	4.29	6.4
F-test (p-value)	-	0.016	-	-

The values with in a column with different letter are significantly different at $P \leq 0.05$

4.10 Economic analysis

The data presented in Table 4.10, revealed lower variable costs for planting wheat with relay seeder due to lower cultivation costs as compared with conventional seeding of wheat. Gross returns from relay seeding of wheat were higher by Rs. 19,352 to 26,401 per ha due to additional yield of seed cotton and increase in grain and straw yields of wheat over CT and manual relay seeding of wheat. Similarly, net returns were Rs. 19,282 to 26,332 per ha higher (an increase of 27-37%) under relay seeding of wheat using tractor operated relay seeder compared with conventional CW system due to higher gross returns and lower variable costs (Table 4.7). Net return from CW system with manual broadcasting of wheat (T7 and T8) into standing cotton crop was statistically similar to CT (Table B24 in Appendix B). The benefit to cost ratio was also significantly higher for the relay seeded wheat as compared with conventional CW system and manual relay broadcasting of wheat. This is consistent with Aryal *et al* (2015) who have reported that shifting from CT to ZT wheat production system reduces the farmers total input cost ha⁻¹ by 20% (USD 79 per ha) and increases net revenue per ha by 28% (USD 97.5 per ha). Buttar *et al* (2013) have recorded the higher net return in CW system for mechanical relay seeding of wheat into standing cotton as compared with conventional CW system.

Table 4.10: Variable costs, gross income and net income (in Indian Rupees per ha) under different crop establishment methods in cotton–wheat system

Variable cost [§] in wheat (Rs. Per ha)										
Treatment	cultivation cost	seed and seed treatment	Fertilizer cost	Seeding cost	pesticides cost	Irrigation cost	Harvesting and straw collection cost	transportation and marketing cost	Interest on variable costs	Total variable cost
T ₁	3250	3190	5383	1437.5	2095	195	4500	1750	491	22291
T ₂ , T ₃ , T ₄	0	3190	5383	3386	2095	195	4500	1750	461	20960
T ₅	0	3190	5383	560	2095	195	4500	1750	398	18070
T ₆ , T ₇ , T ₈	0	3190	5383	3386	2095	195	4500	1750	461	20960
T ₉	0	3190	5383	560	2095	195	4500	1750	398	18070
Treatment	Variable cost of cotton			Total variable cost of CW	Gross return			Net income of the CW system	Benefit cost ratio (BCR) of system	
	Variable cost	Additional cost	Total		Wheat	Cotton	System			
T ₁	53828	0	53828	76118	69095	78195	147290	71172	1.94b	
T ₂ , T ₃ , T ₄	53828	1400	55228	76187	79867	86775	166642	90454	2.19a	
T ₅	53828	1400	55228	73298	56807	86775	143582	70284	1.96b	
T ₆ , T ₇ , T ₈	53828	1400	55228	76187	84381	89310	173691	97504	2.28a	
T ₉	53828	1400	55228	73298	54553	89310	143863	70565	1.96b	
F-test (p-value)	-	-	-	-	-	-	-	-	0.0004	

[§] = 1 Indian Rs = US \$ 0.0161, the values with in a column with different letter are significantly different at $P \leq 0.05$

SUMMARY

Cotton–wheat is important cropping system in South Asia and occupies 4.02 million ha. Cotton-Wheat Production System is followed on 1.40 million ha and on 2.62 million ha in India and Pakistan respectively. Wheat planting after cotton is usually delayed due to late pickings and time needed for seedbed preparation, resulting in low wheat yield. This reduction in yield is primarily attributed to poor and erratic germination because of low ambient temperature that prevail at that time. Moreover, late planted wheat plants have to complete all growth and developmental stages in lesser time as starch accumulation process is terminated at the same specific temperature irrespective of time of sowing because of photosensitive nature of wheat. Few farmers sow wheat through broadcasting in standing cotton for timely sowing but on a small scale. This methodology has also limitations of poor germination and low fertilizer use efficiency. A 2-wheel self-propelled relay seeder was developed in 2008 and has the capability of opening a narrow strip (25-35 mm) using straight steel blades on the rotor in front of zero till furrow opener to facilitate placement of seed and fertilizer while moving between the two rows of standing cotton (generally 675 mm apart). The timely sowing of wheat with non significant damage to cotton was demonstrated through engine operated relay planting. However, for popularising the relay planting in CW rotation in South Asia, self propelled small machine is insufficient. Hence, there is a need of a tractor operated high clearance relay seeder which in one pass can plant a width equal to 3-4 rows of cotton crop.

Therefore, to study feasibility of relay seeding of wheat in cotton, a prototype of high clearance platform (110 cm from ground) for tractor was designed and developed to facilitate the movement of tractor in standing cotton. Two innovative relay seeders (RS) (suitable for 67.5 and 101.0 cm row spacing) with three types of furrow openers (strip till rotor-STR), zero till inverted T-type-ZTT and zero till double disc-ZTDD) were developed and evaluated for their performance under two cotton genotypes. Replicated on-station field experiments included two cotton hybrids having different canopy cover (RCH 776 and MRC 7017), two RS for different row spacing and three types of furrow openers (STR, ZTDD and ZTT).

Field trial was laid out in a strip-plot design with three replications. Treatments included two *Bt*-cotton genotypes (RCH 776 and MRC 7017) having different canopy cover and vigor in the main plots. For ease in the movement of tractor and relay seeders, cotton

genotypes were planted in strips. Data collected for all the dependent variables were subjected to analysis of variance in factorial strip plot design using SAS 9.2 software package. The RS with double disc opener vis-à-vis conventional till wheat (CTW) were also evaluated on five farmers' fields. Student's T-test using SAS 9.2 software package was performed for comparing grain yield between two treatments in experiment 2. The economic analysis was also performed to quantify the net returns and benefit cost ratio (BCR) of using RS for seeding wheat in cotton as compared with conventional tillage wheat. Student's T-test using SAS 9.2 software package was performed for comparing economics of different cotton-wheat systems. Based on the study the following conclusions were drawn:

- The average speed of travel of ZTDD openers was 9.3 and 16.6 percent higher as compared with STR and ZTT openers, respectively. Therefore, the field capacity of RS with ZTDD openers was 8.7 and 13.6 percent higher as compared with RS having STR and ZTT openers, respectively.
- The fuel consumption was 26 and 44.2 percent higher for STR openers as compared with ZTDD and ZTT openers. The fuel consumption was at par for ZTT and ZTDD openers, irrespective of the size of RS used.
- The fuel consumption, power required, field capacity of 15-row RS was 10.6, 31.8 and 13.6 percent higher as compared with 12-row RS, irrespective of the type of furrow openers used.
- Number of cotton bolls detached from cotton plants due to movement of tractor and relay seeder with ZTDD was 39.8 and 40.7 percent lower than STR and ZTT furrow openers. Number of cotton bolls detached from cotton plants due to movement of tractor and relay seeder was lower by 40.1 percent for 15-rows RS as compared with 12-Row RS. Therefore, the lowest damage was observed for the 15-row RS with ZTDD openers as compared with the all other combinations. However, the overall loss of cotton bolls was under 2 percent due to RS operation.
- The weeds and plant residue accumulation was 39.9 and 38.7 percent lesser for the ZTDD openers as compared with STR and ZTT openers respectively. Also the weed accumulation was 51.3 percent lower for 15-row RS as compared with 12-row RS, irrespective of type of furrow openers used.

- Mean cotton yield for 67.5 cm and 101 cm row spacing under relay seeding was 11-14 % higher compared with conventional sowing irrespective of cotton genotype used. This increase in cotton yield covers for the loss of cotton yield due movement of RS mounted on high clearance tractor in the standing cotton.
- Establishment count of relay seeded wheat with ZTDD and STR-furrow openers was 26.2 and 22.6 percent higher as compared with ZTT openers. Whereas, the emergence count for MB treatment was lowest (-32.1 percent). Also, the establishment was statistically at par for 15-row RS and 12-row RS.
- The crop duration (sowing to maturity) of relay seeded wheat was 31 days more as compared with conventional sowing of wheat after cotton harvest.
- The spike density, number of grains per spike and test weight of relay seeded wheat (T1-T6) was 40.7, 10.9 and 13.0 percent higher as compared with CTW(T9). The spike density, number of grains per spike and test weight was statistically at par for 15-row and 12-row RS.
- Relay seeding of wheat on an average produced 18.8 percent more yield compared with T9. Whereas, the lowest yield was recorded for (T7 and T8) MB of wheat. The RS with ZTDD and STR openers produced at par wheat yield, whereas, the STR openers produced significantly higher yield compared with ZTT openers.
- RS with ZTDD openers produced significantly higher (average 6.4 percent) wheat yield on-farm trials as compared to CT wheat.
- There was 27-37 percent higher net return (Rs. 19,282 to 26,332 per ha) with relay seeding of wheat in north-west India as compared with CTW.
- The benefit cost ratio is significantly higher for (2.19 and 2.28) for 12-row and 15-row RS as compared with for CTW and MB (1.94 and 1.96), respectively.

SUGGESTIONS FOR FUTURE WORK

- Need to develop the mechanism for real time centering (automatic centering) of furrow openers in two adjacent cotton rows.
- Development of sprayers and weeders for increasing the annual usage of high clearance tractor in CW rotation
- Relay seeding of summer moong in wheat for sustainable intensification of RW system

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**DETAILS OF THE DIGITAL TONG TESTER USED FOR POWER
MEASUREMENT**

Name of the Instrument: AC (TRMS) Digital Tong Tester/Clamp meter

Model: 3510PHW

Accuracy:

Range	Resolution	Accuracy	Overload protection
80.0 hp (<100A)	0.01 hp	Typically 2% of the reading	600 VAC/1000 ACC
800.0 hp (>100A)	0.1 hp	Typically 2% of the reading	600 VAC/1000 ACC

Procedure for power measurement:

1. Set the rotary switch to the “kW/KVA” position refer Fig. A.
2. Insert the test leads in to the input jack (Black to COM and Red to V)
3. Connect the black lead COM to the neutral line.
4. Connect the red lead V to the power line and clamp the same conductor where V (red) terminal is connected.
5. The power clamp will automatically select the appropriate range.
6. Read the watt and hp values displayed on the LCD
7. Press range button to display the required parameters
8. $PF = \frac{kW}{KVA} = \cos \theta (\theta = \text{phase angle})$
9. KVA (Apparent power): $KVA = \frac{V * A}{1000}$
10. KVA (Reactive power): $KVAR = \sqrt{(KV - A)^2 - (kW)^2} = KVA * \sin \theta$
11. Hp (horse power) = 0.746 kW

Table B1: ANOVA (Number of Monopodial branches plant⁻¹)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	8.67500000	2.89166667	8.20	0.0003
Error	36	12.70000000	0.35277778		
Corrected Total	39	21.37500000			

R-Square	Coeff Var	Root MSE	MONO Mean
0.405848	22.62670	0.593951	2.625000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SPACING	1	1.22500000	1.22500000	3.47	0.0706
HYBRID	1	7.22500000	7.22500000	20.48	<.0001
SPACING*HYBRID	1	0.22500000	0.22500000	0.64	0.4297

Means comparison for factor (spacing) using LSD test

Alpha	0.05
Error Degrees of Freedom	36
Error Mean Square	0.35
Critical Value of t	2.03
Least Significant Difference	0.38

Means with the same letter are not significantly different.			
t Grouping	Mean	N	SPACING
A	2.80	20	101
A	2.45	20	67.5

Means comparison for factor (Hybrid) using LSD test

Alpha	0.05
Error Degrees of Freedom	36
Error Mean Square	0.35
Critical Value of t	2.03
Least Significant Difference	0.38

Means with the same letter are not significantly different.			
t Grouping	Mean	N	HYBRID
A	3.05	20	RCH 776
B	2.20	20	MRC 7017

Table B2: ANOVA (Number of sympodial branches plant⁻¹)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	29.4000000	9.8000000	0.59	0.6232
Error	36	594.2000000	16.5055556		
Corrected Total	39	623.6000000			

R-Square	Coeff Var	Root MSE	SYM Mean
0.047146	14.82738	4.062703	27.40000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SPACING	1	12.10	12.10	0.73	0.3975
HYBRID	1	0.40	0.40	0.02	0.8772
SPACING*HYBRID	1	16.90	16.90	1.02	0.3183

Means comparison for factor (spacing) using LSD test

Alpha	0.05
Error Degrees of Freedom	36
Error Mean Square	16.5055 6
Critical Value of t	2.02809
Least Significant Difference	2.6056

Means with the same letter are not significantly different.			
t Grouping	Mean	N	SPACING
A	27.950	20	101
A	26.850	20	67.5

Means comparison for factor (spacing) using LSD test

Alpha	0.05
Error Degrees of Freedom	36
Error Mean Square	16.5055 6
Critical Value of t	2.02809
Least Significant Difference	2.6056

Means with the same letter are not significantly different.			
t Grouping	Mean	N	HYBRID
A	27.500	20	RCH 776
A	27.300	20	MRC 7017

Table B3: ANOVA (Number of cotton bolls picked in first picking)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.25	0.049	0.32	0.89
Error	12	1.84	0.153		
Corrected Total	17	2.09			

R-Square	Coeff Var	Root MSE	FIRSTPICK Mean
0.12	3.99	0.39	9.81

Source	DF	Type I SS	Mean Square	F Value	Pr > F
COTTONGEOMETRY	2	0.165	0.082	0.54	0.59
HYBRID	1	0.000042	0.000042	0.00	0.98
COTTONGEOMETE*HYBRID	2	0.082	0.041	0.27	0.76

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.153
Critical Value of t	2.18
Least Significant Difference	0.49

Means with the same letter are not significantly different.			
t Grouping	Mean	N	COTTONGEOMETRY
A	9.91	6	CW(R)101
A	9.84	6	CW67.5
A	9.67	6	CW(R)67.5

Contrast analysis for RS v/s Farmer Practice

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
COTTONGEOMETRY T1 T2 VS T3 (RS VS FARMER PRACTICE)	1	0.0115	0.0115	0.08	0.7887

Table B4: ANOVA (Number of cotton bolls picked in second picking)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.86870583	0.17374117	0.42	0.8253
Error	12	4.95018416	0.41251535		
Corrected Total	17	5.81888998			

R-Square	Coeff Var	Root MSE	SECONDPICK Mean
0.149291	3.985160	0.642274	16.11663

Source	DF	Type I SS	Mean Square	F Value	Pr > F
COTTONGEOMETRY	2	0.64698725	0.32349363	0.78	0.4785
HYBRID	1	0.00005054	0.00005054	0.00	0.9914
COTTONGEOMETE*HYBRID	2	0.22166803	0.11083402	0.27	0.7689

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.412
Critical Value of t	2.18
Least Significant Difference	0.8079

Means with the same letter are not significantly different.			
t Grouping	Mean	N	COTTONGEOMETRY
A	16.38	6	CW(R)101
A	16.01	6	CW(R)67.5
A	15.95	6	CW67.5

Table B5: ANOVA (Number of cotton bolls picked in third picking)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.38	0.077	0.75	0.60
Error	12	1.23	0.10		
Corrected Total	17	1.61			

R-Square	Coeff Var	Root MSE	THIRDPICK Mean
0.24	4.00	0.32	7.98

Source	DF	Type I SS	Mean Square	F Value	Pr > F
COTTONGEOMETRY	2	0.32	0.16	1.61	0.2404
HYBRID	1	0.000054	0.000054	0.00	0.9820
COTTONGEOMETE*HYBRID	2	0.055	0.027	0.27	0.7694

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.10
Critical Value of t	2.18
Least Significant Difference	0.40

Means with the same letter are not significantly different.			
t Grouping	Mean	N	COTTONGEOMETRY
A	8.1488	6	CW67.5
A	8.0011	6	CW(R)101
A	7.8181	6	CW(R)67.5

Contrast analysis for RS v/s Farmer Practice

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
COTTONGEOMETRY T1 T2 VS T3 (RS VS FARMER PRACTICE)	1	0.23	0.23	2.24	0.1606

Table B6: ANOVA (Number of cotton bolls picked in fourth picking)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	56.78	11.35	893.77	<.0001
Error	12	0.15	0.013		
Corrected Total	17	56.93			

R-Square	Coeff Var	Root MSE	FOURTHPICK Mean
0.997	4.49	0.11	2.51

Source	DF	Type I SS	Mean Square	F Value	Pr > F
COTTONGEOMETRY	2	56.76	28.38	2234.14	<.0001
HYBRID	1	0.0015	0.0015	0.12	0.7359
COTTONGEOMETE*HYBRID	2	0.0055	0.0028	0.22	0.8072

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.013
Critical Value of t	2.18
Least Significant Difference	0.14

Means with the same letter are not significantly different.			
t Grouping	Mean	N	COTTONGEOMETRY
A	3.81	6	CW(R)101
A	3.72	6	CW(R)67.5
B	0.00	6	CW67.5

Contrast analysis for RS v/s Farmer Practice

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
COTTONGEOMETRY T1 T2 VS T3 (RS VS FARMER PRACTICE)	1	56.74	56.74	4466.50	<.0001

Table B7: ANOVA (Total bolls picked)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	58.49	11.69	5.64	0.0067
Error	12	24.89	2.07		
Corrected Total	17	83.38			

R-Square	Coeff Var	Root MSE	TOTALPICKED Mean
0.70	3.95	1.44	36.43

Source	DF	Type I SS	Mean Square	F Value	Pr > F
COTTONGEOMETRY	2	57.37	28.69	13.83	0.0008
HYBRID	1	0.00032	0.00032	0.00	0.9902
COTTONGEOMETE*HYBRID	2	1.12	0.56	0.27	0.7682

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	2.07
Critical Value of t	2.18
Least Significant Difference	1.81

Means with the same letter are not significantly different.			
t Grouping	Mean	N	COTTONGEOMETRY
A	38.10	6	CW(R)101
A	37.23	6	CW(R)67.5
B	33.95	6	CW67.5

Contrast analysis for RS v/s Farmer Practice

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
COTTONGEOMETRY T1 T2 VS T3 (RS VS FARMER PRACTICE)	1	55.093	55.093	26.56	0.0002

Table B8: ANOVA (Cotton Yield)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.26	0.052	6.91	0.0030
Error	12	0.091	0.0076		
Corrected Total	17	0.35			

R-Square	Coeff Var	Root MSE	COTTONYIELD Mean
0.74	4.006	0.087	2.173978

Source	DF	Type I SS	Mean Square	F Value	Pr > F
COTTONGEOMETRY	2	0.26	0.129	17.01	0.0003
HYBRID	1	0.0000032	0.0000032	0.00	0.9840
COTTONGEOMETE*HYBRID	2	0.0042	0.0021	0.27	0.7647

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.007586
Critical Value of t	2.17881
Least Significant Difference	0.1096

Means with the same letter are not significantly different.			
t Grouping	Mean	N	COTTONGEOMETRY
A	2.28	6	CW(R)101
A	2.22	6	CW(R)67.5
B	2.01	6	CW67.5

Contrast analysis for RS v/s Farmer Practice

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
COTTONGEOMETRY T1 T2 VS T3 (RS VS FARMER PRACTICE)	1	0.25	0.25	32.55	<.0001

Table B9: ANOVA (Speed of Operation)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	0.41602285	0.03200176	10.14	<.0001
Error	22	0.06945146	0.00315688		
Corrected Total	35	0.48547431			

R-Square	Coeff Var	Root MSE	SPEED Mean
0.856941	3.457651	0.056186	1.624981

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	5	0.39148434	0.07829687	24.80	<.0001
HYBRID	1	0.00348539	0.00348539	1.10	0.3048
TREAT*HYBRID	5	0.01434759	0.00286952	0.91	0.4931
REP	2	0.00670553	0.00335277	1.06	0.3628

Contrast analysis for different furrow openers and Relay Seeders used

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
TREAT LEVEL T1 T2, T3 VS T4, T5, T6	1	0.00001196	0.00001196	0.00	0.9515
TREAT LEVEL T1 T4 VS. T2 T5	1	0.06088916	0.06088916	19.29	0.0002
TREAT LEVEL T1 T4 VS. T3 T6	1	0.13416097	0.13416097	42.50	<.0001
TREAT LEVEL T2 T5 VS. T3 T6	1	0.37581460	0.37581460	119.05	<.0001

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.003
Critical Value of t	2.07
Least Significant Difference	0.07

Means with the same letter are not significantly different.			
t Grouping	Mean	N	TREAT
A	1.78	6	T3
A	1.74	6	T6
B	1.61	6	T1
B	1.61	6	T4
C	1.53	6	T5
C	1.49	6	T2

Table B10: ANOVA (Field Capacity)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	0.01479670	0.00113821	18.07	<.0001
Error	22	0.00138607	0.00006300		
Corrected Total	35	0.01618277			

R-Square	Coeff Var	Root MSE	FIELDCAPACITY Mean
0.914349	3.409811	0.007937	0.232783

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	5	0.01430864	0.00286173	45.42	<.0001
HYBRID	1	0.00007440	0.00007440	1.18	0.2889
TREAT*HYBRID	5	0.00026883	0.00005377	0.85	0.5273
REP	2	0.00014483	0.00007242	1.15	0.3351

Contrast analysis for different furrow openers and Relay Seeders used

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
TREAT LEVEL T1 T2, T3 VS. T4, T5, T6	1	0.00654998	0.00654998	103.96	<.0001
TREAT LEVEL T1 T4 VS. T2 T5	1	0.00121753	0.00121753	19.32	0.0002
TREAT LEVEL T1 T4 VS. T3 T6	1	0.00271063	0.00271063	43.02	<.0001
TREAT LEVEL T2 T5 VS. T3 T6	1	0.00756150	0.00756150	120.02	<.0001

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.000063
Critical Value of t	2.07387
Least Significant Difference	0.0095

Means with the same letter are not significantly different.				
t Grouping	Mean	N	TREAT	
A	0.263	6	T6	
B	0.24	6	T4	
C	0.24	6	T3	
C	0.23	6	T5	
D	0.22	6	T1	
E	0.20	6	T2	

Table B11: ANOVA (Fuel Consumption)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	111.59	8.58	17.33	<.0001
Error	22	10.90	0.49		
Corrected Total	35	122.49			

R-Square	Coeff Var	Root MSE	FUELCONSUMPTION Mean
0.911017	7.019797	0.703887	10.02718

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	5	109.42	21.89	44.17	<.0001
HYBRID	1	0.15	0.15	0.31	0.58
TREAT*HYBRID	5	0.61	0.12	0.25	0.94
REP	2	1.40	0.70	1.42	0.26

Contrast analysis for different furrow openers and Relay Seeders used

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
TREAT LEVEL T1 T2, T3 VS T4, T5, T6	1	9.16	9.16	18.50	0.0003
TREAT LEVEL T1 T4 VS. T2 T5	1	85.95	85.95	173.48	<.0001
TREAT LEVEL T1 T4 VS. T3 T6	1	61.80	61.80	124.74	<.0001
TREAT LEVEL T2 T5 VS. T3 T6	1	1.99	1.99	4.01	0.0577

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.49
Critical Value of t	2.07
Least Significant Difference	0.84

Means with the same letter are not significantly different.			
t Grouping	Mean	N	TREAT
A	12.72	6	T4
A	12.00	6	T1
B	9.68	6	T6
C	9.19	6	T5
C	8.62	6	T3
D	7.95	6	T2

Table B12: REGRESSION ANALYSIS (fuel consumption v/s power required)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	398.91	398.91	2480.92	<.0001
Error	9	1.44714	0.16		
Corrected Total	10	400.36			

R-Square	Coeff Var	Root MSE	Dependent Mean
0.9964	2.6973	0.40099	14.866

Parameter Estimates					
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > t
Intercept	1	-2.01386	0.359	-5.60	0.0003
FC	1	4.00869	0.080	49.81	<.0001

Table B13: ANOVA (Power Required)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	134.7720222	10.3670786	26.64	<.0001
Error	22	8.5628155	0.3892189		
Corrected Total	35	143.3348377			

R-Square	Coeff Var	Root MSE	POWER_REQUIRED Mean
0.940260	8.466549	0.623874	7.368694

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	5	131.0758760	26.2151752	67.35	<.0001
HYBRID	1	0.5401270	0.5401270	1.39	0.2514
TREAT*HYBRID	5	0.7700979	0.1540196	0.40	0.8464
REP	2	2.3859213	1.1929606	3.07	0.0670

Contrast analysis for different furrow openers and Relay Seeders used

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
TREAT LEVEL T1 T2, T3 VS T4, T5, T6	1	36.96558934	36.96558934	94.97	<.0001
TREAT LEVEL T1 T4 VS. T2 T5	1	93.70468647	93.70468647	240.75	<.0001
TREAT LEVEL T1 T4 VS. T3 T6	1	28.63813995	28.63813995	73.58	<.0001
TREAT LEVEL T2 T5 VS. T3 T6	1	18.73726817	18.73726817	48.14	<.0001

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.389219
Critical Value of t	2.07387
Least Significant Difference	0.747

Means with the same letter are not significantly different.			
t Grouping	Mean	N	TREAT
A	10.4064	6	T4
B	8.4221	6	T1
B	8.2083	6	T6
C	6.5314	6	T5
C	6.2507	6	T3
D	4.3933	6	T2

Table B14: ANOVA (Cotton bolls damaged)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	80747.4881	6211.3452	3.27	0.0070
Error	22	41757.3902	1898.0632		
Corrected Total	35	122504.8783			

R-Square	Coeff Var	Root MSE	DBOLLS Mean
0.659137	29.07831	43.56677	149.8257

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	5	72797.22535	14559.44507	7.67	0.0003
HYBRID	1	557.93311	557.93311	0.29	0.5932
TREAT*HYBRID	5	3950.81537	790.16307	0.42	0.8323
REP	2	3441.51430	1720.75715	0.91	0.4185

Contrast analysis for different furrow openers and Relay Seeders used

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
TREAT LEVEL T1 T2, T3 VS T4, T5, T6	1	51055.18351	51055.18351	26.90	<.0001
TREAT LEVEL T1 T4 VS. T2 T5	1	6.33796	6.33796	0.00	0.9544
TREAT LEVEL T1 T4 VS. T3 T6	1	13518.56076	13518.56076	7.12	0.0140
TREAT LEVEL T2 T5 VS. T3 T6	1	14110.32212	14110.32212	7.43	0.0123

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	1898.063
Critical Value of t	2.07387
Least Significant Difference	52.165

Means with the same letter are not significantly different.			
t Grouping	Mean	N	TREAT
A	214.28	6	T1
B	191.83	6	T2
B	156.34	6	T3
B	140.83	6	T5
D	116.33	6	T4
D	79.33	6	T6

Table B15: ANOVA (Percent cotton bolls damaged)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	5.98106882	0.46008222	3.80	0.0029
Error	22	2.66552640	0.12116029		
Corrected Total	35	8.64659523			

R-Square	Coeff Var	Root MSE	PERCENT Mean
0.691725	29.11005	0.348081	1.195741

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	5	5.47556843	1.09511369	9.04	<.0001
HYBRID	1	0.02984686	0.02984686	0.25	0.6246
TREAT*HYBRID	5	0.22998801	0.04599760	0.38	0.8573
REP	2	0.24566552	0.12283276	1.01	0.3792

Contrast analysis for different furrow openers and Relay Seeders used

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
TREAT LEVEL T1 T2, T3 VS T4, T5, T6	1	4.13387880	4.13387880	34.12	<.0001
TREAT LEVEL T1 T4 VS. T2 T5	1	0.00062210	0.00062210	0.01	0.9435
TREAT LEVEL T1 T4 VS. T3 T6	1	0.85668011	0.85668011	7.07	0.0143
TREAT LEVEL T2 T5 VS. T3 T6	1	0.81113134	0.81113134	6.69	0.0168

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.12116
Critical Value of t	2.07387
Least Significant Difference	0.4168

Means with the same letter are not significantly different.				
t Grouping	Mean	N	TREAT	
	A	1.7654	6	T1
B	A	1.5602	6	T2
B	C	1.2782	6	T3
	C	1.0696	6	T5
D	C	0.8847	6	T4
D		0.6163	6	T6

Table B16: ANOVA (Seed cotton lost)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	574.35	44.18	3.32	0.0064
Error	22	292.52	13.29		
Corrected Total	35	866.87			

R-Square	Coeff Var	Root MSE	SEEDCOTTON1 Mean
0.66	40.70	3.64	8.95

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	5	481.29	96.25	7.24	0.0004
HYBRID	1	9.11	9.11	0.69	0.4166
TREAT*HYBRID	5	24.13	4.82	0.36	0.8682
REP	2	59.80	29.90	2.25	0.1292

Contrast analysis for different furrow openers and Relay Seeders used

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
TREAT LEVEL T1 T2, T3 VS T4, T5, T6	1	210.45	210.45	15.83	0.0006
TREAT LEVEL T1 T4 VS. T2 T5	1	36.77	36.77	2.77	0.1105
TREAT LEVEL T1 T4 VS. T3 T6	1	78.59	78.59	5.91	0.0237
TREAT LEVEL T2 T5 VS. T3 T6	1	222.89	222.89	16.76	0.0005

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	13.2966 3
Critical Value of t	2.07387
Least Significant Difference	4.3661

Means with the same letter are not significantly different.			
t Grouping	Mean	N	TREAT
A	15.564	6	T2
B	11.843	6	T1
B	8.068	6	T5
C	6.838	6	T4
C	6.724	6	T3
C	4.718	6	T6

Table B17: ANOVA (Weeds/plant residues accumulated)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	2379.896354	183.068950	4.89	0.0006
Error	22	822.987333	37.408515		
Corrected Total	35	3202.883687			

R-Square	Coeff Var	Root MSE	WEEDACCUMLATION Mean
0.743048	29.73202	6.116250	20.57126

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	5	2209.385792	441.877158	11.81	<.0001
HYBRID	1	12.195694	12.195694	0.33	0.5738
TREAT*HYBRID	5	70.690004	14.138001	0.38	0.8584
REP	2	87.624864	43.812432	1.17	0.3286

Contrast analysis for different furrow openers and Relay Seeders used

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
TREAT LEVEL T1 T2, T3 VS T4, T5, T6	1	1820.518401	1820.518401	48.67	<.0001
TREAT LEVEL T1 T4 VS. T2 T5	1	0.209795	0.209795	0.01	0.9410
TREAT LEVEL T1 T4 VS. T3 T6	1	253.267353	253.267353	6.77	0.0163
TREAT LEVEL T2 T5 VS. T3 T6	1	238.898493	238.898493	6.39	0.0192

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	37.40
Critical Value of t	2.07
Least Significant Difference	7.32

Means with the same letter are not significantly different.				
t Grouping	Mean	N	TREAT	
	A	31.639	6	T1
B	A	28.325	6	T2
B	C	23.084	6	T3
D	C	16.900	6	T5
D	E	13.960	6	T4
	E	9.520	6	T6

Table B18: ANOVA (Establishment count)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	58854.15	3097.58	34.41	<.0001
Error	34	3060.58	90.017		
Corrected Total	53	61914.73			

R-Square	Coeff Var	Root MSE	GERMINATION Mean
0.950568	6.46	9.48	146.72

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CWSYSTEM	8	57199.42	7149.92	79.43	<.0001
HYBRID	1	10.33	10.33	0.11	0.7368
CWSYSTEM*HYBRID	8	600.15	75.01	0.83	0.5798
REP	2	1044.24	522.12	5.80	0.0068

Contrast analysis for different furrow openers and Relay Seeders used

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
FARMER PRACTICE VS ALL	1	3330.67	3330.67	37.00	<.0001
FARMER PRACTICE VS RS	1	6182.41	6182.41	68.68	<.0001
67.5 CM VS 101 CM COTTON SPACING	1	4.01	4.01	0.04	0.8340
12-ROW RS VS 15-ROW RELAY SEEDER)	1	0.19	0.19	0.00	0.9633
STR VS ZTT	1	11682.42	11682.42	129.78	<.0001
STR VS ZTDD	1	8205.72	8205.72	91.16	<.0001
ZTT VS ZTDD	1	39470.05	39470.05	438.47	<.0001

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	34
Error Mean Square	90.017
Critical Value of t	2.03
Least Significant Difference	11.13

Means with the same letter are not significantly different.			
t Grouping	Mean	N	CWSYSTEM
	A	179.767	6 T9
B	A	174.370	6 T4
B	A	171.617	6 T8
B	A	168.938	6 T1
B		167.492	6 T5
	C	137.432	6 T2
	C	135.864	6 T6
	D	97.656	6 T3
	D	87.389	6 T7

Table B19: ANOVA (Spike density)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	205086.05	10794.00	10.45	<.0001
Error	34	35112.68	1032.72		
Corrected Total	53	240198.74			

R-Square	Coeff Var	Root MSE	SPIKEDENSITY Mean
0.853	10.93	32.13	293.84

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CWSYSTEM	8	192288.52	24036.06	23.27	<.0001
HYBRID	1	2572.81	2572.81	2.49	0.1237
CWSYSTEM*HYBRID	8	6752.25	844.03	0.82	0.5927
REP	2	3472.46	1736.23	1.68	0.2013

Contrast analysis for different furrow openers and Relay Seeders used

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
FARMER PRACTICE VS ALL	1	13458.23	13458.23	13.03	0.0010
FARMER PRACTICE VS RS	1	24539.17	24539.17	23.76	<.0001
67.5 CM VS 101 CM COTTON SPACING	1	18447.71	18447.71	17.86	0.0002
12-ROW RS VS 15-ROW RELAY SEEDER)	1	22093.35	22093.35	21.39	<.0001
STR VS ZTT	1	60840.76	60840.76	58.91	<.0001
STR VS ZTDD	1	743.62	743.62	0.72	0.4021
ZTT VS ZTDD	1	48131.88	48131.88	46.61	<.0001

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	34
Error Mean Square	1032.72
Critical Value of t	2.032
Least Significant Difference	37.70

Means with the same letter are not significantly different.				
t Grouping	Mean	N	CWSYSTEM	
A	354.68	6	T5	
A	348.89	6	T4	
A	340.69	6	T8	
A	338.50	6	T1	
B	320.54	6	T6	
B	292.85	6	T2	
C	236.46	6	T9	
C	235.06	6	T3	
D	176.94	6	T7	

Table B20: ANOVA (Number of seeds per spike)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	263.92	13.89	3.95	0.0002
Error	34	119.56	3.51		
Corrected Total	53	383.49			

R-Square	Coeff Var	Root MSE	NUMBER Mean
0.68	3.65	1.87	51.30

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CWSYSTEM	8	179.37	22.42	6.38	<.0001
HYBRID	1	5.64	5.64	1.60	0.2139
CWSYSTEM*HYBRID	8	41.92	5.24	1.49	0.1973
REP	2	36.99	18.49	5.26	0.0102

Contrast analysis for different furrow openers and Relay Seeders used

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
FARMER PRACTICE VS ALL	1	13.083	13.08	3.72	0.0621
FARMER PRACTICE VS RS	1	6.4437	6.44	1.83	0.1848
67.5 CM VS 101 CM COTTON SPACING	1	22.31	22.31	6.35	0.0166
12-ROW RS VS 15-ROW RELAY SEEDER)	1	28.78	28.78	8.19	0.0072
STR VS ZTT	1	2.60	2.60	0.74	0.3957
STR VS ZTDD	1	29.38	29.38	8.36	0.0067
ZTT VS ZTDD	1	49.47	49.47	14.07	0.0007

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	34
Error Mean Square	3.51
Critical Value of t	2.03
Least Significant Difference	2.2

Means with the same letter are not significantly different.				
t Grouping	Mean	N	CWSYSTEM	
A	52.862	6	T4	
A	52.772	6	T8	
A	52.334	6	T7	
B	52.078	6	T3	
B	51.958	6	T5	
B	51.734	6	T2	
B	51.361	6	T6	
B	49.910	6	T1	
C	46.711	6	T9	

Table B21: ANOVA (Test weight)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	186.62	9.82	9.09	<.0001
Error	34	36.75	1.08		
Corrected Total	53	223.38			

R-Square	Coeff Var	Root MSE	TESTWT Mean
0.83	2.32	1.03	44.72

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CWSYSTEM	8	176.70	22.08	20.43	<.0001
HYBRID	1	0.005	0.005	0.01	0.9429
CWSYSTEM*HYBRID	8	5.92	0.74	0.68	0.7018
REP	2	3.99	1.99	1.85	0.1732

Contrast analysis for different furrow openers and Relay Seeders used

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
FARMER PRACTICE VS ALL	1	0.21	0.21	0.20	0.6581
FARMER PRACTICE VS RS	1	0.11	0.11	0.10	0.7514
67.5 CM VS 101 CM COTTON SPACING	1	24.66	24.66	22.82	<.0001
12-ROW RS VS 15-ROW RELAY SEEDER)	1	35.82	35.82	33.14	<.0001
STR VS ZTT	1	2.88	2.88	2.67	0.1117
STR VS ZTDD	1	40.96	40.96	37.89	<.0001
ZTT VS ZTDD	1	65.57	65.57	60.66	<.0001

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	34
Error Mean Square	1.08
Critical Value of t	2.03
Least Significant Difference	1.21

Means with the same letter are not significantly different.						
t Grouping				Mean	N	CWSYSTEM
		A		46.17	6	T7
B		A		46.00	6	T3
B		A	C	45.70	6	T5
B	D	A	C	45.54	6	T2
B	D	A	C	45.23	6	T6
B	D		C	44.89	6	T1
	D		C	44.66	6	T8
	D			44.40	6	T4
		E		39.85	6	T9

Table B22: ANOVA (Wheat yield)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	28.32	1.49	9.34	<.0001
Error	34	5.42	0.16		
Corrected Total	53	33.75			

R-Square	Coeff Var	Root MSE	WYIELD Mean
0.84	8.68	0.39	4.60

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CWSYSTEM	8	26.45	3.31	20.72	<.0001
HYBRID	1	0.0002	0.00023	0.00	0.9698
CWSYSTEM*HYBRID	8	0.47	0.059	0.37	0.9298
REP	2	1.40	0.70	4.39	0.0201

Contrast analysis for different furrow openers and Relay Seeders used

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
FARMER PRACTICE VS ALL	1	2.11	2.11	13.25	0.0009
FARMER PRACTICE VS RS	1	3.18	3.19	19.98	<.0001
67.5 CM VS 101 CM COTTON SPACING	1	0.26	0.27	1.68	0.2033
12-ROW RS VS 15-ROW RELAY SEEDER)	1	0.55	0.56	3.49	0.0703
STR VS ZTT	1	12.96	12.97	81.26	<.0001
STR VS ZTDD	1	0.05	0.053	0.33	0.5696
ZTT VS ZTDD	1	11.36	11.369	71.23	<.0001

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	34
Error Mean Square	0.16
Critical Value of t	2.03
Least Significant Difference	0.47

Means with the same letter are not significantly different.			
t Grouping	Mean	N	CWSYSTEM
A	5.35	6	T5
A	5.16	6	T1
A	5.14	6	T6
B	5.08	6	T8
B	4.93	6	T4
B	4.64	6	T2
C	4.25	6	T9
D	3.49	6	T3
D	3.35	6	T7

Table B23: TTEST (Grain yield at on-farm trials)

N	Mean	Std Dev	Std Err	Minimum	Maximum
5	0.2660	0.1474	0.0659	0.1000	0.4500

Mean	95% CL Mean	Std Dev	95% CL Std Dev
0.2660	0.0830	0.4490	0.4236

DF	t Value	Pr > t
4	4.03	0.0157

Table B24: ANOVA (Economics)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	2031054404	507763601	13.97	0.0004
Error	10	363385109	36338511		
Corrected Total	14	2394439514			

R-Square	Coeff Var	Root MSE	INCOME Mean
0.848238	7.535568	6028.143	79995.87

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TREAT	4	2031054404	507763601	13.97	0.0004

Contrast analysis for different furrow openers and Relay Seeders used

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
TREAT LEVEL T2-T4, V/S T1 RELAY SEEDING V/S FARMER PRACTICE	1	1040319620	1040319620	28.63	0.0003
TREAT LEVEL T2-T4, V/S T3-T5 RELAY SEEDING V/S BROADCASTING	1	1664421625	1664421625	45.80	<.0001
TREAT LEVEL T1, V/S T3-T5 FARMER PRACTICE V/S BROADCASTING	1	1117015	1117015	0.03	0.8643

Means comparison for factor using LSD test

Alpha	0.05
Error Degrees of Freedom	10
Error Mean Square	3633851 1
Critical Value of t	2.22814
Least Significant Difference	10967

Means with the same letter are not significantly different.			
t Grouping	Mean	N	TREAT
A	97504	3	T4
A	90454	3	T2
B	71172	3	T1
B	70565	3	T5
B	70284	3	T3

Submitted Research Papers or Articles

S No	Title of Research Paper	Name of Authors	Name of Journal	NAAS Rating	Current Status
1	Development and feasibility of innovative relay seeders for seeding wheat into standing cotton using high clearance tractor in cotton-wheat system	Manpreet Singh, Jaskarn Mahal, Harminder Sidhu, Gursahib Manes, M L Jat, Yadvinder Singh	Applied Engineering in Agriculture	6.49	Submitted
2	Evaluation of furrow openers for relay seeding wheat in cotton under two plant geometries: wheat emergence, productivity and profitability of cotton-wheat system in North-West India	Manpreet Singh, Harminder Singh Sidhu, Jaskarn S Mahal, Gursahib S Manes, M L Jat, Amrit K Mahal, Parvinder Singh, Yadvinder Singh,	Experimental Agriculture	7.07	Submitted
3	Theoretical analysis of stability of High Clearance Tractor for moving in inclined terrain	Manpreet Singh, Jaskarn S Mahal, Gursahib S Manes,	Agricultural Research	5.88	Submitted



Manpreet Singh - FMPE <msbham@pau.edu>

Manuscript submitted - ASABE ASE-11251-2015

1 message

mccann@asabe.org <mccann@asabe.org>

Sun, Mar 1, 2015 at 10:27 PM

To: msbham@pau.edu

Cc: msbham@pau.edu, jsmahal@pau.edu, H.Sidhu@cgiar.org, manesgs@pau.edu, m.jat@cgiar.org, yadvinder16@rediffmail.com

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DEVELOPMENT AND FEASIBILITY OF INNOVATIVE RELAY SEEDERS FOR SEEDING WHEAT INTO STANDING COTTON USING HIGH CLEARANCE TRACTOR IN COTTON-WHEAT SYSTEM

Journal:	American Society of Agricultural and Biological Engineers
Manuscript ID:	MS-11251-2015.R1
Journal Name:	Applied Engineering in Agriculture
Manuscript Type:	Full-length article
Date Submitted by the Author:	n/a
Complete List of Authors:	Singh, Manpreet; Punjab Agricultural University, Farm Machinery & Power Engineering Mahal, Jaskarn; Punjab Agricultural University, Farm Machinery & Power Engineering Sidhu, Harminder; Borlaug Institute for South Asia (CIMMYT-BISA). Manes, Gursahib; Punjab Agricultural University, Farm Machinery & Power Engineering Jait, M.; International centre for Maize and Wheat Improvement (CIMMYT), Global Conservation Agriculture Program Singh, Yadvinder; Borlaug Institute for South Asia (CIMMYT-BISA).
Keywords:	High clearance tractor, Relay seeder, Relay wheat, Cotton-wheat system, furrow openers
Abstract:	Cotton-wheat is important cropping system in South Asia and occupies 4.19 M ha. Wheat planting after cotton is usually delayed due to late pickings and time needed for seedbed preparation, resulting in low wheat yield. For timely sowing of wheat seed in standing cotton is adopted on a small scale, however, it has limitations of poor germination and low fertilizer use efficiency. Therefore, to study feasibility of relay seeding of wheat in cotton, a prototype of high clearance platform (115 cm from ground) for tractor was developed to facilitate the movement of tractor in standing cotton. Two innovative relay seeders (RS) (suitable for 67.5 and 101 cm row spacing) with three types of furrow openers (strip till rotor - STR), zero till inverted T-type - ZTT and zero till double disc - ZTDD) were developed and evaluated for their performance under two Bt cotton genotypes. The forward speed of travel of ZTDD openers was 9.3 and 16.6 % more compared with STR and ZTT openers respectively. STR openers consumed more fuel (12.36 l ha ⁻¹) than ZTT (8.57 l ha ⁻¹) and ZTDD openers (9.15 l ha ⁻¹). The field capacity for 12 rows and 15 rows RS was 0.22 and 0.25 ha h ⁻¹ , respectively. The average power consumption for operating the three types of furrow openers was 6.4 hp and 8.4 hp for 12-row and 15-row RS, respectively. Number of cotton bolls detached from plants due to operation of tractor mounted RS was significantly lower in

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101 cm cotton row spacing compared with 67.5 cm row spacing. Overall loss of cotton bolls due to the movement of tractor and relay seeders was under 2%. The average number of bolls detached from the plant was about 29% lesser for ZTDD furrow openers compared with STR and ZTT openers. Germination count of relay seeded wheat with STR and ZTDD furrow openers was 23 and 26% more compared with ZTT openers, respectively. This study demonstrates that seeding of wheat in standing cotton is feasible with 4-wheel high clearance tractor driven innovative RS.

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1 DEVELOPMENT AND FEASIBILITY OF INNOVATIVE RELAY
 2 SEEDERS FOR SEEDING WHEAT INTO STANDING COTTON
 3 USING HIGH CLEARANCE TRACTOR IN COTTON-WHEAT
 4 SYSTEM

5 **Manpreet-Singh, J. S. Mahal, H. S. Sidhu, G. S. Manes, M. L. Jat, Yadvinder-Singh**

6 The authors are Manpreet-Singh, PhD student, J. S. Mahal, Senior Research Engineer-care-Dean, College of Agricultural Engineering
 7 and Technology, Punjab Agricultural University, Ludhiana, Punjab, India, H. S. Sidhu, Senior Agricultural Engineer, Borlaug Institute for
 8 South Asia (CIMMYT-ISA), Ludhiana, Punjab, India, G. S. Manes, Senior Research Engineer-care-Head, Department of farm machinery
 9 and Power Engineering, Punjab Agricultural University, Ludhiana, Punjab, India, M. L. Jat, Senior Cropping System Agronomist,
 10 International Centre for Maize and Wheat Improvement (CIMMYT), NASC Complex, Patna, New Delhi, India, and Yadvinder-Singh,
 11 DNSA fellow, Department of Soils, Punjab Agricultural University, Ludhiana, Punjab, India. Corresponding author: Manpreet-Singh, PhD
 12 student, Punjab Agricultural University, Ludhiana, Punjab, India; phone: +91-8146333222; e-mail: msbham@pau.ac.in

13 **ABSTRACT.**

14 *Cotton-wheat is important cropping system in South Asia and occupies 4.19 M ha. Wheat planting after cotton*
 15 *is usually delayed due to late pickings and time needed for seedbed preparation, resulting in low wheat yield.*
 16 *For timely sowing of wheat seed in standing cotton is adopted on a small scale, however, it has limitations of*
 17 *poor germination and low fertilizer use efficiency. Therefore, to study feasibility of relay seeding of wheat in*
 18 *cotton, a prototype of high clearance platform (110 cm from ground) for tractor was developed to facilitate the*
 19 *movement of tractor in standing cotton. Two innovative relay seeders (RS) (suitable for 67.5 and 101 cm row*
 20 *spacing) with three types of furrow openers (strip till rotor - STR), zero till inverted T-type - ZTT and zero till*
 21 *double disc - ZTDD) were developed and evaluated for their performance under two cotton genotypes. The*
 22 *forward speed of travel of ZTDD openers was 9.3 and 16.6 % more compared with STR and ZTT openers*
 23 *respectively. STR openers consumed more fuel (12.36 l ha⁻¹) than ZTT (8.57 l ha⁻¹) and ZTDD openers (9.15 l*
 24 *ha⁻¹). The field capacity for 12-row and 15-row RS was 0.22 and 0.25 ha h⁻¹, respectively. The average power*
 25 *consumption for operating the three types of furrow openers was 6.4 hp and 8.4 hp for 12- row and 15-row RS,*
 26 *respectively. Number of cotton bolls detached from plants due to operation of tractor mounted RS was*
 27 *significantly lower in 101 cm cotton row spacing compared with 67.5 cm row spacing. Overall loss of cotton*
 28 *bolls due to the movement of tractor and RSs was under 2%. The average number of bolls detached from the*
 29 *plant was about 29% lesser for ZTDD furrow openers compared with STR and ZTT openers. Germination count*
 30 *of relay seeded wheat with STR and ZTDD furrow openers was 23 and 26% more compared with ZTT openers,*

31 *respectively. This study demonstrates that seeding of wheat in standing cotton is feasible with 4-wheel high*
32 *clearance tractor driven innovative RS.*

33 **Keywords.** *Cotton-wheat system, Furrow openers, High clearance tractor, Relay wheat, Relay seeder*

34 INTRODUCTION

35 Cotton (*Gossypiumhirsutum* L.)-wheat (*Triticumaestivum* L.) (CW) is a well-established crop production system
36 of north-western (NW) plains of the Indian sub-continent and adjoining areas of the Punjab-Sindh provinces of
37 Pakistan. The cotton-wheat system covers 4.19 M ha in South Asia dominant in NW Indo-Gangetic Plain in
38 Pakistan and western India (Yadvinder-Singh et al. 2014). About 90% of the cotton area in Punjab, Haryana,
39 and North Rajasthan in India and 80% of the cotton area in Pakistan is under cotton-wheat cropping system
40 (Mayee et al. 2008). The normal time of wheat sowing in the region is last week of October to first fortnight of
41 November. Delay in wheat sowing after the normal sowing window causes significant reduction in its
42 productivity (Bajwa, 2011). The sowing of wheat after 20th November in this region reduces the productivity at
43 the rate of 1.0-1.5 % day⁻¹ (Nasrullah et al.2010). On an average, productivity of wheat in CW system is about
44 3.2 tha⁻¹against 4.7 tha⁻¹ in rice-wheat system in Indian Punjab (Buttar et al. 2013).Wheat planting after cotton
45 harvest is often delayed due to late pickings of cotton and subsequent tillage operations required for wheat
46 planting. This is a system inbuilt problem and farmers has to sacrifice the yield losses of either of the crops in
47 the system and cotton being a commercial crop, the losses are to be borne by wheat. The practice of relay
48 seeding involves planting a second crop after an initial crop has reached maturity, but before it is ready for
49 harvest. (Coolman and Hoyt, 1993). Delay in wheat sowing without disturbing the cotton crop can be avoided
50 by relay seeding of wheat by manual broadcasting in standing cotton (Khan and Khaliq, 2005).However, manual
51 broadcasting of wheat seed in cotton may lead to poor crop establishment due to poor seed-soil contact.
52 Presently none of the available traditional planters are capable of seeding wheat in standing cotton crop. A
53 three- row self-propelled walk behind type relay seeder (RS) was developed for seeding 3 rows of wheat in two
54 adjacent cotton rows (Buttar et al. 2013). The yield gains in wheat with RS were12-41% higher than the
55 conventional crop planted after cotton. However, adoption of the three-row RS for wheat planting by the
56 relatively large holding farmers of north-western IGP of South Asia is very limited, because of its low capacity
57 (0.6 ha day⁻¹) and drudgery. Hence, there is a need of a 4-wheel tractor operated high clearance RS which can
58 plant wheat between in four cotton rows in a single pass. For this purpose study was undertaken to develop, (a)
59 platform for a high clearance tractor and (b) RS for high clearance tractor for satisfactory seeding of wheat in
60 standing cotton with minimal damage to the crop. This paper describes the development and evaluation of two

61 types of relay seeding machines for high clearance tractor suitable for two planting geometries and two cotton
62 genotypes with suitable types of seed row openers in terms of their operational parameters, crop damage and
63 wheat establishment.

64 MATERIAL AND METHODS

65 DEVELOPMENT OF HIGH CLEARANCE PLATFORM OF THE TRACTOR

66 The traditional four wheel tractors with ground clearance of around 45 to 50 cm cannot move in the standing
67 cotton field as the plants are about 100 to 130 cm tall. To address this issue, a high clearance platform
68 attachment for a four-wheel tractor was developed through collaborative research of International Centre of
69 Maize and Wheat Improvement (CIMMYT), Borlaug Institute for South Asia (BISA), India, and Punjab
70 Agricultural University, (PAU) Ludhiana, India and was got fabricated from a local machinery manufacturer,
71 Rajar Agricultural works, Mullampur, Ludhiana (Punjab), India. This platform increased the ground clearance of
72 the tractor to 110 cm to make the tractor move easily above the standing cotton. The track width of mounted
73 tractor was increased by 1.5 times the standard one (from 135 cm to 202 cm), which enables high clearance
74 tractor to move in both 67.5 and 101 cm row geometries of cotton and increase the stability of the tractor. Any
75 traditional tractor (ground clearance ~45 cm) can be converted to high clearance tractor by mounting on high
76 clearance platform in 4 to 6 hours. To determine the stability of the tractor, centre of gravity (CG) of the normal
77 and high clearance tractor was calculated by standard weighing technique, (John et al. 1989).

78 DEVELOPMENT OF RELAY SEEDER

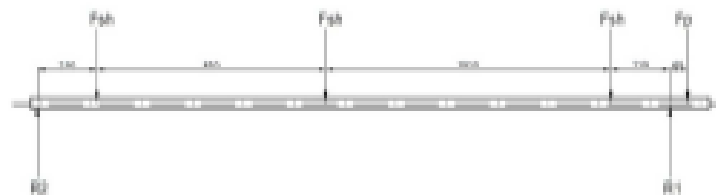
79 The functional requirements of the RS are; (1) main frame of the RS should have high clearance so that it can
80 move above the 115- 120 cm high cotton crop, (2) it should be able to drill wheat seed and fertilizer directly in
81 between the two rows of cotton, (3) should cause minimal damage to standing cotton in respect of loss of
82 cotton balls, (4) its width should be more than the high clearance tractor track width of 202cm, and (5) it should
83 be able to sow into 67.5 cm and 101 cm row to row spacing of the cotton, which are common among the farmers
84 in the region.

85 DESIGN CONSIDERATION FOR DIFFERENT COMPONENTS OF RS

86 The following design load considerations for different components of RS such as opener tines; sub-frame;
87 chains to drive STR openers, power transmission shafts 'A', 'B' and 'C' and selection of V-belts were taken,
88 figure 3.

- 89 1. Draft of zero till tine, $d_p = 147N$ (Kepner et al. 1987; Sharma & Mukesh 2008).

- 90 2. Force/draft acting on sub-frame of 15-row RS having 5 tines mounted on it, $D_s = 5 \times d_f$ N
- 91 3. Power required at PTO for 1 cm of tilling width = 0.3 kW (Kapur et al. 1987).
- 92 Design power for V-belt selection, kW = 0.3x number of STR openers x width of STR blade.
- 93 4. Design power for chain and sprocket assembly for operating 5 STR openers = 0.3x number of STR
- 94 openers x width of STR blade.
- 95 5. Load on shaft 'B' due to chain assemblies, $F_{CB} = F + 2 k_f w C$, where F = tension on tighter side of
- 96 chain (N), k_f = Load factor for chain, w = weight of chain m^{-1} length of chain, C = Centre distance
- 97 between shafts 'B' and STR shaft, Load on shaft B due to v-belt pulley $F_p = F_1 + F_2$, where F_1 and F_2 , are
- 98 belt tensions on both sides, Figure 1 (Sharma & Aggarwal 2011). Shaft 'B' was designed for the
- 99 bending and torsional stresses. Similar procedure was followed to design shaft 'A' and different
- 100 component of 12 row RS.



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Figure 1. Design forces acting on the shaft due to v-belt pulley and chains for driving strip till rotor openers

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FABRICATION OF RELAY SEEDERS

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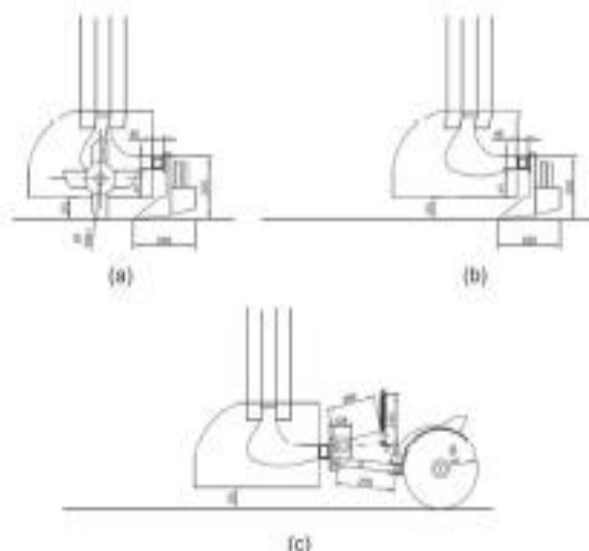
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RSs with 12 and 15 rows for seeding wheat into 67.5 cm and 101 cm row spacing of cotton were developed through collaborative research of CIMMYT-BISA and Department of Farm Machinery and Power Engineering, PAU, Ludhiana and was got fabricated from M/s Jagajit Industries, Cheema Mandi, Mansa (Punjab), India. The 67.5 cm is the standard recommended cotton row geometry for the region. Wider row spacings of 90 cm and 101 cm for different *Bt*-cotton hybrids are also being evaluated under All India (ICAR) Coordinated Cotton Improvement Research Project, (AICCIP, 2014). The 101 cm cotton row geometry was selected as it suits to the track with (202 cm) of high clearance tractor. Three types of furrow openers (zero-till inverted T-type - ZTT, zero till double disc - ZTDD and strip till rotor- STR) were fabricated and evaluated for seeding of wheat, (fig. 2). STR openers make a narrow strip (2.5–3.5 cm) using steel blades mounted on a rotor in front of each zero till furrow opener to facilitate placement of seed and fertilizer. The ZTT opener is a zero till furrow opener which opens the furrow (width 2-3 cm) and places both seed and fertilizer in the soil. The ZTDD furrow opener has two spring mounted discs to open furrow for placement of seed and fertilizer. The depth of seeding is controlled by the spring tension whereas, in case of SRT and ZTT furrow openers separate depth control wheels were

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Figure 2. Different type of furrow openers tested with RS; (a) STR, (b) ZTT and (c) ZTDD

120 mounted on the frame of RS. The main frame of RSs has a ground clearance of 114 cm enabling its movement
 121 above the standing cotton with minimal interference with the plants. The 12-row RS consists of 4 seeding units
 122 (36 cm wide) having 3 metering units mounted on each unit and thus covering 4 rows of cotton crop in a single
 123 pass. The seeding unit of 12-row RS consists of a toolbar with 3 furrow openers mounted at 18 cm apart.
 124 Similarly, 15-row RS consists of 3 seeding units (72 cm wide) having 5 metering units and it covers 3 rows of
 125 cotton crop in a single pass. The seeding unit of 15-row RS consists of a toolbar with 5 furrow openers mounted
 126 18 cm apart. Brief specifications of 12-row and 15-row RSs are included in Table 1.

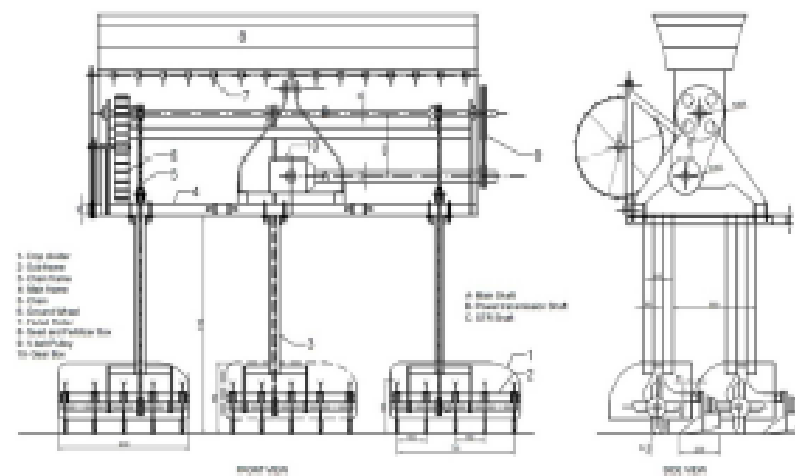
127 Table 1. Brief specifications of the 12-row and 15-row relay seeders (RS)

S/N	Description or component	12-row RS	15-row RS
1	Type of implement	Tractor mounted (Three point hitch)	Tractor mounted (Three point hitch)
2	Power required (horse power)	35 or above	35 or above
3	Ground clearance of machine (cm)	114	114
4	Working width (cm)	270	303
5	Gear box	Bevel crown wheel and pinion	Bevel crown wheel and pinion
Strip Tillage Unit			
6	Type of rotor drive	Chain drive	Chain drive
7	Number of blades	4	4
8	Type of blade	Knife	Knife
9	Number of flanges	12	15
Furrow opener			
10	Number of tool bars and mounting on main frame	4; Alternate on front and back bar of main frame	3; Alternate on front and back bar of main frame
11	Number of furrow openers	12; 3 on each tool bar	15; 5 on the each tool bar
12	Type of furrow openers	*STR, ZTT, ZTDD	STR, ZTT, ZTDD
13	Number of crop dividers	4	3
14	Row spacing (cm)	18 cm between 3 openers of tool bar and 32 cm between adjacent set of openers of adjacent tool bar	18 cm between 5 openers of tool bar and 29 cm between adjacent set of openers of adjacent tool bar
15	Seed metering device	Flatbed feed rollers	Flatbed feed rollers
16	Fertiliser metering device	Flatbed feed rollers	Flatbed feed rollers

128 * STR- strip till, ZTT-zero till row, ZTDD-zero till double disc opener

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129 The width of unit for 12 and 15 -row RS is 45 and 80 cm at bottom and 5 cm at the top. The main frame of RS
 130 moves above the cotton plant and seeding assemblies move between the rows of cotton. Four seeding units for
 131 12-row seeder were staggered on to main frame of RS (alternate 2 on front tool bar and remaining 2 on rear tool
 132 bar of the machine) to provide more open space to cotton plant during machine operation. Similarly, 3 seeding
 133 units (2 on front tool bar and one in center of rear tool bar) were clamped alternately to the both bars of the main
 134 frame of 15-row RS (fig3).



135

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Figure 3. Front and side view of 15-row relay seeder with strip till rotor furrow openers

137 The traditional ground wheel for metering the seed and fertilizer was modified for taking power from the tractor
 138 rear wheel. This arrangement was designed to check obstruction of cotton plants with RS components. The
 139 weight of the ground wheel develops sufficient friction among the power wheel and tractor rear wheel to rotate
 140 the power wheel, which transmits power to seed and fertilizer metering mechanisms. The power wheel is
 141 hinged to main frame of the RS and it engages with rear wheel of tractor. A chain is attached with the ground
 142 wheel and machine frame and its length is adjusted so that the power wheel got disengaged from the rear wheel
 143 of tractor as and when the RS is lifted during turning by the operator. This arrangement checks the unnecessary
 144 dropping seed and fertilizer from the RS while sowing in the field. Two adjustable depth wheels were mounted
 145 on the main frame to adjust the working depth of machine while seeding wheat into standing cotton, in case of
 146 strip and zero tillage conditions. The depth of double disc openers is adjusted by the spring tension.

147 CROP DIVIDERS FOR RELAY SEEDERS AND TRACTOR

148 Shoe type crop dividers/lifters were fabricated and attached in front of seeding units and front wheel of tractor to
 149 avoid damage to cotton plants during seeding wheat into standing cotton. Crop dividers lift the logged cotton
 150 branches and place them above the tractor wheels to reduce the damage to the crop by high clearance tractor.

151 Four dividers with 45 cm bottom width and three dividers with 85 cm bottom width were fabricated and
 152 attached to the seeding units of 12-row and 15-row RS, respectively.

153 FEASIBILITY ANALYSIS OF RELAY SEEDERS

154 Replicated field experiment was conducted on a sandy loam soil (with pH 8.07 with 5.7 g kg⁻¹ organic carbon
 155 (Walkley and Black, 1934) during the year 2013–2014 at the research farm of the Borlaug Institute for South
 156 Asia (BISA) at Lodowal, (30° 59' N and 75° 44' E), Ludhiana (Punjab), India. After harvest of well-fertilized
 157 (120 kg N + 26 kg P+25 kg K ha⁻¹) wheat in April 2013, experimental field was irrigated and seed bed for
 158 cotton was prepared using one discing and two tine cultivators followed by planking. Experiment was laid out
 159 in a strip plot design with three replications. Treatments included two cotton hybrids (RCH 776 and MRC 7017)
 160 having different canopy cover and vigor in the main plots. The sub-plot treatments included 6 combinations of
 161 wheat sown with two types of RSs (for 67.5 and 101 cm cotton row spacing) with three types of relay seeding
 162 furrow openers (STR, ZTT and ZTDD) into standing cotton crop. For ease of movement of tractor and RSs, two
 163 cotton hybrids were planted in strips. The details of sub-plot treatments are provided in Table 2. The sub-plot
 164 size was 219 m² and 252 m² for 67.5 and 101 cm row spacing of cotton, respectively. An alley of 10 m was
 165 kept between the two replications as well as at head lands in order to facilitate free movement of the tractor and
 166 implements. Cotton was planted on 23 April, 2013.

167 Table 2. Sub-plot treatment details for comparative evaluation of 12-row and 15-row relay seeders (RS)

Treatment no.	*Treatment abbreviation	Treatment details
T1	12-row STR RS	12-row RS with strip tillage rotor furrow opener. Relay seeding was done after 1 st picking of cotton on 14 th November, 2013. Three rows of wheat at 18-cm apart were sown in 67.5 cm row spacing covering 4 rows of cotton.
T2	12-row ZTT RS	Same as for T1, except zero till inverted T-type furrow opener RS used for seeding wheat.
T3	12-row ZTDD RS	Same as for T1, except zero till double disc furrow opener RS used for seeding wheat.
T4	15-row STR RS	15-row RS with strip tillage in 101 cm row spacing. Five rows of wheat at 18-cm apart were seeded in between two rows of cotton and covering three rows of cotton. Other details are the same as in T1.
T5	15-row ZTT RS	Same as for T4, except RS with zero-till till inverted T-type furrow openers were used for seeding wheat.
T6	15-row ZTDD RS	Same as for T4, except RS with double disc furrow openers were used for seeding wheat.

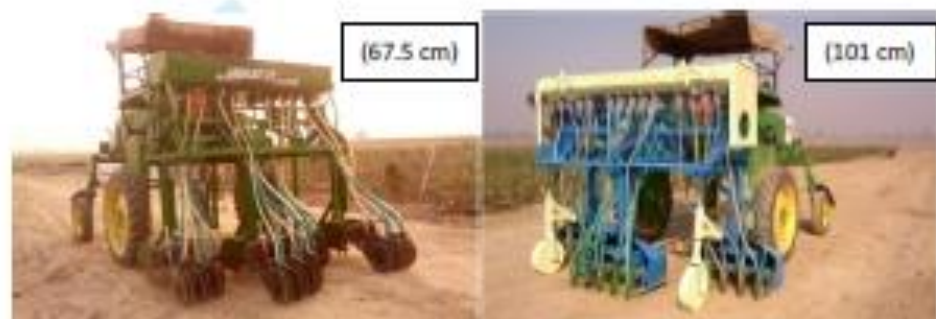
168 * STR- Strip till rower, RS-Relay seeder, ZTT- Zero till till and ZTDD-Zero till double disc

169 Four-wheel tractor (John Deere 5038) was mounted on the high clearance platform and the working clearance of
 170 the tractor was 110 cm. The RSs (suitable for 67.5 and 101 cm row spacing of cotton) were mounted on the
 171 three point linkage system of the tractor, Figure 4. Tractor was operated at 1st low gear at 1300-1400 engine
 172 rpm.

173 CROP MANAGEMENT

174 Two cotton hybrids (MRC 7017 and RCH 776) were planted under two crop geometries (67.5 cm row by 75 cm
 175 plant spacing and 101 cm row by 50 cm plant spacing). Cotton was planted using a tractor operated inclined
 176 plate planter using a seed rate of 3 kg ha⁻¹. All the crop management practices except the method of seeding

177 were similar for all the treatments. After the first picking of cotton on 4th November, 2013, flood irrigation (7.5-
 178 8.0 cm) was applied to on 7th November, 2013 and the wheat (HD 2967) variety was sown using a seed rate of
 179 100 kg ha⁻¹ with the newly developed RS on 15th November 2013. Other agronomic practices for raising wheat
 180 were similar for all the treatments as recommended by the Punjab Agricultural University, Ludhiana (Bajwa,
 181 2013). A uniform dose of fertilizer nutrients (120 kg N, 26 kg P and 25 kg K ha⁻¹) was applied to the wheat.
 182 Whole of the P and K, and 50% of N was applied at seeding. Remaining 50% of fertilizer N was top dressed
 183 before the first post-sowing irrigation applied at 3 weeks after sowing
 184



185
 186 **Figure 4. Relay seeders attached with the high clearance tractor.**

187 MEASUREMENT OF DEPENDENT PARAMETERS

188 The speed of operation, field capacity and fuel consumption of RS for different types of furrow openers was
 189 measured after 25 m run of the tractor while relay seeding wheat into standing cotton. The speed of operation
 190 and fuel consumption were measured in duplicate for all experimental plots. The speed of operation was
 191 calculated by measuring time taken by RS to sow 25 m length of field. Fuel flow meter (Aqua Metro) with least
 192 count of 1 ml, was installed in the fuel line of the tractor to measure the volume of fuel consumed in 25 m length
 193 of travel. Tractor PTO operated alternator was loaded with the help of constant load of heating element of 18
 194 kW for estimation of power consumed by different furrow openers. The load was distributed equally on three
 195 phases by using 3 coils of 6 kW. The alternator was operated at various engine rpm (1000 to 2000 rpm with an
 196 increase of 100 rpm each time) and the corresponding power consumed by heating elements and fuel
 197 consumption of the tractor was measured. The actual electric load was measured by digital electronic clamp-
 198 meter (MECO Model 3510 PHW) having least count of 0.01 hp, with accuracy of 2% of reading. The
 199 corresponding fuel consumption was measured with fuel flow meter installed in the diesel supply of the tractor.
 200 The actual power produced by the tractor at a particular fuel consumption rate was calculated by dividing the

201 power produced by alternator efficiency. The power consumed by the RSs for various types of furrow openers
202 was predicted using simple linear regression analysis using SAS 9.2 software.

203 The monopods and sympods were counted from 20 randomly selected cotton plants within each replication. The
204 height of 20 tagged plants was also measured using steel rule. The damage to standing cotton while relay
205 seeding of wheat was measured in terms of number of cotton bolls and seed cotton yield lost due to the
206 movement of RS and tractor. The damage to the crop was measured by counting the number of broken bolls
207 after each pass of RS in the standing cotton. Percent loss of cotton bolls was calculated as the ratio of number of
208 cotton bolls damaged by RS to the total number of bolls per plant. Seed cotton was manually collected and
209 weighed after sun drying the cotton bolls damaged by RS and data are reported as loss of seed cotton yield.
210 Clogging of cotton residues and weeds into RS openers was determined to examine the ease of RS operation in
211 standing cotton. Grassy weeds usually emerge between the rows of cotton crop and which may entangle the
212 sowing tines of RS. The accumulated residues on the machine openers were collected after each pass of RS and
213 weighed. The emergence count (number of plants that had emerged through the soil) in relay seeded wheat was
214 recorded for each type of furrow opener 20 days after seeding from three randomly selected locations within
215 each plot. Three, 1-m long adjacent rows in 67.5 cm cotton row spacing and five, 1-m long adjacent rows in 101
216 cm row spacing were selected for collecting data on wheat emergence count in each treatment. The data were
217 then converted to number of plants m^{-2} .

218 STATISTICAL ANALYSIS

219 Data collected for all the dependent variables were subjected to analysis of variance in factorial strip plot design
220 using SAS 9.2 software package. The differences between treatment means were considered significant when p
221 is ≤ 0.05 .

222 RESULTS AND DISCUSSIONS

223 The performance of RSs was evaluated in terms of damage to cotton and establishment of wheat.

224 STABILITY OF HIGH CLEARANCE TRACTOR

225 The CG of high clearance tractor (G^*) was (80.9, 113.7, 100.1) cm compared to normal tractor (G) (92.4, 80.3,
226 67.5) cm in longitudinal, vertical and transverse plane from the contact point of right rear wheel with ground,
227 Table 3.

228

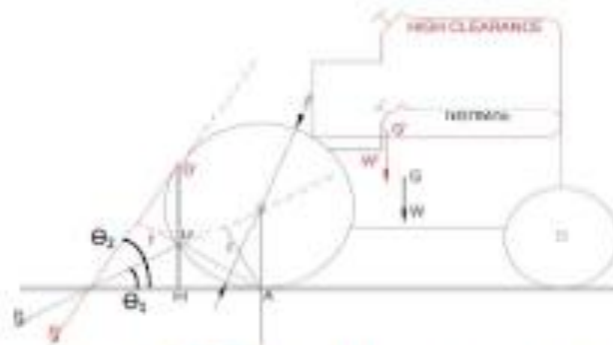
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Table 3. Brief specifications of the normal tractor and tractor mounted on the high clearance platform

Specifications	Normal Tractor	Tractor mounted on high clearance platform
Ground clearance, cm	45	110
Turning radius, cm	270	302
Weight, kg	2005	2550
Speed reduction (over normal)	-	17%
Track width, cm	135	202

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233

Figure 5. Forces acting on the normal and high clearance tractor while hitching.

- 234 • The stability of high clearance tractor ($\frac{P'}{P}$) while hitching was calculated using static forces as under:

$$\frac{P'}{P} = \frac{W \times 92.36 \times l'}{W' \times 90.34 \times l}$$

- 235 Where $W = 2005$ kg and $W' = 2550$ kg, $P =$ maximum pull for normal tractor and $P' =$ maximum pull for high
- 236 clearance tractor. Also, from figure 5 we have,

$$\frac{l'}{l} = \frac{\sin \theta_1}{\sin \theta_2}$$

- 237 As the tractor hitch point was lifted from D to E, which means $\theta_2 > \theta_1$ and angle of pull is $0 < \theta_1 < 30^\circ$ so, the
- 238 value of $\frac{l'}{l} < 1$.

- 239 Case 1: Assuming $\theta_2 = 2 \theta_1$ and $\theta_1 = 15^\circ$ we have $P' = 0.58 P$

- 240 Case 2: Assuming $\theta_2 = 1.5 \theta_1$ and $\theta_1 = 15^\circ$ we have $P' = 0.61 P$

- 241 Case 3: Assuming $\theta_2 = \theta_1$, we have $P' = 0.90 P$

- 242 Therefore, maximum draw bar pull in case of high clearance tractor is reduced compared with the normal tractor
- 243 and is dependent on angle of pull, for obtaining higher pull, the angle of pull should be kept as low as possible.

- 244 • The stability of high clearance tractor while turning ($\frac{P'}{P}$) was calculated using static forces as under:

$$\frac{V}{V'} = 0.97 \sqrt{\frac{r'}{r}}$$

245 Where V = maximum velocity at turning for normal tractor and V' = maximum velocity at turning for high
 246 clearance tractor. The steering system was adjusted to increase the turning radius so, $r' > r$, for critical case if
 247 $r' = r$, this gives the safe turning velocity for the high clearance tractor, which will be higher compared to
 248 normal tractor as track width of high clearance tractor is increased by 50% of the normal tractor.

249 OPERATIONAL PARAMETERS OF RELAY SEEDERS

250 Cotton hybrids showed no significant effect on fuel and power consumption, forward speed and field capacity of
 251 RSs. The cotton hybrids x RSs interaction effects on these dependent parameters were non-significant. Type of
 252 furrow opener significantly affected the forward speed of travel and field capacity of different RSs (Table 4).
 253 The speed of operation and field capacity was lowest (1.49 - 1.53 km h⁻¹ and 0.20 - 0.23 ha h⁻¹) for the ZTT
 254 openers due to frequent clogging of the openers with cotton and weed residues. STR furrow opener helps to
 255 reduce the clogging of openers by cutting the weeds and plant residues ahead of tine openers. The fuel
 256 consumption for STR openers was 35 and 40% more compared to ZTDD and ZTT openers, respectively. The
 257 forward speed of travel for ZTDD furrow openers was 9.3 and 16.6% more compared with STR and ZTT
 258 openers, respectively. As expected, the regression model for predicting the power required for the operating RS
 259 from the fuel consumption of the tractor was highly significant ($p < 0.0001$). Regression coefficient for
 260 predicting the tractor power from fuel consumed was significant for the regression equation

$$\text{Power, hp} = -2.014 + 4.01 * (\text{Fuel consumed, l h}^{-1})$$

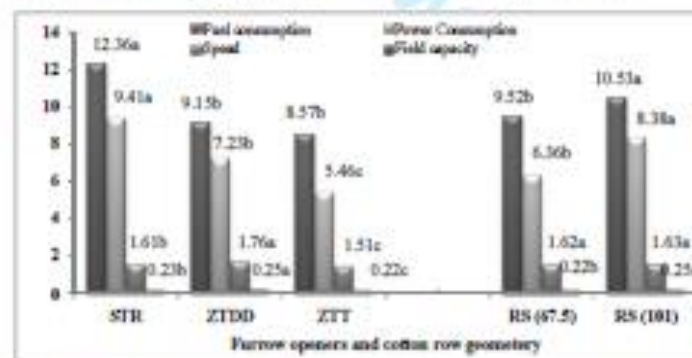
261 Table 4. Effect of cotton hybrids and different type of furrow openers on operational parameters of relay seeders (RS) for seeding wheat into
 262 standing cotton

Treatments	Fuel consumption (l ha ⁻¹)	Forward speed (km h ⁻¹)	Field capacity (ha h ⁻¹)	Power consumption (hp)
Cotton hybrids				
BCII 776	10.09	1.63	0.23	7.49
MBC 7017	9.96	1.62	0.23	7.25
LSD(p value)	NS	NS	NS	NS
Relay seeders (RSs)				
T1 (12-row STR RS)	12.00a	1.61b	0.22d	8.42b
T2 (12-row ZTT RS)	7.95d	1.49c	0.20a	4.39d
T3 (12-row ZTDD RS)	8.62cd	1.78a	0.24bc	6.25c
T4 (15-row STR RS)	12.72a	1.61b	0.24b	10.41a
T5 (15-row ZTT RS)	9.20bc	1.53c	0.23c	6.53c
T6 (15-row ZTDD RS)	9.68b	1.74a	0.26a	8.21b
LSD(p value)	<0.0001	<0.0001	<0.0001	<0.0001
Interaction A x B	NS	NS	NS	NS

263 Values with in a column with different letter are significantly different at $p \leq 0.05$.

264 The power required for 15- row RS was 31.8 % more than for 12- row RS, irrespective of type of furrow opener
 265 used. Power consumption was significantly more for STR openers compared with ZTT and ZTDD furrow
 266 openers. The Power consumption for STR openers was 72 and 30% more compared ZTT and ZTDD furrow

267 openers, respectively. Also, Power consumption for ZTT openers was 32% lower compared with ZTDD furrow
 268 openers. The predicted power requirement on per unit time basis was more for ZTDD openers than for the time
 269 openers. This trend may be reversed if power is predicted by fuel consumed per unit area basis.
 270 The contrast analysis of furrow openers showed that fuel consumption was significantly higher for 15- row RS
 271 (10.53 l ha^{-1}) compared with 12- row RS (9.52 l ha^{-1}) as the average row to row spacing wheat is 20.2 cm for 15-
 272 row and 22.5 cm for the 15-row RS, respectively, figure 6. Thus, the 12- row RS will have lesser number of
 273 seeded rows per unit width compared with 15- row RS. The STR openers had significantly more fuel
 274 consumption (12.36 l ha^{-1}) compared to ZTT (8.57 l ha^{-1}) and ZTDD furrow openers (9.15 l ha^{-1}). The higher
 275 fuel consumption in STR openers was due to tilling of narrow strip ahead of tine openers for achieving better
 276 soil seed contact. Chaudhuri, (2001) has reported among the different type of furrow openers, disc-type openers
 277 are generally popular for conventional tillage due to their lower draught, less soil disturbance and lesser
 278 variation in depth. The average operational speed was significantly higher (1.76 km h^{-1}) for the ZTDD openers
 279 compared with for STR opener (1.61 km h^{-1}) and ZTT furrow openers (1.51 km h^{-1}), respectively. This might be
 280 due to better cutting of weeds and lesser force required for opening the furrow compared with STR and ZTT
 281 furrow openers. Similarly, the field capacity of RS with ZTDD furrow openers was significantly higher
 282 compared with both ZTT and STR furrow openers. As expected, field capacity was significantly more for 15-
 283 row RS than for 12-row RS as the higher operational width (3.03 vs. 2.7 m) of machine.



284

285 **Figure 6.** Effect of three types of furrow openers and two row geometries in cotton on operational parameters of relay seeders
 286 Note: Unit for fuel consumption is l ha^{-1} , Power required is in hp, Speed of operation are in km h^{-1} , and field capacity is in ha h^{-1} .
 287 STR- strip till rate, ZTDD-zero till double disc, ZTT-zero till tine openers. Values with for a dependant parameter with different letter are
 288 significantly different at $p \leq 0.05$

289 EFFECT OF RELAY SEEDING ON STANDING COTTON

290 RCH 776 has significantly more number of monopods compared to MRC 7017 but the sympods are nearly same
 291 for both the hybrids. The cotton geometry has no significant effect on the number of monopods and sympods of
 292 cotton. RCH 776 has 1 more monopod compared to the MRC 7017, more monopods make the plants bushy and
 293 plant has wider canopy. However, the average height of cotton plants height was similar for the two hybrids,

294 Table 5. There was no significant effect of cotton hybrids on the cotton bolls damaged by movement of RS and
 295 high clearance tractor. The mean number of bolls lost was about 28% lower for ZTDD openers compared with
 296 STR and ZTT furrow openers. However, the loss of cotton bolls by the RS and the tractor was less than 2%.
 297 This loss in cotton bolls was compensated by the 4th picking of cotton in the relay seeded crop. Buttar et al.
 298 (2013) had recorded 11% higher seed cotton yield under relay seeding of wheat compared with conventional
 299 practice. Fourth picking in relay seeded plots was made possible as the crop was allowed to grow after the third
 300 picking, which provided additional seed cotton yield.

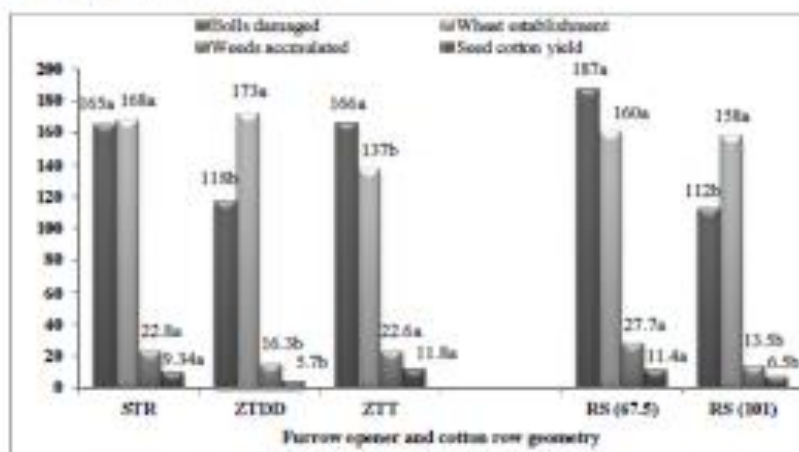
301 Table 5. Effect of geometry and hybrid on mean (\pm Standard error, SE) plant height, number of monopods and sympods for cotton plant

Treatments	Monopods (plant ⁻¹)	Sympods (plant ⁻¹)	Plant height, cm
	Mean \pm SE	Mean \pm SE	Mean \pm SE
NCII 776	3.05 \pm 0.2	27.5 \pm 0.8	128.6 \pm 0.5
MRC 7017	2.20 \pm 0.2	27.3 \pm 1.5	128.3 \pm 0.3
Lsd (0.05)	<0.0001	NS	NS
Cotton Row spacing (67.5)	2.43 \pm 0.2	28.9 \pm 1.2	129.6 \pm 0.8
Cotton Row spacing 101	2.80 \pm 0.1	28.0 \pm 1.3	128.5 \pm 1.4
Lsd (0.05)	NS	NS	NS

302
 303 The contrast analysis showed that number of cotton bolls detached per plot from plants due to the movement of
 304 RS and high clearance tractor was significantly lower (112) for 15- row RS compared with for 12- row RS (187)
 305 (figure 7). This was due to 25% reduction in the number of passes of the tractor in the field due to more
 306 machine width of 15- row RS compared to 12- row RS. Furthermore, wider row to row spacing (101 cm) for the
 307 movement of tractor and the seeding units for 15-row compared to 12- row RS, reduced the contact of machine
 308 parts with cotton and thereby reduced the crop damage. The number of bolls detached was significantly lower
 309 for ZTDD openers compared with the STR and ZTT openers, figure 7. RS with ZTDD openers does not require
 310 depth control wheels for machine as the depth of seeding is maintained by the spring tension, whereas, depth
 311 wheels are required for ZTT openers to stabilize the RS. Cotton plants obstruct the movement of depth wheels
 312 due to less space between cotton plants thus resulting in increase in damage of cotton plants/bolls. Also, the
 313 ZTDD openers cut the lodged cotton branches and residue that comes in front of the openers whereas these
 314 branches and residues entangle in the furrow openers (STR and ZTT) and in some cases it may even uproot the
 315 whole cotton plant.

316 There was no significant difference between cotton hybrids on seed cotton loss due to movement of RS and high
 317 clearance tractor. The mean loss of seed cotton due to relay seeding was 43% more for 12- row RS (for 67.5 cm
 318 row spacing of cotton) compared with for 15- row RS (for 101 cm row spacing of cotton). The contrast analysis
 319 indicated that the RS for wider row spacing (101 cm) of cotton using ZTDD openers is causing lesser damage to
 320 cotton plants as compared to RS suitable for narrow row spacing (67.5 cm) of cotton using ZTT and STR

321 openers, figure 7. The loss of seed cotton was significantly 63 and 106 % lower for ZTDD openers compared
 322 with STR and ZTT openers, respectively, Table 6.



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 331

Figure 7. Effect of three types of furrow openers and two row geometries in cotton on performance of relay seeders

Note: Unit for cotton boll damage is number per plant, wheat establishment is in number of plant m^{-2} , Weed/cotton leaves accumulated are in $g m^{-2}$ (fresh weight basis), and seed cotton yield loss is in $kg ha^{-1}$. STR- strip till rotor, ZTDD-zero till double disc, ZTT-zero till tine openers. Values with for a dependent parameter with different letter are significantly different at $p \leq 0.05$

Table 6. Effect of different cotton hybrids, and different type of furrow opener on performance of RS for seeding wheat into standing cotton

Treatments	Cotton bolls damaged (Number plant ⁻¹)	Cotton bolls damaged (% of total)	Seed cotton loss ($kg ha^{-1}$)	Fresh weight of weeds/ plant residue accumulated ($g m^{-2}$)	Wheat establishment (Plants m^{-2})
Cotton hybrids					
BCII 776	154	1.22	8.46	21.2	160
MRC 7017	146	1.17	9.46	20.0	159
LSD (P)	NS	NS	NS	NS	NS
Relay seeders					
T1 (12-row STR, RS)	214a	1.77a	11.84ab	31.6a	169a
T2 (12-row ZTT, RS)	192ab	1.58ab	15.56a	28.3ab	137b
T3 (12-row ZTDD, RS)	156bc	1.28bc	6.72c	23.3bc	174a
T4 (15-row STR, RS)	116cd	0.88cd	6.86c	14.6cd	167a
T5 (15-row ZTT, RS)	141bc	1.07c	8.07bc	16.9cd	136b
T6 (15-row ZTDD, RS)	79d	0.62d	4.72c	9.3e	172a
LSD (p)	0.0003	<0.0001	0.0004	<0.0001	<0.0001
Interaction Axb	NS	NS	NS	NS	NS

332 Values with in a column with different letter are significantly different at $p \leq 0.05$
 333 1 Plot size of 250 m².

334

335 EFFECT ON WEED/PLANT RESIDUE ACCUMULATION

336 RS type (12- row and 15- row) and type of furrow openers showed significant effect on the amount of
 337 accumulation of weed/cotton residues (figure 7). Both cotton hybrids had similar effect on residue
 338 accumulation. The contrast analysis showed that the residue accumulation was significantly lower with ZTDD
 339 openers compared to STR furrow openers for 12- row RS. ZTDD openers cut the cotton residues coming in
 340 front of it and move over it without dragging the residues, ZTT and STR furrow openers drag the fallen
 341 branches of cotton and weeds causing accumulation of the residues. The residue accumulation was significantly
 342 lower for RS in 101 cm cotton row spacing compared with RS suitable for 67.5 cm row spacing.

343

344 **EFFECT ON WHEAT ESTABLISHMENT**

345 Interaction effects of type of machine, cotton genotypes and type of furrow openers on wheat emergence count
 346 were non-significant, figure 8. RS type (12- row and 15- row) and cotton hybrids (MRC 7017 and RCH 776)
 347 had no significant effect on emergence count of wheat (fig. 7). But type of furrow opener significantly
 348 influenced emergence count. Establishment count of relay seeded wheat with STR and ZTDD furrow openers
 349 was 23 and 26% more compared with ZTT openers, respectively (Table 6). The lesser establishment count of
 350 wheat in ZTT furrow openers was due to uneven depth of seeding caused by significantly higher plant residue
 351 accumulation compared with the other furrow openers. Emergence count was also lesser for the ZTT furrow
 352 openers compared with STR furrow openers because of adverse effect of uneven depth on germination in case
 353 of STR openers was compensated by better soil seed contact. The double-disc openers gave most evenness of
 354 drilling in soils having crop residue as compared to other openers (Ozmeri, 1986, Wilkins et al. 1983).
 355 Chaudhuri, (1994), investigated the performance of inverted, double-disc and shoe-type furrow openers with
 356 wheat crop under normal (18.59 %) and deficit (14.35 %) soil moisture conditions on dry basis and reported that
 357 standard deviation of depth of sowing was least for the double-disc furrow openers in both the experiments.



358

359 **Figure 8. Establishment of wheat in standing cotton with 67.5 cm (left) and 101 cm row spacing (right)**360 **CONCLUSIONS**

361 Based on the study, it may be concluded that the RSs mounted on a high clearance tractor can be used for relay
 362 planting of wheat in cotton with minor damage to cotton crop (< 2%). RS for 101 cm cotton spacing has
 363 significantly lesser damage to cotton bolls, seed cotton yield loss and weed accumulation compared to 67.5 cm
 364 row spacing RS as wider cotton geometry has more open space for movement through of RS and tractor. Also,
 365 RS with ZTDD furrow openers compared to STR and ZTT openers showed better performance in terms of field
 366 capacity, ease of operation, damage to standing cotton and establishment of wheat.

15

Thank you for reviewing for ASABE Publications

367

368 **ACKNOWLEDGEMENTS**

369 The study was financially supported by International Maize and Wheat Improvement Centre (CIMMYT) under
 370 CGIAR Research Program on WHEAT (CRP 3.1). Authors thank Borlaug Institute for South Asia (BISA) for
 371 providing land and other resources needed for the study. The support of Rajar Agricultural works, Mullampur,
 372 Punjab for fabrication of high clearance tractor platform and Jagjit Industries, Choema Mandi, Punjab, India for
 373 fabrication of relay seeders is thankfully acknowledged. First author also thank Punjab Agricultural University,
 374 Ludhiana for granting study leave to him for PhD programme.

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- 412

7/7/2015

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EVALUATION OF FURROW OPENERS FOR RELAY SEEDING WHEAT IN COTTON UNDER TWO PLANT GEOMETRIES: WHEAT EMERGENCE, PRODUCTIVITY AND PROFITABILITY OF COTTON-WHEAT SYSTEM IN NORTH-WEST INDIA --Manuscript Draft--

Manuscript Number:	
Full Title:	EVALUATION OF FURROW OPENERS FOR RELAY SEEDING WHEAT IN COTTON UNDER TWO PLANT GEOMETRIES: WHEAT EMERGENCE, PRODUCTIVITY AND PROFITABILITY OF COTTON-WHEAT SYSTEM IN NORTH-WEST INDIA
Short Title:	High clearance relay seeder for wheat in cotton
Article Type:	General
Corresponding Author:	Manpreet Singh, M.Tech Punjab Agricultural University Ludhiana, Punjab INDIA
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Punjab Agricultural University
Corresponding Author's Secondary Institution:	
First Author:	Manpreet Singh, M.Tech
First Author Secondary Information:	
Order of Authors:	Manpreet Singh, M.Tech Harminer Singh Sidhu, PhD Jaskum S Mahal, PhD Gursahib S Manes, PhD M L Jat, PhD Amrit K Mahal, PhD Parvinder Singh, M Sc. Yadvinder Singh, PhD
Order of Authors Secondary Information:	
Manuscript Region of Origin:	INDIA
Abstract:	Cotton-wheat (CW) is the second most important cropping system after rice-wheat (RW) in South Asia. Wheat yields under conventional CW system are generally lower compared to RW system due to delayed seeding. Relay seeding of wheat can help timely sowing, capturing residual soil moisture of last irrigation to cotton, and increase productivity and profitability of CW system. On-station and on-farm participatory experiments were carried out to evaluate the performance of newly developed relay seeders (RS) attached to high clearance four-wheel tractor for seeding wheat in standing cotton planted at row spacings of 67.5 cm and 101 cm. Replicated on-station field experiment included two cotton genotypes having different canopy cover (RCH 776 and MRC 7017), two types of RS (12-row in 5 rows of cotton at 67.5 cm and 15-row in 4 rows of cotton at 101 cm) three types of furrow openers (strip till rotor-STR, zero till double disc-ZTDD and zero till line-ZTT). The RS with ZTDD furrow opener vis-a-vis conventional till wheat (CTW) were also evaluated on five farmer's fields. Relay planting of wheat allowed one additional boll picking leading to increase in seed cotton yield by about 12% compared with CTW. Cotton genotypes and RS had no effect on wheat emergence and wheat yield. Relay seeders with STR and ZTDD furrow openers performed better in terms of wheat emergence and grain yield compared to ZTT openers. Wheat sowing using RS was advanced by 31 days, which increased grain

	<p>yield by 18.8% compared with CTW. Net returns from CW system with relay seeding of wheat were Indian Rs. 19, 282 to 26, 332 ha⁻¹ higher compared with conventional CW system. Results from on-farm participatory trials revealed that wheat yield under relay seeding on average increased by 6.4% compared to CTW. Our study suggests that high clearance 26 four-wheel tractor driven innovative relay seeder with ZTDD/STR furrow openers can be efficiently used for timely seeding of wheat in cotton for higher productivity and profitability of CW system.</p>
--	--

INTRODUCTION

Cotton (*Gossypium hirsutum* L.)-wheat (*Triticum aestivum* L.) system is the second important system after rice-wheat (RW) in terms of area covering 4.19 M ha in South Asia (Yadvinder singh *et al.*, 2014). About 80-90% of the area under cotton in North-West (NW) India and East Pakistan is under cotton-wheat (CW) system (Mayee *et al.*, 2008). The optimum time of wheat sowing in NW India is last week of October to first fortnight of November (Bajwa, 2011). Wheat planting after cotton harvest is often gets delayed due to late pickings in cotton and the time involved in its seed bed preparation. The sowing of wheat after 20th November reduces its productivity at the rate of 1.0-1.5% day⁻¹ of delay (Nasrullah *et al.*, 2010; Subhan *et al.*, 2004). Therefore, average productivity of wheat in CW system is lower (about 3.2 t ha⁻¹) compared to the productivity of about 4.7 t ha⁻¹ in RW system of Indian Punjab (Buttar *et al.*, 2013). Delay in wheat sowing in CW system can be avoided by relay seeding by manual broadcast (MB) or direct sowing of wheat using self propelled walk behind type relay seeder (RS) in standing cotton (Khan and Khaliq, 2005; Buttar *et al.*, 2013). The wheat yield gains with self-propelled walk behind type RS were 12 to 41% compared with conventional till wheat (CTW) after cotton harvest. However, farmers' adoption of this 3-row walk behind type RS for planting wheat in CW system is very limited due its low capacity (< 0.6 ha day⁻¹) and drudgery. Hence, there is a need for a 4-wheel tractor operated RS, which can sow wheat in standing cotton crop with different row geometries. A high capacity 4-wheel high clearance tractor driven RSs with different types of furrow openers were developed for seeding of three or five rows of wheat in to adjacent rows of cotton planted at two row spacings causing minimal damage to the crop (Manpreet-singh *et al.*, (2015). This paper focuses on the field evaluation of the two types of RSs and three types of furrow openers (zero-till tine, zero till double disc and strip till rotor) driven by high clearance 4-wheel high clearance tractor in two cotton genotypes for relay seeding of wheat in cotton in CW system of NW India.

MATERIAL AND METHODS

Development of high clearance 4-wheel tractor operated RS

A four-wheel tractor was mounted on high clearance platform, which increased the ground clearance from 45 cm to 115 cm and facilitated easy movement of the tractor above the standing cotton crop (Manpreet-singh *et al.*, (submitted)). The working clearance (from ground) of the tractor was 110 cm. Two RSs (suitable for 67.5 and 101 cotton row spacing) fitted with three types of furrow openers (zero-till inverted T-type-ZTT, Zero till double disc-ZTDD and strip till rotor-STR) were used for relay seeding of wheat in cotton. The 12-row RS consisted of 4 seeding units each having 3 furrow openers (36 cm wide) and thus covering 4 rows of cotton crop in a single pass, Figure 1. Similarly, 15- row RS consisted of 3 seeding units each having 5 furrow openers (72 cm wide) thus covering three rows of cotton crop in a single pass, Figure 2. The RSs were mounted on the three point linkage system of the tractor. Tractor was operated at 1st low gear at 1300-1400 engine rpm and delivered ~400 rpm at PTO for powering the strip tillage rotor of RS. The forward speed of travel was 1.75 km h⁻¹ and the field capacity of 12 and 15 row RSs is 1.8- 2.0 ha day⁻¹.

Evaluation of Relay Seeders for planting wheat in standing cotton

One on-station and five on-farm participatory field experiments were conducted during 2013-14 in Punjab India to evaluate and validate the RSs. The on-station field experiments were

92 conducted on a sandy loam soil during 2013–2014 at the research farm of the Borlaug
93 Institute for South Asia (BISA) at Ladhawal (30° 59' N and 75° 44' E), Ludhiana (Punjab),
94 India. The soil in the 0–15 cm layer was non-saline (electrical conductivity 0.26 dS m⁻¹) with
95 pH ranging from 8.07 with 5.7 g kg⁻¹ organic carbon (Walkley and Black, 1934), 10.8 mg ha⁻¹
96 Olsen P and 69.2 mg ha⁻¹ NH₄OAc-extractable K. The climate of the region is subtropical,
97 semi-arid. Under average climatic conditions, the area receives about 699 mm of rainfall
98 during the cotton season (May–November) and 237 mm during the wheat season
99 (November– May). Temperature data during May 2013 to April 2014 were recorded from the
100 automatic weather station installed at the BISA farm (Figure 3). The mean daily minimum
101 and maximum temperatures during the cotton season ranged from 6.0 to 27.4°C and 27.9 to
102 45.9 °C respectively, and the corresponding values during the wheat season were 2.4–20.9°C
103 and 14.5–39.0°C.

104

105 *Experiment 1. On-station evaluation of relay seeder*

106

107 Field trial was laid out in a strip-plot design with three replications. Treatments included two
108 Bt-cotton genotypes (RCH 776 and MRC 7017) having different canopy cover and vigor in
109 the main plots. For ease in the movement of tractor and RSs, cotton genotypes were planted
110 in strips. The sub-plot treatments included 8 combinations of two types of RSs (suitable for
111 cotton with either 67.5 cm or 101 cm row spacing), four types of relay seeding methods
112 (manual broadcast-MB, STR-RS, ZTDD-RS, ZTT-RS) and conventional till wheat (CTW).
113 The details of treatments are given in Table 1. Plot size was 219 and 252 m² for 67.5 and 101
114 cm row to row spacing in cotton, respectively (13 rows for 67.5 cm and 10 rows for 101 cm
115 spacing). An alley way of 10 m was kept between the two replications as well as at head
116 lands to facilitate movement of the tractor and implement.

117

118 *Cotton crop management*

119

120 After the harvest of general crop of well-fertilized wheat in mid-April, two Bt cotton
121 genotypes (MRC 7017 and RCH 776) were planted on 22 April, 2013 under two geometries
122 (67.5 cm row by 75 cm plant spacing and 101 cm row by 50 cm plant spacing). Cotton was
123 planted with tractor operated inclined plate cotton planter using a seed rate of 3 kg ha⁻¹. The
124 crop management practices except the method of seeding were common for all the
125 treatments. A uniform recommended dose of 150 kg N ha⁻¹ as urea, 30 kg ha⁻¹ of P as
126 diammonium phosphate (DAP) and 25 kg K ha⁻¹ as muriate of potash (MOP) was applied to
127 the cotton crop. While whole of the P and K was applied at seeding, fertilizer N was applied
128 in equal split doses; 50 % N top dressed after thinning in the fourth week after sowing and the
129 remaining 50 % N applied at flowering stage. Two percent solution of potassium nitrate
130 (13:0:45) was sprayed four times at weekly interval starting from the initiation of flowering
131 in the cotton. The first irrigation to cotton crop was applied at 35 days after sowing and
132 remaining 4 irrigations were applied at 2-3 weeks interval. The sucking pests (aphids) of
133 cotton were controlled by spraying Imidacloprid 200 SL (100 ml ha⁻¹). Four sprays of Ethion
134 50 EC (2 l ha⁻¹) were made to protect cotton against whitefly attack. After the first picking of
135 cotton on 04 November, 2013, flood irrigation (75–80 mm) was applied on 07 November,
136 2013. Wheat was sown into the residual moisture using the relay seeding on 15 November,
137 2013. The third picking of cotton was done at 25 days after relay seeding. In the relay seeded
138 plots cotton stalks were manually pulled out after applying first post-sowing irrigation at 25
139 days after planting. In the conventional wheat (T1), pre-sowing irrigation was applied in
140 standing cotton 4 days before stalk pulling and the wheat was sown after conventional tillage
141 using seed-cum-fertilizer drill on 13 December 2013. In relay seeding treatments, one

142 additional picking of cotton was made at the time of manual uprooting of cotton stalks when
143 majority of immature bolls were fully opened.

144

145 *Wheat crop management*

146

147 Wheat (HD-2967) was sown using a seed rate of 100 kg ha⁻¹. Crop management practices
148 except the method of seeding were similar for all the treatments. A uniform dose of fertilizer
149 nutrients (120 kg N, 26 kg P and 25 kg K ha⁻¹) was applied to the wheat. Whole of the P and
150 K, and 50% of N was applied at seeding. Remaining 50% of fertilizer N was top dressed
151 before the first post-sowing irrigation applied at 3 weeks after sowing. The broad leaf weeds
152 and *phalaris minor* were controlled by applying Algrip 20 WP (*metolachlor*) at 25 g ha⁻¹ and
153 *clodinafop* (15 WP) at 400 g ha⁻¹. Four irrigations of 7.5 cm each were applied to the crop.
154 Rogor 30 EC (*dimethoate*) was sprayed at 375 ml dissolved in 250 l ha⁻¹ water for control of
155 aphids.

156

157 *Plant observations*

158 *Cotton*

159

160 Seed cotton yield was recorded after every picking from 20 randomly selected and tagged
161 plants within each plot. The total yield is the sum of the three pickings from T1 and four
162 pickings from the relay-seeded treatments (T2-T9). The cotton with the relay seeding
163 remained in the main field for 30 days more than conventional CW system.

164

165 *Wheat*

166

167 Crop emergence count (plants that had emerged through the soil) at 20 days after seeding,
168 and grain yield and yield components (spike density, number of grains per spike and grain
169 weight) were measured at harvest. Emergence count was recorded in three randomly selected
170 locations within each plot from 1-m long three adjacent rows in case of 67.5 cm cotton row
171 spacing and 1-m long five adjacent rows (101 cm row spacing) and 1 m × 1 m area in MB
172 and CTW. Spike density was measured in three randomly selected locations within each plot
173 as in case of emergence count. The number of grains per spike was recorded from 15
174 randomly selected spikes in each plot at maturity. Grain yield was determined on two
175 randomly selected locations within each plot from an area of 10 m², varying slightly due to
176 change in row geometry in cotton. Wheat was manually harvested and threshed using small
177 plot power thresher and grain yield was reported on air dry weight basis. Average grain
178 weight was determined on 1000 grains.

179

180 *Experiment 2. On-farm evaluation of relay seeder in wheat*

181

182 Five on-farm single replicated trials were conducted in 2013-14 to evaluate the performance
183 of tractor operated RS with double disc furrow openers for the sowing wheat in standing
184 cotton vis-a-vis CTW during 2013-14 in district Bathinda representing CW belt of Punjab,
185 India. The locations of the experimental sites along with sowing date of wheat are provided in
186 Table 2. The climate of the region (district Bathinda) is subtropical, semi-arid. Under average
187 climatic conditions, the area receives about 460 mm of rainfall during the cotton season
188 (April–November) and 75 mm during the wheat season (November– April). The 12- row RS
189 with double disc furrow openers was used for seeding wheat into standing Bt-cotton (Super
190 6488) planted at 67.5 row spacing and compared with CT wheat establishment. Relay seeding
191 of wheat was done before the third picking of cotton. Relay seeding of wheat in on-farm trials

192 was delayed due to non-availability of RS on time as only one prototype of RS was available
193 and the machine could only be spared after the completion of wheat planting in experiment 1.
194 Plot size varied from 400 to 500 m². All locations were sown with the same variety of wheat
195 (PAU 621) at a rate of 100 kg ha⁻¹. Farmers managed their cotton and wheat crops and
196 followed the crop management practices as described under experiment 1, which were the
197 same for both the treatments. Wheat yield at maturity was measured by harvesting 4.05 m²
198 for relay seeded wheat and 3 m² for CT wheat from two random locations within each plot.

199

200 *Economic analysis*

201

202 The variable cost of growing wheat in each treatment was calculated by taking into account
203 the costs of inputs (seed, fertilizers and pesticides), tillage (discing, cultivator and planking),
204 seeding under different treatments (seed-cum-fertilizer drill, broadcast seeding and tractor
205 operated RS), hiring of manual labour, custom hire for machinery operations, transport and
206 marketing. Hiring charges for combine harvester and straw chopper/trolley were included for
207 calculating harvesting and threshing costs. Electricity for pumping water is supplied free of
208 cost to the farmers, the cost of irrigation included the cost of labour involved in applying
209 irrigation water. The cost of a 50-kg bag of urea, DAP and muriate of potash was taken as
210 Indian Rs. (INR) 270, 1210 and 840 (1 Rs = US\$ 0.0161), respectively. The charges for
211 human labour hiring were taken as Rs. 35 h⁻¹. The cost of labour for fertilizer application,
212 pesticide spray and irrigation was included for each of these operations. The charges for
213 discing, cultivators and planking were Rs. 1438, 1313 and 500 ha⁻¹ respectively. The cost of
214 seeding was considered as Rs. 1438 ha⁻¹ for conventional sowing (T1), Rs. 3386 ha⁻¹ for relay
215 seeding and Rs. 560 ha⁻¹ for MB. The cost of RS was taken as Rs. 100,000 and its fuel
216 consumption is 4.0 l h⁻¹. The RS can seed wheat at 0.18 ha h⁻¹ with a working window period
217 of 20 days in a year and its life was taken as 10 years. The market price of wheat grain as
218 fixed by Govt of India was Rs. 14000 t⁻¹ and prevailing market price of straw was Rs. 2.25
219 kg⁻¹. The market price of seed cotton was taken as Rs. 39 kg⁻¹. Straw yield of wheat was
220 calculated on the basis of straw–grain ratio of 1:1. The data on variable cost for the cultivation
221 of cotton and wheat for the year 2013–2014 were obtained from the Department of
222 Economics and Sociology, Punjab Agricultural University, Ludhiana, India. The interest on
223 variable cost was considered as 9% for the half crop season. The variable cost used for cotton
224 was similar under different RS treatments, except the additional cost for 4th picking of cotton
225 under relay planting treatments. The value of increased cotton yield in relay planting
226 treatments (T2–T9) was included for calculating gross returns. The gross and net returns were
227 calculated by subtracting total variable costs from the gross return.

228

229 *Statistical analysis*

230

231 Data collected for all the dependent variables were subjected to analysis of variance in
232 factorial strip plot design using SAS 9.2 software package. Before analysis, the Levene's test
233 was performed to test the homogeneity of variances using the proc GLM procedure with the
234 HOVTEST option in the MEANS statement. Differences between treatment means were
235 compared using a LSD test at P < 0.05 (Gomez and Gomez, 1984). Student's T-test using
236 SAS 9.2 software package was performed for comparing grain yield between two treatments
237 in experiment 2. The economic analysis was also done by Student's T-test using SAS 9.2
238 software package.

239

240

241

RESULTS

Effect on seed cotton yield

Cotton genotypes (MRC 7017 and RCH 776) and row spacing (67.5 cm and 101 cm) showed no significant effect on number of mature bolls in all the four pickings (Table 3). Average number of mature bolls at fourth picking was 4/plant in all the relay seeded treatments. Total number of mature bolls/plant was significantly more (10%) for cotton genotypes in relay seeded treatments compared to CTW (T1). Cotton genotypes and their interaction with crop establishment methods had no significant effect on seed cotton yield. Mean seed cotton yield for 67.5 and 101 cm row spacings under relay seeding was 11-14% higher compared with conventional crop.

Effect on wheat establishment

There was no significant interaction effect of type of cotton genotypes, relay seeders (or row spacing) and type of furrow openers on wheat emergence at 20 days after sowing. Relay seeders (for 67.5 cm and 101 cm cotton row spacing) and cotton genotypes had no significant effect on emergence count of wheat (Table 4). Furrow openers (STR, ZTT, ZTDD) and MB significantly influenced the emergence count (Figure 4 and 5). Wheat seeded with STR and ZTDD furrow openers, and CT (T1) resulted in significantly higher emergence count compared with ZTT furrow openers. Emergence count was markedly lower for MB compared to relay seeded wheat due to poor soil-seed contact.

Time saving under relay planting of wheat

The relay seeding advanced the sowing of wheat by 31 days compared to CTW Wheat crop, however matured at the same time under both of the planting methods. The crop duration (sowing to maturity) was thus 165 days and 134 days for relay seeded and CTW, respectively.

Effect on yield and yield contributing parameters in wheat

Relay seeded treatments had about 27.3% more spike density compared with conventional sown wheat and MB (Table 4). Number of grains/spike was significantly higher in relay seeded as compared to CTW. Mean grain weight of CTW was significantly lower (13%) compared to that for relay seeded in standing cotton.

There was no significant effect of cotton genotypes and row geometry (3 rows in 67.5 cm row spacing and 5 rows in 101 cm row spacing) of relay seeders on wheat yield (Table 4). All the relay seeded treatments, except ZTT furrow openers (T3) produced significantly higher wheat yield compared to CTW (Table 4). Wheat yield was significantly lower for the MB compared with drilling sowing using relay seeders and CTW. The grain yield was significantly higher for STR compared with ZTT furrow openers.

Performance of relay seeded wheat on farmers' fields

Relay sowing of wheat advanced the sowing of wheat by 5 to 11 days compared with CT wheat cultivation after cotton harvest (Table 5). Student's t-test analysis showed significantly lower yields for CTW compared with relay seeding. On average 6.4% higher grain yield was recorded for relay seeding compared with CTW.

292

293 *Economic analysis*

294

295 The data presented in table 6 revealed lower variable costs for planting wheat with relay
 296 seeder due to less cultivation costs compared with CTW (T1). Gross returns from relay
 297 seeding of wheat were higher by INR. 19, 352 - 26, 401ha⁻¹. Similarly, net returns were
 298 INR.19, 282 - 26, 332 ha⁻¹ more (an increase of 27– 37%) under relay seeding of wheat using
 299 high clearance tractor compared with conventional CW system due to higher gross returns
 300 and lower variable costs (Table 7). Net returns from CW system with MB (T5 and T9) in
 301 standing cotton were statistically similar to CTW. The gross return of cotton in conventional
 302 CW system was significantly lower compared with relay seeding and MB treatments. The
 303 benefit to cost ratio was also significantly higher for the relay seeded compared with
 304 conventional and relay MB of wheat in cotton. All the economic indicators were statically
 305 similar for row spacing of cotton i.e. 67.5 cm and 101 cm.

306

307

DISCUSSION

308

309 *Effect on cotton yield*

310

311 Relay seeding of wheat increased cotton yield by creating opportunity for one additional
 312 picking, which was made possible due to the extended growing period of the cotton for about
 313 30 days. This extra growing period helped in fully opening of the majority of the immature
 314 bolls at the time of pulling out of cotton stalks leading to 11-14% increase in seed cotton
 315 yield over CTW. Consistent with our study, Buttar *et al.*, (2013) recorded significantly higher
 316 seed cotton yield under relay seeding of wheat compared with cotton followed by CTW.

317

318 *Effect on wheat establishment and yield contributing parameters*

319

320 The lower wheat emergence count in ZTT compared to STR and ZTDD furrow openers was
 321 mainly due to the uneven depth of seeding caused by significantly higher weeds/plant
 322 residues accumulation in front of furrow openers (Manpreet-Singh *et al.*, 2015). Emergence
 323 count was higher for the STR compared with ZTT openers because of the better seed-soil
 324 contact. Emergence count in wheat was markedly lower for the MB due to poor soil and seed
 325 contact compared with drill sowing with relay seeders. Better wheat emergence under drill
 326 sowing compared to MB has been reported by many researchers (Shaalan *et al.*, 1997;
 327 Tanveer *et al.*, 2003; Ali *et al.*, 2012) due to the placement of seed at optimum and uniform
 328 depth under drill sowing. However, Fischer *et al.*, (1976) found a wide range in optimum
 329 plant density (80–200 plants m⁻², provided that plant density was even) for maximum yield
 330 for a range of irrigated spring wheat varieties grown under climatic conditions fairly similar
 331 to those of northwest India, suggesting adequate plant population in all crop establishment
 332 methods in our experiment.

333

334 The lower spike density in CTW might be attributed to adverse effect of prevailing low
 335 temperature coinciding with the tillering stage of wheat. The poor crop establishment in MB
 336 was however, the main reason for significantly lower spike density compared with the other
 337 treatments. Khan and Khaliq, (2005) reported a similar negative effect of late sowing on
 338 spike density in wheat. Fewer number of grains/spike in the CTW could be attributed to
 339 higher temperatures experienced by the crop at anthesis and grain development stages due to
 340 late sowing compared with timely sown relay seeded wheat (Table 4). Delayed sowing of
 341 wheat commonly has a negative influence on the number of grains/spike (Jan *et al.*, 2000).

342 Higher mean grain weight for relay wheat compared with CTW is attributed to a longer grain
343 filling period available to the early sown crop. These results are in accordance with those of
344 Green *et al.*, (1985) and Jan *et al.*, (2000) who reported that grain weight decreased
345 significantly with delay in sowing.

346

347 The contrast analysis of establishment count and yield contributing parameters of wheat
348 showed that the all the four parameters such as; effective tillers; grains spike⁻¹ and test weight
349 were more for relay CW system compared with conventional CW system in spite of having
350 more establishment count of CTW, (Figure 6). Contrast analysis among the different cotton
351 geometries (relay seeders) showed that all the four parameters were statically similar;
352 therefore, the relay seeders are versatile enough for different geometries popular in the
353 region. Among the three furrow openers used the ZTDD and STR openers performed better
354 compared with ZTT openers for all parameters.

355

356 *Effect on wheat Yield*

357

358 Grain yield of wheat is a product of spike density, number of grains/spike and grain weight.

359 Early sowing of relay wheat by 31 days compared to CTW increased all the three yield
360 parameters thereby increasing grain yield by 19%. Khan and Khaliq (2005) reported that the
361 relay seeded wheat produced 13.2% higher grain weight as compared to CTW. This is
362 consistent with the observation made by Buttar *et al.*, (2013) who reported 25% higher grain
363 yield of wheat sown with manual walk behind self propelled relay seeder compared to CTW.

364 The short duration of CTW and unfavourable temperature regime during grain development
365 phase experienced by the crop adversely affected the yield of CTW. The lower grain yields
366 recorded in ZTT furrow opener (T3) in 67.5 cm- row spacing of cotton and MB were due to
367 poor crop establishment caused by uneven seeding depth and/or poor soil-seed contact.
368 Dawelbeit and Babiker (1997) and Khan *et al.*, (2007) have also reported lower grain yields
369 from seed broadcasting compared to drill sowing of wheat. There was no significant effect of
370 row geometries in cotton (3 rows in 67.5 cm row spacing and 5 rows in 101 cm row spacing)
371 on wheat yield. The performance of relay seeders as well as furrow openers was similar in
372 both the cotton genotypes. Porter and Khalilian (2005) have reported that yield of CTW was
373 not affected by skip-row geometry designed to allow for relay intercropping of either soybean
374 or cotton.

375

376 The contrast analysis of wheat yield showed that grain yield was significantly more for relay
377 CW system compared with conventional CW system, (Figure 7). Contrast analysis among the
378 different cotton geometries (relay seeders) showed no significant effect on wheat yield.
379 Among the three furrow openers used the ZTDD and STR openers produced significantly
380 higher yield of wheat compared with ZTT openers. STR openers requires power transmission
381 system to drive the strip tillage rotor and depth control wheels whereas, the ZTDD openers
382 mounting is simple and robust and depth of seeding is maintained by the springs mounted on
383 the twin disc openers. Therefore, the ZTDD openers are better compared with STR in context
384 of machine simplicity (lesser number of moving parts).

385

386 The advantage of early sowing by relay seeding was lower on farmers' fields compared to
387 that recorded in experiment 1 due to delay in timely availability of relay seeder. The single
388 prototype of relay seeder could be made available only after the completion of seeding wheat
389 in experiment 1. Moreover, two days were needed to transport the machine as well as the
390 high-clearance tractor to the farmers' locations, about 250 km away from the experiment site
391 at Ludhiana. The greater increase in gain yield from relay seeding compared to CTW can be

392 expected when seeding of wheat is accomplished in the first fortnight of November in this
393 region.

394

395 *Economic analysis*

396

397 Gross returns from relay seeding of wheat were higher due to lower tillage costs and higher
398 yields of seed cotton and grain and straw of wheat over CTW and MB of wheat. Net returns
399 were INR19, 282 - 26, 332 ha⁻¹ more (an increase of 27– 37%) under relay seeding of wheat
400 using high clearance tractor compared with conventional CW system. The relay seeding of
401 wheat using different furrow openers included single operation, while CTW needed 5-6
402 tillage operations. This is consistent with ARYAL *et al.*, (2015) who have reported that
403 shifting from CT to ZT wheat production system reduces the farmers total input cost ha⁻¹ by
404 20% (USD 79 ha⁻¹) and increases net revenue per ha by 28% (USD 97.5 ha⁻¹). Buttar *et al.*,
405 (2013) have also recorded higher net returns from mechanical relay seeding of wheat into
406 standing cotton compared with conventional CW system.

407

408 CONCLUSIONS

409

410 Our study demonstrates that wheat can be successfully (in terms seed emergence and damage
411 to standing cotton) relay seeded in cotton with either 67.5 cm or 101 cm row spacing, using
412 specifically designed relay seeders attached to a high clearance 4-wheel tractor. Both double
413 disc and strip till rotor furrow openers for relay seeders resulted in 23-26% higher emergence
414 count of wheat compared with ZTT openers, irrespective of cotton cultivar. The relay seeding
415 increased wheat yield by about 19 % and provided 27-37 % higher net returns in CW system
416 compared to conventional sowing. Considering the case of Punjab only this intervention may
417 increase the wheat production by 0.29 million tons without any adverse effect of cotton yield.

418

419 ACKNOWLEDGEMENTS

420

421 The study was financially supported by International Maize and Wheat Improvement Centre
422 (CIMMYT) under CGIAR Research Program on WHEAT (CRP 3.1). The Land and other
423 resources provided by BISA are thankfully acknowledged. The support of Rajar Agricultural
424 works, Mullampur, Punjab for fabrication of high clearance tractor platform and Jagajit
425 Industries, Cheema Mandi, Punjab, India for fabrication of relay seeder is thankfully
426 acknowledged. The support of PAU, Ludhiana for granting study leave for First author's PhD
427 thesis research under this study is also thankfully acknowledged.

428

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- 487
488
489
490
-

491 **Figure legends**

492

493 **Figure 1** Relay seeders seeding wheat in cotton with 67.5 and 101 cm row spacing driven by
494 high clearance tractor

495

496 **Figure 2** Relay seeders seeding wheat in cotton with 101 cm row spacing driven by high
497 clearance tractor

498

499 **Figure 3** Weekly average minimum, maximum temperatures and rainfall recorded in 2013-
500 2014

501

502 **Figure 4** Wheat establishments in 67.5 cm row spacing of cotton

503

504 **Figure 5** Wheat establishments in 101 cm row spacing of cotton

505

506 **Figure 6** Effect of Cotton wheat systems, Cotton row geometries and relay seeder furrow
507 openers on harvesting parameters of wheat

508

509 **Note:** Unit for establishment count is number m^{-2} , Effective tillers are in number m^{-2} , Grains
510 per spike are in Number spike⁻¹, and Test weight is in g.

511 STR- strip till rotor, ZTDD-zero till double disc, ZTT-zero till tine openers.

512 Values with for a dependent parameter (in a contrast group) with different letter are
513 significantly different at $p \leq 0.05$ and dependent parameters with same and no letter are
514 statically same for each contrast group.

515

516 **Figure 7** Effect of Cotton wheat systems, Cotton row geometries and relay seeder furrow
517 openers on wheat yield

518

519 **Note:** STR- strip till rotor, ZTDD-zero till double disc, ZTT-zero till tine openers.

520 Values with for a dependent parameter (in a contrast group) with different letter are
521 significantly different at $p \leq 0.05$ and dependent parameters with same and no letter are
522 statically same in each contrast group.

Table

[Click here to download Table: Tables.doc](#)*Table 1. Sub-plot treatment details for experiment 1.*

Treatment no.	Treatment abbreviation	Treatment details
T1	CTW	Conventional till wheat after cotton harvest. Irrigation was applied to standing cotton 4 days before stalk pulling. Seedbed preparation involved one discing followed by two comb harrowings and two plankings. Wheat was sown at a row-to-row distance of 20 cm, using a conventional four-wheel tractor drawn seed- cum fertilizer drill.
T2	12-row STR RS	12-row relay seeding with strip tillage. Relay seeding was done after 1 st picking of cotton on 14 th November, 2013, using strip tillage with no prior tillage. Three rows of wheat at 18-cm apart were sown in 67.5 cm row spacing covering 4 rows of cotton.
T3	12-row ZTT RS	Same as for T2, except zero till tine opener relay seeder used for seeding wheat.
T4	12-row ZTDD RS	Same as for T2, except zero till double disc opener relay seeder used for seeding wheat.
T5	MB-67.5 cm	Manual broadcast under 67.5 row spacing. Wheat seed was manually broadcasted in standing irrigation water after 1 st picking of cotton with 67.5 cm row spacing.
T6	15-row STR RS	15-row relay seeding with strip tillage in 101 cm row spacing. Five rows of wheat at 18-cm apart were seeded in between two rows of cotton and covering three rows of cotton. Other details are the same as in T2.
T7	15-row ZTT RS	Same as for T6, except relay seeder with zero-till tine openers was used for seeding wheat,
T8	15-row ZTDD RS	Same as for T6, except relay seeder with zero-till double disc openers was used for seeding wheat,
T9	MB-101 cm	Same as in T5

Table 2. Details of on-farm trials conducted at different location in district Bhatinda in Punjab (India) during 2013-14.

Location	Longitude (degree)	Latitude (degree)	DOS	
			RS	CT
Machhana	30° 3' N	74° 51' E	25-11-2013	30-11-2013
SangatMandi	30° 9' N	74° 58' E	30-11-2013	11-12-2013
Malwala	30° 3' N	74° 54' E	1-12-2013	10-12-2013
Bhagwanghar	30° 4' N	74° 55' E	3-12-2013	9-12-2013
Jodhpur Romana	30° 9' N	74° 54' E	3-12-2013	8-12-2013

Table 3. Growth and yield attributing characters of cotton and seed yield as influenced by different planting methods in cotton-wheat system

Cotton-wheat system	Plant height	Number of mature bolls plant ⁻¹				Total bolls plant ⁻¹	Seed cotton yield (t ha ⁻¹)
		1 st picking	2 nd picking	3 rd picking	4 th picking		
A. Cotton Hybrids							
MRC 7017	128.6 (0.51)	9.8 (0.14)	16.1 (0.24)	8.0 (0.12)	2.5 (0.63)	36.4 (0.86)	2.17 (0.06)
RCH 776	129.0 (0.43)	9.8 (0.09)	16.1 (0.15)	8.0 (0.09)	2.5 (0.63)	36.4 (0.64)	2.17 (0.04)
LSD (p value)	NS	NS	NS	NS	NS	NS	NS
B. Crop establishment methods							
Cotton at 67.5 cm + relay wheat	128.5 (0.27)	9.7 (0.11)	16.0 (0.18)	7.8 (0.09)	3.7a (0.04)	37.3a (0.41)	2.23a (0.02)
Cotton at 101 cm + relay wheat	129.1 (0.74)	9.9 (0.16)	16.4 (0.26)	8.0 (0.06)	3.8a (0.06)	37.8a (0.6)	2.29a (0.04)
Cotton at 67.5 cm + Conventional wheat	128.8 (0.66)	9.8 (0.17)	16.0 (0.27)	8.1 (0.14)	0.0b	34.2b (0.58)	2.01b (0.03)
LSD (<i>P</i> 0.05)	NS	NS	NS	NS	0.0001	0.0003	0.0001

The values with in a column with different letter are significantly different at $P \leq 0.05$, standard error in parentheses

Table 4. Wheat emergence, grain yield and yield attributing characters as influenced by different planting methods in cotton-wheat system.

	Emergence (count m ⁻²)	Spike density (m ⁻²)	Number of grains spike ⁻¹	Grain weight (g)	Wheat Yield (t ha ⁻¹)
Cotton hybrids					
MRC 7017	146 (6.54)	286.9 (12.4)	51.0 (0.44)	44.7 (0.41)	4.61 (0.14)
RCH 776	147 (6.74)	300.7 (13.6)	51.6 (0.59)	44.7 (0.39)	4.60 (0.17)
LSD (p value)	NS	NS	NS	NS	NS
Cotton wheat system					
T1 (CTW)	180a (4.4)	236.5c (9.6)	46.7c (0.59)	39.9a (0.28)	4.25c (0.11)
T2 (12-row STR.RS)	169ab (4.3)	338.5a (11.5)	49.9b (1.13)	44.9bcd (0.68)	5.16a (0.11)
T3 (12-row ZTT.RS)	137c (3.6)	292.9b (17.1)	51.7ab (0.55)	45.6abcd (0.15)	4.65bc (0.21)
T4 (12-row ZTDD.RS)	174ab (3.7)	348.9a (12.0)	52.9a (0.84)	44.4d (0.28)	4.93ab (0.08)
T5 (MB-67.5 cm)	98d (5.1)	235.1c (10.4)	52.1ab (0.59)	46.0ab (0.34)	3.50d (0.11)
T6 (15-row STR.RS)	167b (4.0)	354.7a (11.4)	52.0ab (0.8)	45.7abc (0.25)	5.35a (0.21)
T7 (15-row ZTT.RS)	136c (2.6)	320.5ab (18.9)	51.4ab (0.87)	45.2abcd (0.40)	5.14a (0.15)
T8 (15-row ZTDD.RS)	172ab (2.4)	340.7a (14.1)	52.8a (1.12)	44.7cd (0.53)	5.08ab (0.25)
T9 (MB-101 cm)	87d (6.2)	176.9d (11.9)	52.3a (1.08)	46.2a (0.53)	3.36d (0.18)
LSD (p value)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Interaction AxB	NS	NS	NS	NS	NS

The values with in a column with different letter are significantly different at $P \leq 0.05$, standard error in parentheses

Table 5. Saving in time of planting and effect on wheat yield from 12 -row tractor operated RS with disc openers in on-farm trials conducted in district Bhatinda in Punjab (India) in 2013-14.

Location	Saving in days	Wheat Yield (t ha ⁻¹)		% Yield gain over CT
		RS	CT	
Machhana	5	4.85	4.53	7.2
SangatMandi	11	4.43	3.98	11.3
Malwala	9	4.85	4.75	2.1
Bhagwanghar	6	4.63	4.50	2.8
Jodhpur Romana	5	4.03	3.70	8.8
Mean	-	4.56	4.29	6.4
LSD (p value)	-	0.016	-	-

The values with in a column with different letter are significantly different at $P \leq 0.05$

Table 6. Variable costs (in Indian Rupees ha⁻¹) under different crop establishment methods in cotton-wheat system

Treatment	Variable cost ^a in wheat (Rs. ha ⁻¹)										Total Variable cost of cotton ^b (Rs. ha ⁻¹)
	cultivation cost	seed and seed treatment	Fertilizer cost	Seeding cost	pesticides cost	Irrigation cost	Harvesting and straw collection cost	transportation and marketing cost	Interest on variable costs	Total variable cost	
T ₁	3250	3190	5383	1437.5	2095	195	4500	1750	491	22291	53828
T ₂ , T ₃ , T ₄	0	3190	5383	3386	2095	195	4500	1750	461	20960	55228
T ₅	0	3190	5383	560	2095	195	4500	1750	398	18070	55228
T ₆ , T ₇ , T ₈	0	3190	5383	3386	2095	195	4500	1750	461	20960	55228
T ₉	0	3190	5383	560	2095	195	4500	1750	398	18070	55228

^a 1 Indian Rs = US \$ 0.0161

The values with in a column with different letter are significantly different at $P \leq 0.05$

^b Variable cost for the cotton is similar for all the treatments except the cost of one additional manual picking @ Rs. 1400

Table 7. Variable costs, gross income and net income (in Indian Rupees ha⁻¹) under different crop establishment methods in cotton-wheat system

Treatment	Total variable cost of CW, Rs. ha ⁻¹	Gross return, Rs. ha ⁻¹			Net income of the CW system, Rs. ha ⁻¹	Benefit cost ratio (BCR) of system
		Wheat	Cotton	CW System		
T ₁	76118	69095b (2800)	78195c (338)	147290b (2788)	71172b (2788)	1.94b (0.037)
T ₂ , T ₃ , T ₄	76187	79867ab (2856)	86775b (113)	166642a (2859)	90454a (2859)	2.19a (0.038)
T ₅	73298	56807c (1804)	86775b (113)	143582b (1905)	70284b (1905)	1.96b (0.026)
T ₆ , T ₇ , T ₈	76187	84381a (3852)	89310a (450)	173691a (4049)	97504a (4049)	2.28a (0.053)
T ₉	73298	54553c (5146)	89310a (450)	143863b (5254)	70565b (5254)	1.96b (0.072)
LSD	-	10967	1040.4	11236	11236	0.15

The values with in a column with different letter are significantly different at $P \leq 0.05$, standard error in parentheses

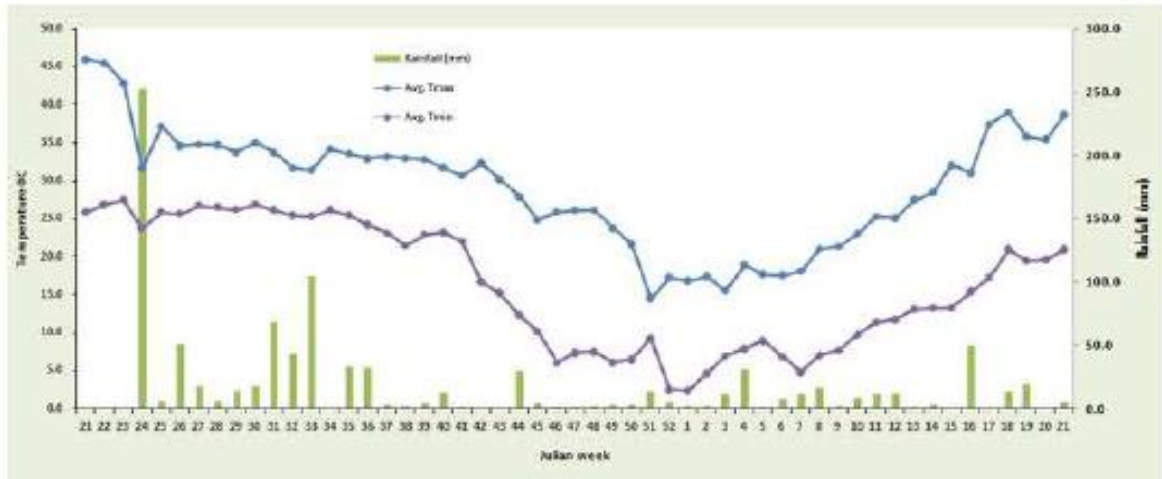
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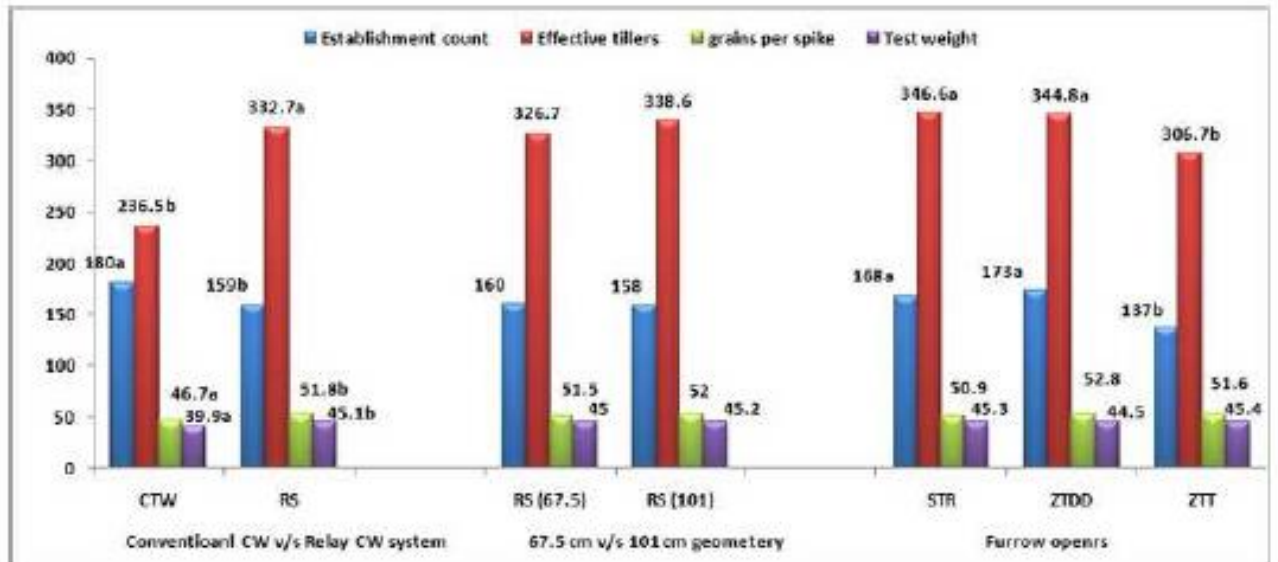
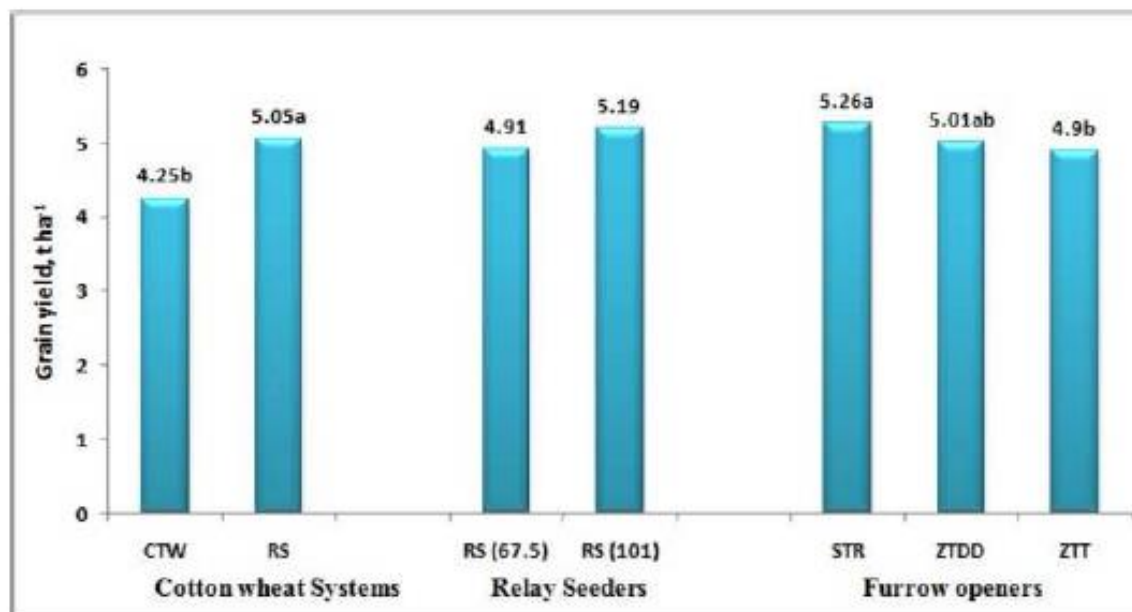


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Manpreet Singh - FMPE <msbham@pau.edu>

Agricultural Research: Submission Confirmation for Theoretical analysis of stability of High Clearance Tractor for moving in inclined terrain

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Theoretical analysis of stability of High Clearance Tractor for moving in inclined terrain --Manuscript Draft--

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Article Type:	Brief Research Article
Corresponding Author:	manpreet Singh, M.Tech Punjab Agricultural University, Ludhiana Patiala, Puerto Rico INDIA
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Punjab Agricultural University, Ludhiana
Corresponding Author's Secondary Institution:	
First Author:	manpreet Singh, M.Tech
First Author Secondary Information:	
Order of Authors:	manpreet Singh, M.Tech Jaskam Singh Mahal, PhD Gursahib Singh Manes, PhD
Order of Authors Secondary Information:	
Funding Information:	
Abstract:	A high clearance platform attachment for a four-wheel tractor was developed for relay seeding of wheat in standing cotton crop. The stability of the high clearance tractor was analysed in while the tractor at inform stability conditions. A computer program was developed to analyze the system to predict the effect of both the implement weight and the slope angle on the tractor stability and traction ability, and drawbar loading. The program was used to analyze a tractor system moving at uniform motion up and downhill. The results of this analysis showed that the normal tractor is safe to move at uphill ground slopes of 260 and 300 with a mounted implement of 600kg. The newly developed high clearance tractor with implement having weight of 600 kg is safe against pitching while moving uphill at ground slope of 240. The limiting ground slope for climbing by HCT without implement is also 240 (due to $F > F_{max}$. Therefore it can be concluded that the HCT with or without implement can move uphill at a slope of 24 degree. The normal tractor with same implement weight can climb at higher slope as compared to HCT. Also, The normal tractor with implement is safe for pitching while moving downhill slope of 50 degree. However, the HCT may overturn at 45 degree downhill slope.

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THEORETICAL ANALYSIS OF STABILITY OF HIGH CLEARANCE TRACTOR FOR MOVING IN INCLINED TERRAIN

Manpreet Singh, Jankaran Singh Mahal and Gurshahib Singh Maner

Abstract

A high clearance platform attachment for a four-wheel tractor was developed for relay seeding of wheat in standing cotton crop. The stability of the high clearance tractor was analysed in while the tractor at inform stability conditions. A computer program was developed to analyze the system to predict the effect of both the implement weight and the slope angle on the tractor stability and traction ability, and drawbar loading. The program was used to analyze a tractor system moving at uniform motion up and downhill. The results of this analysis showed that the normal tractor is safe to move at uphill ground slopes of 25° and 30° with a mounted implement of 600kg. The newly developed high clearance tractor with implement having weight of 600 kg is safe against pitching while moving uphill at ground slope of 24°. The limiting ground slope for climbing by HCT without implement is also 24° (due to $F = F_{max}$). Therefore it can be concluded that the HCT with or without implement can move uphill at a slope of 24 degree. The normal tractor with same implement weight can climb at higher slope as compared to HCT. Also, The normal tractor with implement is safe for pitching while moving downhill slope of 50 degree. However, the HCT may overturn at 45 degree downhill slope.

Keywords: Tractor stability, High Clearance tractor, Pitch, Skid.

Introduction

The traditional four wheel tractors with ground clearance of around 45 to 50 cm cannot move in the standing cotton field as the plants are about 100 to 130 cm tall. To address this issue, a high clearance platform attachment for a four-wheel tractor was developed in collaboration with International Centre of Maize and Wheat Improvement- Borlaug Institute for South Asia (CIMMYT-BISA), India, and Punjab Agricultural University, (PAU) Ludhiana, India and was got fabricated from a local machinery manufacturer Rajar Agricultural works, Mullana, Ludhiana (Punjab), India. This platform increased the ground clearance of the tractor to 110 cm to make the tractor move easily above the standing cotton. The track width of mounted tractor was increased by 1.5 times the standard one (from 135 cm to 202.5 cm), which enables high clearance tractor (HCT) to move in both 67.5 and 101.0 cm row geometries of cotton. Any traditional tractor (ground clearance ~45 cm) can be converted to high clearance tractor by mounting on high clearance platform in 4 to 6 hours, Fig 1.

The increased ground clearance of this high clearance tractor can be a major source of fatal and serious farm work injuries. Globally, the death toll of tractor rollover accidents is more than 400, and approximately 16,000 people are injured each year (Abubakar et al. 2010). Therefore, tractor stability and the reduction of injuries related to tractor rollovers are areas addressed by many researchers (Yoder and Murphy 2000). Kise and Zhang (2006) declared, "The use of 'sensor in-the-loop (SIL)' online tractor attitude and motion simulation provides rollover warnings based on estimated look-ahead tractor attitude and motion status. The validation test results indicated that the SIL vehicle attitude simulator could predict the attitude and motion status of the vehicle

approximately 8 m ahead of its actual position with favourable and consistent accuracy at all test sites." Another effort to prevent tractor overturns is designing a chassis balancing system. In this regard, Mashadi and Neuroloahi(2009) designed an automatic control system (ACS) for a modified tractor to maintain its stability during work on steep side-slope lands. In this system, tractor stability was achieved by keeping the chassis at a horizontal level using hydraulic jacks, which received commands from ACS. Spencer (1978) developed a theoretical model for predicting the conditions of overturning and controlling the instability of 2-wheel drive tractors with towed implements. The minimum safe operating slope of a loaded silage trailer is 27%, at a path angle of 15 degrees from the straight line up the sloping ground. Ahmadi (2011) reported, "Three possibilities exist about a tractor that works on sloping lands while being subjected to position disturbances: 1- Stability 2- Instability due to overturn 3- Instability due to skid." He developed a dynamic overturning model for tractors operating across irregular sloping grounds. The mechanics and dynamical behaviour of a tractor-trailer system moving up and down on sloping ground under different operating conditions were theoretically simulated by Abu-Hamdeh and Al-Jalil (2004).

The purpose of this study was to analyse and compare the stability and traction ability of normal (ground clearance 45 cm) and high clearance tractor with Relay Seeder mounted at rear, while moving up or down on a sloping ground.

Materials and Methods

Stability of high clearance tractor

To study the stability of the tractor the CG of the normal and high clearance tractor was calculated by standard weighing technique (John *et al* 1989). In this analysis, the following simple assumptions were made:

- (i) Forward motion is uniform; this assumes constant implement forces and no acceleration.
- (ii) Lines of forces on wheels are either tangential or radial or may be resolved as such; wheel sinkage and tyre distortion (but not normal tyre deflection) are neglected.
- (iii) The tractor is symmetrical about the longitudinal vertical plane; all the forces and moments may be considered to act in this plane.
- (iv) Other forces, such as the change in position of the fuel and oil in the tractor on sloping ground, air resistance and other minor forces are neglected.

Notations

Symbol	Description	Symbol	Description
W	Weight of normal tractor (alone)	R_r	Soil reaction against the rear wheels of the tractor
W_i	Weight of Implement	R_r	Rolling resistance of the rear wheels of the tractor
W'	Weight of HCT (alone)	R_f	Rolling resistance of the front wheels of the tractor
R_f	Soil reaction against the front wheels of the tractor	β	Angle of the (uphill or downhill) grade relative to horizontal
F	Total of net traction force required at rear wheels of tractor	c	Coefficient of rolling resistance, 0.05
F_{max}	Required traction force for tractor	μ	Traction coefficient for dry ploughed soil,

		movement			0.55
1	X_1	distance of CG from rear wheel soil contact point (normal tractor)	X_2	distance of hitch point rearward of the rear axle of the normal tractor	
2					
3	X'_1	distance of CG from rear wheel soil contact point (HCT)	X'_2	distance of hitch point rearward of the rear axle of the HCT	
4					
5	X_3	wheel base of the normal and HC	Y_1	height of CG from ground for normal tractor	
6					
7	Y'_1	height of CG from ground for HCT			
8					

10 Considering the case of uniform forward motion with no acceleration, the inertia force and couples are omitted.

11 Summation of forces parallel to the direction of motion in Fig 2, we have

$$12 \quad F - R_1 - R_2 - W \sin\beta = 0 \quad \text{--- (1)} \quad (\text{Abu-Hamdeh and Al-Jalil 2004})$$

17 Summation of forces in the direction normal to the tractive surface, we have

$$18 \quad R_2 + R_1 - W \cos\beta - W_r = 0 \quad \text{--- (2)}$$

23 Taking moments about the contact point of rear wheel of tractor and soil surface, we have

$$24 \quad W_r (X_2) + R_1 (X_3) + W \sin\beta (Y_1) - W_1 \cos\beta (X_1) = 0 \quad \text{--- (3)}$$

29 Further, solving these equation for R_1 , R_2 , F and F_{max}

$$30 \quad R_1 = [(W_r X_2) - (W Y_1) \sin\beta] / X_3$$

$$31 \quad R_2 = (W + W_r) \cos\beta - (R_1)$$

$$32 \quad F_{max} = m R_2$$

$$33 \quad F = c(R_1 + R_2) + (W + W_r) \sin\beta$$

44 The slope angle was varied upto $\pm 51^\circ$ (for upward slope and down slope) with a step of 1 degree. The corresponding values of R_1 , R_2 , F and F_{max} were calculated using a visual basic program. The specification data for validated for JOHN DEERE 5038 tractor, Table 1.

50 Results and discussion

51 The effect of slope and implement weight on the different dependent parameters R_1 , R_2 , F and F_{max} is shown in the figure 3 to 10.

54 Stability of normal tractor moving uphill

55 The stability of the tractor is determined by the value of the soil reaction on the front wheels R_1 , which predict whether the tractor is stable ($R_1 > 0$) or unstable ($R_1 < 0$) and tend to turn over backwards. As expected, the soil reaction at front wheels was reduced with increase of slope angle, due to the phenomenon of weight

transfer. The tractor with implement load of 600 kg is safe to move uphill slope of 35° whereas, the same tractor without mounted implement is safer to move on ground slope of 48° , Fig. 3.

The traction force required for normal tractor varied from 100 kg to 2100 kg for different ground slopes and implement weight. As expected, the net traction force required to move up hill by the tractor increases with increase in slope angle of ground and implement weight. F_{max} is limited by the traction ability of tractor, it increases with slope angle and implement. The ground slope at which the tractor starts skidding ranges between 18 and 24 degrees for corresponding implement weight of 0 and 600 kg, respectively, Fig. 4. Therefore, the normal tractor with implement having weight of 600 kg is safe against pitching at ground slope of 35° but can never move on this slope due to tractor rear wheel skidding. Therefore, the limiting ground slope for normal tractor with 600 kg implement is 24° .

Stability of high clearance tractor moving uphill

The tractor with implement load of 600 kg is safe to move uphill slope of 24° whereas, the same tractor without mounted implement is safer to move on ground slope of 36° , Fig. 5 and Fig. 6. The ground slope at which the tractor starts skidding ranges between 24 and 30 degrees for corresponding implement weight of 0 and 600 kg, respectively. Therefore, the tractor with implement having weight of 600 kg is safe against pitching at ground slope of 24° at the same time with no skid of rear wheel (upto 24°). Also, the limiting ground slope for climbing by tractor without implement is 24° . Therefore it can be concluded that the HCT with or without implement can move uphill at a slope of 24 degree. The normal tractor with same implement weight can climb at higher slope as compared to HCT.

Stability of normal tractor moving downhill

As expected, the soil reaction at front wheels was increased with increase of downhill slope, due to the phenomenon of weight transfer towards front wheels. Therefore, Soil reaction at front wheels, $R_f > 0$ for all ground slopes and safe against pitching. The net traction force required to move downhill decreases with increase in slope angle and implement weight i.e. at steeper slopes the tractor moves down by its own weight, Fig. 7 and Fig. 8.

Similar trend of soil reaction at front wheel and traction force was observed for HCT. The HCT while moving downhill may pitch on front wheels as reaction on rear wheels becomes zero at ground slope of 45° , Fig. 9 and Fig. 10.

Conclusion:

The results of this analysis showed that the normal tractor is safe to move at uphill ground slopes of 25° and 30° with a mounted implement of 600kg. The newly developed high clearance tractor with implement having weight of 600 kg is safe against pitching while moving uphill at ground slope of 24° . The limiting ground slope for climbing by HCT without implement is also 24° (due to $F = F_{max}$). Therefore it can be concluded that the HCT with or without implement can move uphill at a slope of 24 degree. The normal tractor with same implement weight can climb at higher slope as compared to HCT. The normal tractor with implement is safe for pitching while moving downhill slope of 50 degree. However, the HCT may overturn at 45 degree downhill slope.

Acknowledgement

The study was financially supported by International Maize and Wheat Improvement Centre (CIMMYT) under OGLAR Research Program on WHEAT (CRP 3.1). The Land and other resources provided by BISA are thankfully acknowledged.

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Table 1: Specifications of the normal tractor and tractor mounted on the high clearance platform

Specifications	Normal Tractor	Tractor mounted on high clearance platform
Ground clearance, mm	0.45	1.10
Speed reduction (over normal)	-	17%
Track width, mm	1350	2020
Weight with operator, kg	2005	2545
Wheel base	1.97	1.97
CG (X, Y, Z), mm	924, 802.5, 675	808.7, 1137, 1001
Height of hitch point from ground	0.46	1.10
Distance of hitch point from rear axle	0.78	0.78



Fig. 1 Tractor (normal) and mounted on high clearance platform

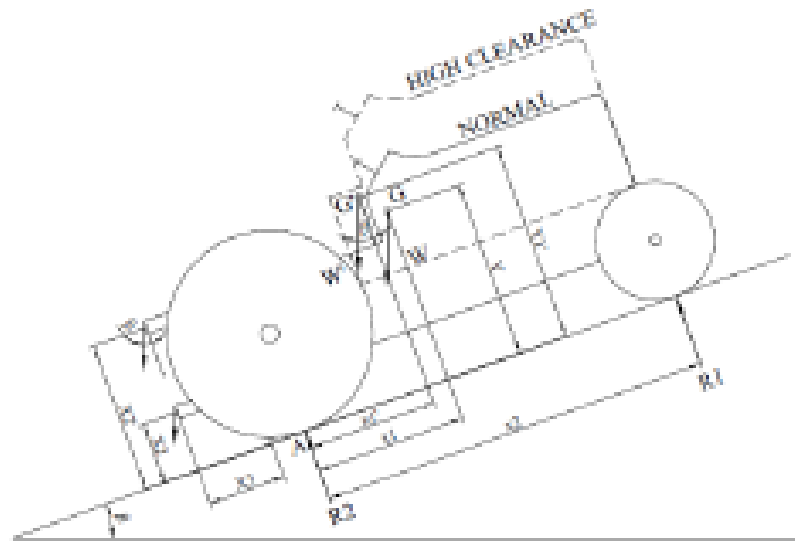


Fig. 2 Forces acting on the normal and high clearance tractor while operating on uphill slope (pitching)

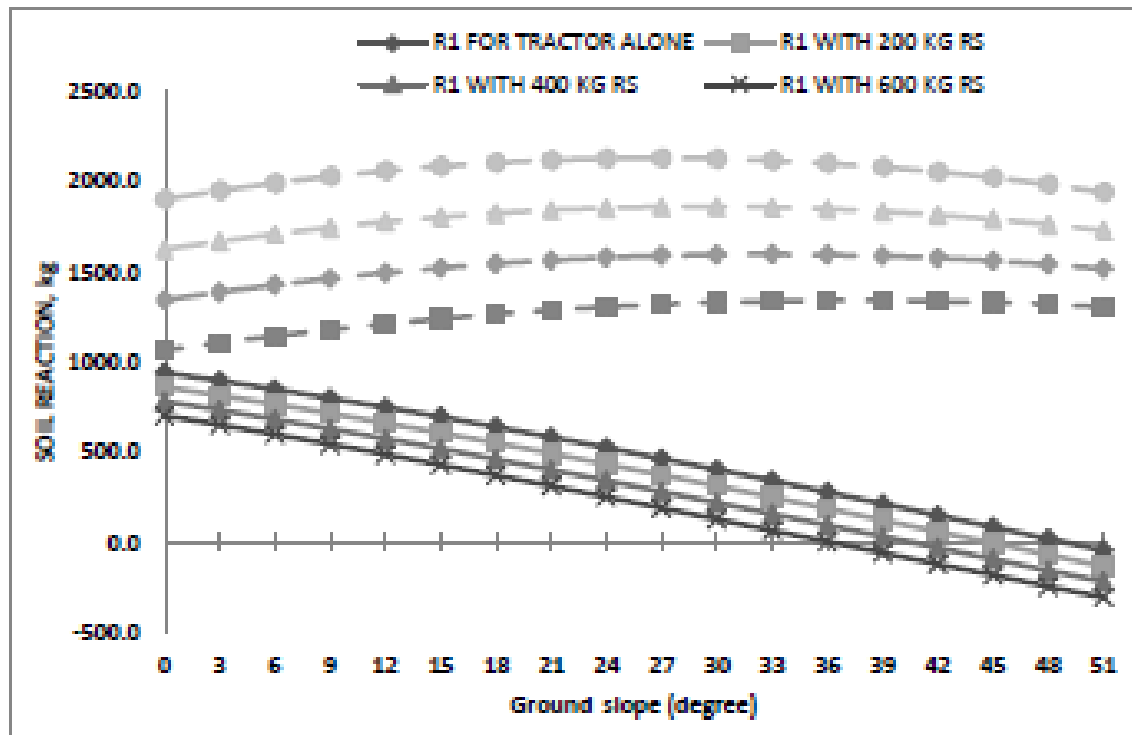


Fig. 3 Soil reactions at different ground slope at front and rear wheel of normal tractor while moving uphill

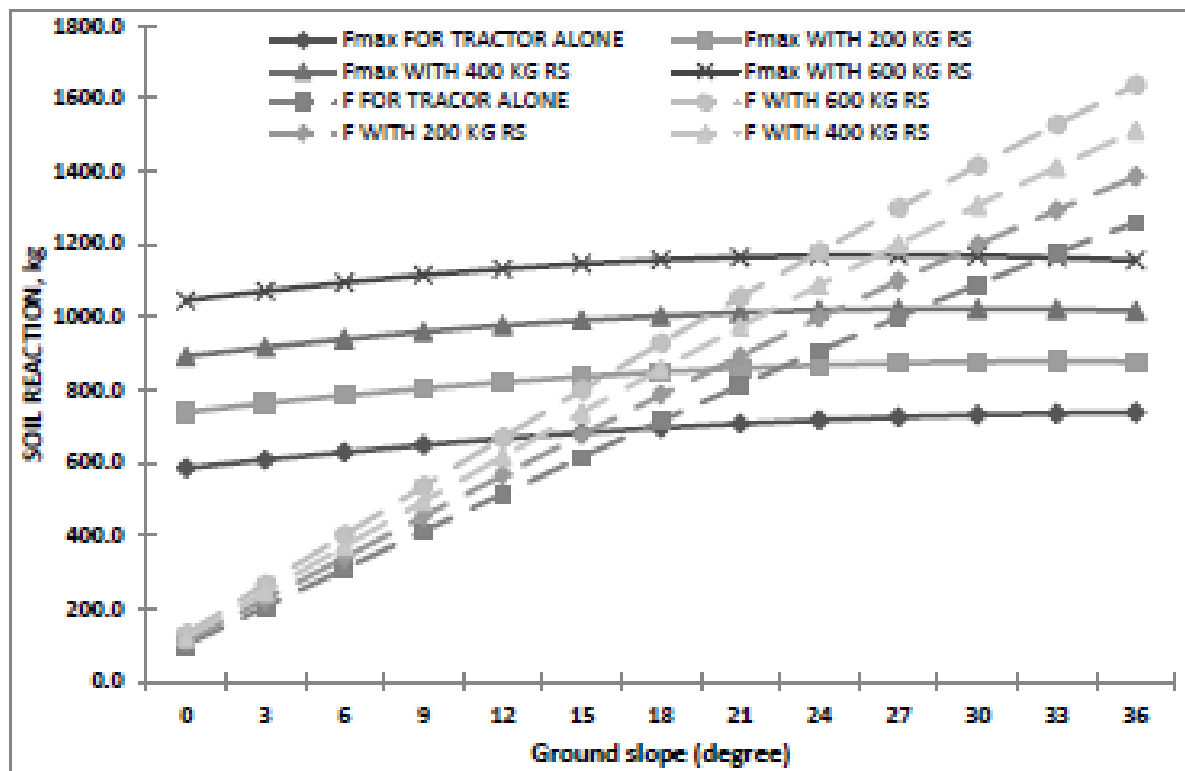


Fig. 4 Traction force required at rear wheels (F) and maximum traction force developed by the normal tractor (F_{max}).

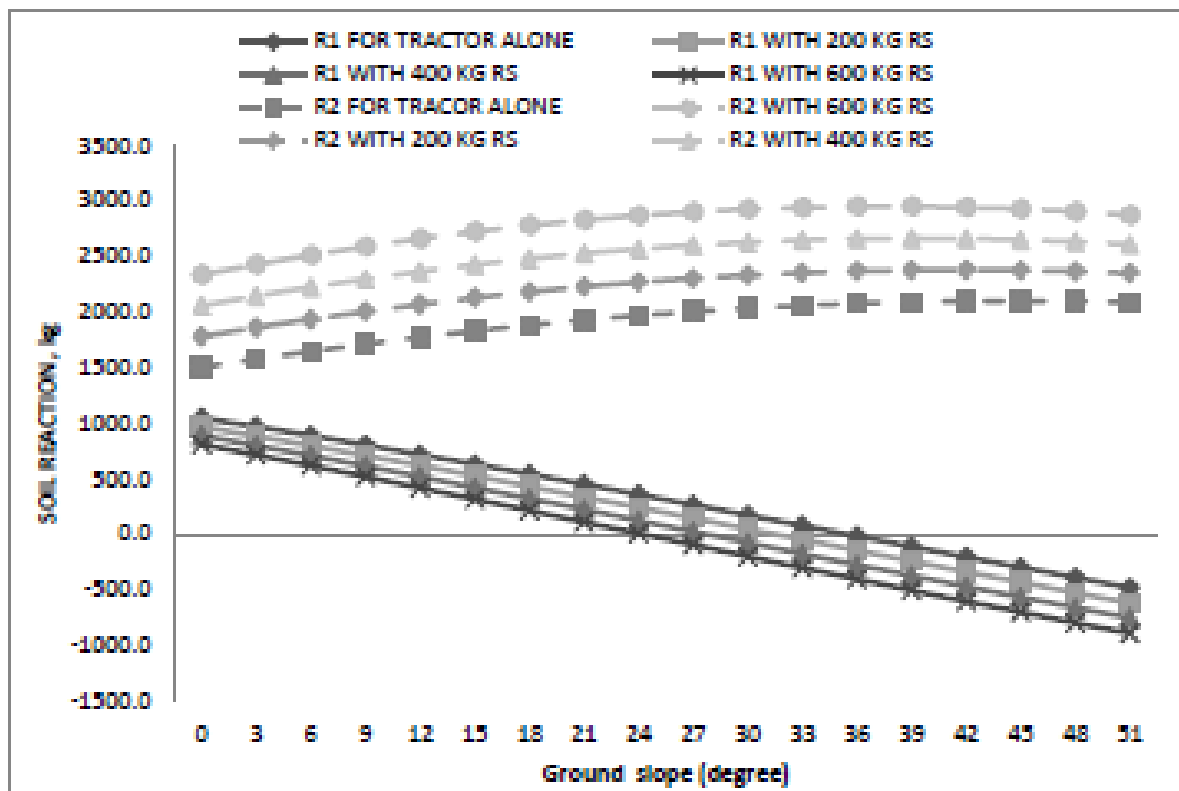


Fig. 5 Soil reactions at different ground slope at front and rear wheel of normal tractor while HCT uphill

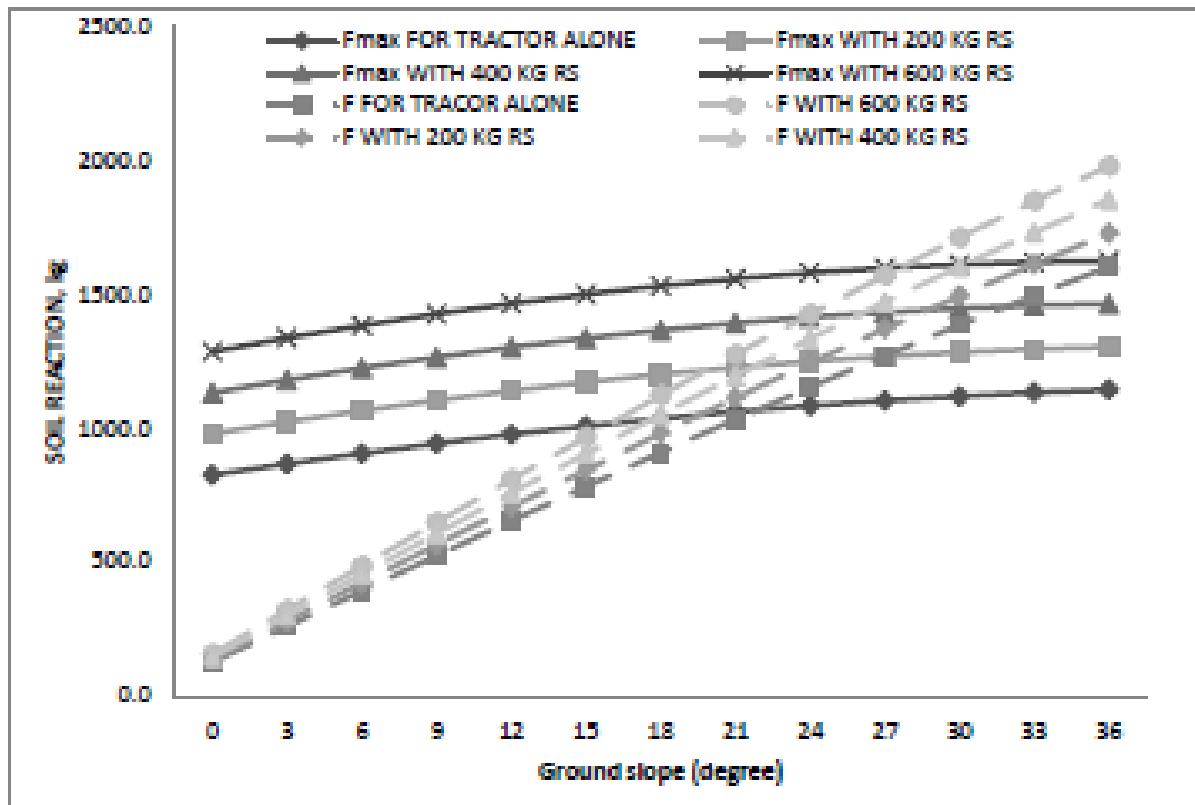


Fig. 6 Traction force required at rear wheels (F) and maximum traction force developed by HCT (F_{max}).

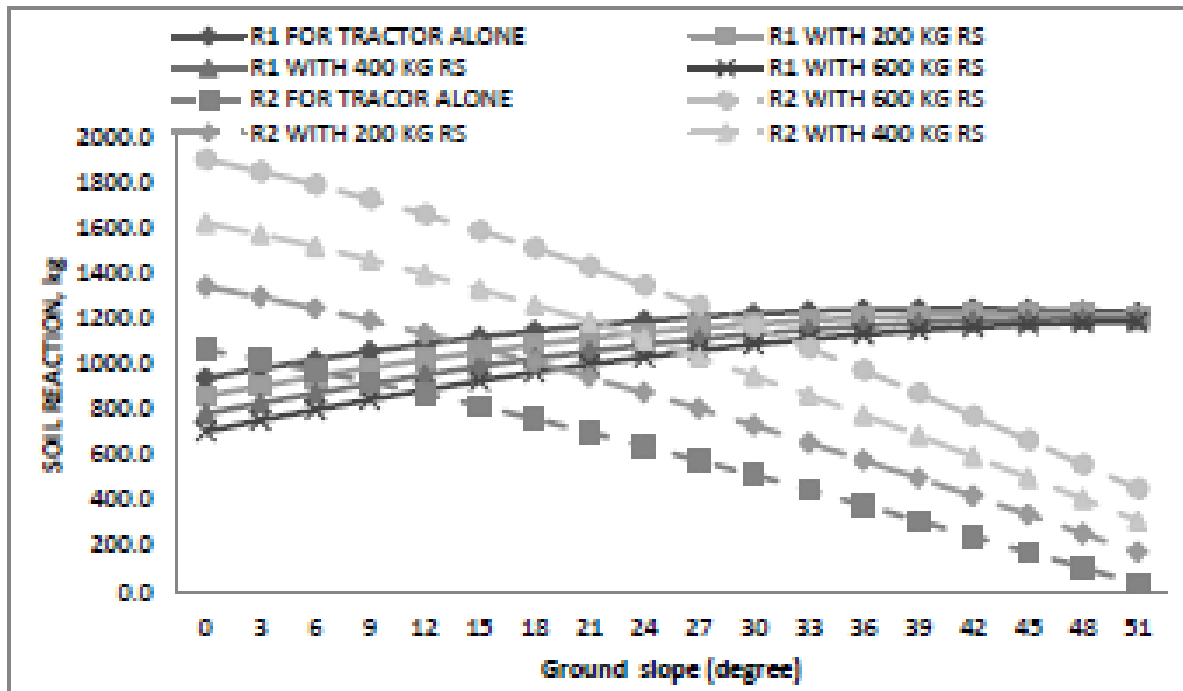


Fig. 7 Soil reactions at different ground slope at front and rear wheel of normal tractor while moving downhill

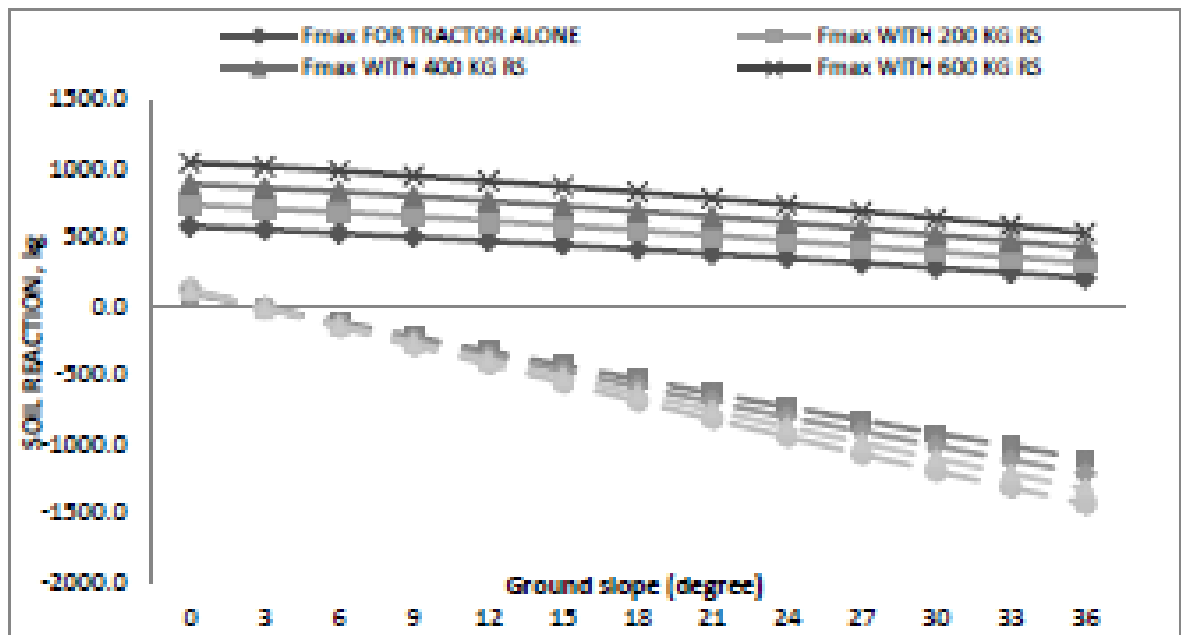


Fig. 8 Traction force required at rear wheels (F) and maximum traction force developed by the normal tractor (F_{max}).

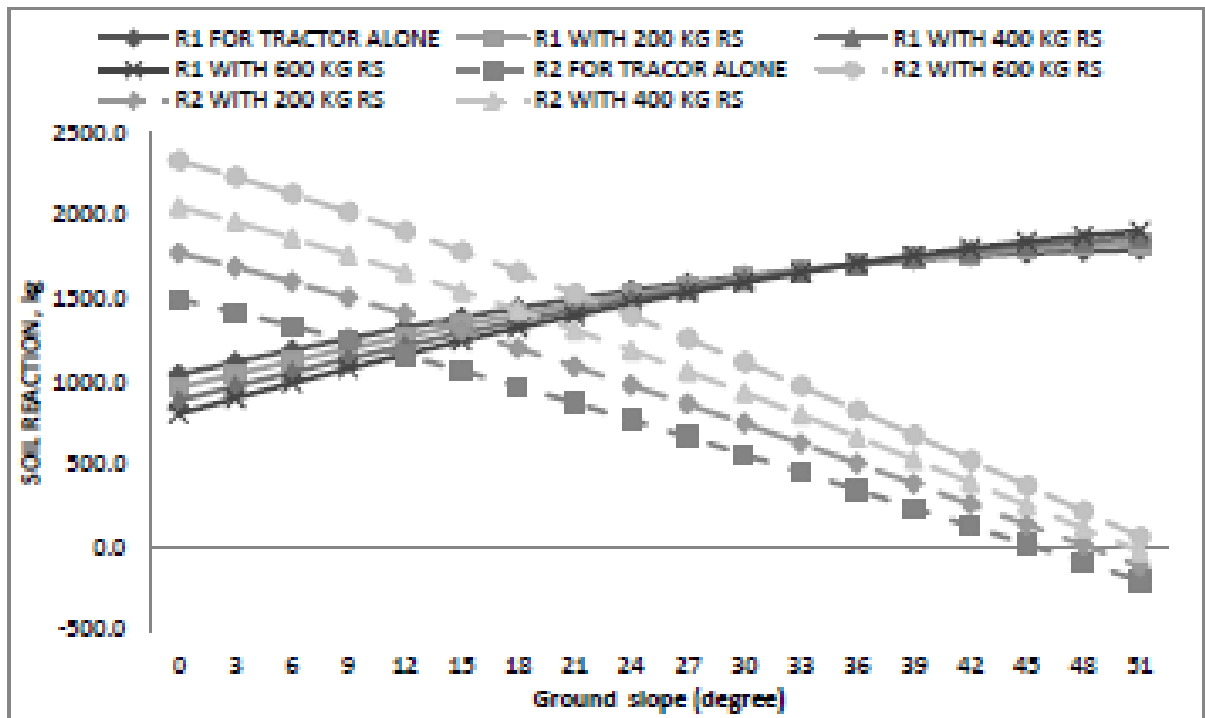


Fig. 9 Soil reactions at different ground slope at front and rear wheel of normal tractor while moving downhill

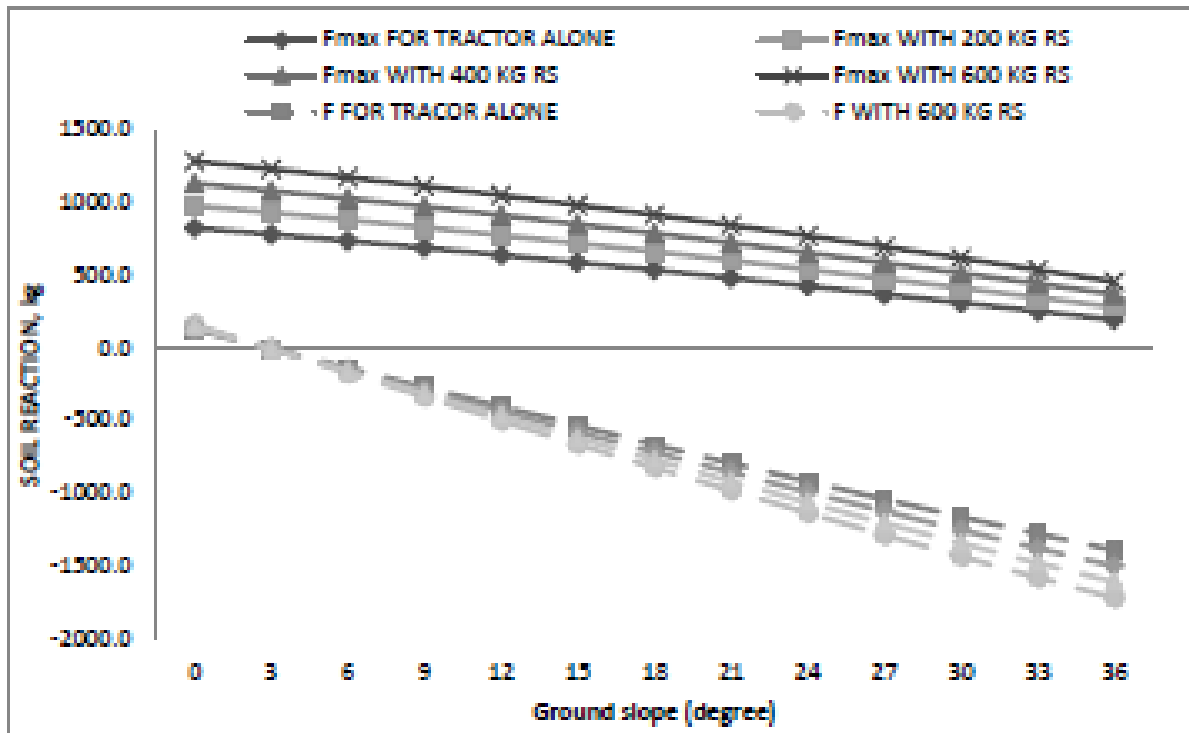


Fig. 10 Traction force required at rear wheels (F) and maximum traction force developed by the normal tractor (F_{max}).

VITA

Name of the student : **MANPREET SINGH**
Father's Name : S. Harjinderjit Singh
Mother's Name : Smt. Kanta Devi
Nationality : Indian
Date of Birth : 15-10-1979
Permant Address : H No 1354, Street No 13, Gurbax Colony,
Patiala-147001

EDUCATIONAL QUALIFICATION

Bachelor's Degree : B Tech (Agricultural Engineering)
University and year of award : Punjab Agricultural University, Ludhiana, 2001
OGPA : 7.11
Master's Degree : M Tech (Farm Power and Machinery)
University and year of award : Punjab Agricultural University, Ludhiana, 2003
OGPA : 7.62
Ph. D
University : Punjab Agricultural University, Ludhiana
OGPA : 8.41
Title of Master's Thesis : Design and development of straw push-through
assembly for a No-till drill
Awards/Distinction : Best M. Tech Thesis award by Indian National
Academy of Engineering (INAE) in year 2004
Publications
a) Research paper : 07
b) Book Chapter : 01