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Design and development of tractor-drawn onion (*Allium cepa*) harvester

TAPAN KUMAR KHURA[1], INDRA MANI[2] and A P SRIVASTAVA[3]

Indian Agricultural Research Institute, Pusa, New Delhi 110 012

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ABSTRACT

The commonly used manual harvesting of onion (*Allium cepa* L.) is time consuming, less efficient and full of drudgery so the mechanization of onion harvesting is essentially needed. Various crop-machine and operational variables related to design of mechanical onion harvester were evaluated in laboratory and field. The main components of the harvester were digging, conveying and separating units. Six different shape digging blades were evaluated for the digging efficiency. The minimum mean draft of 625.6N was observed for inverted V- shaped blade. The optimal design values of variables like length, speed ratio and slope of the elevator were determined as 1.2 m, 1.25:1 and 15°, respectively. During the field evaluation, the prototype onion digger, with the above design values, performed as per the recommended standards with digging efficiency 97.7%, separation index 79.1%, bulb damage 3.5%, fuel consumption 4.1 litre/ha (12.81 litre/ha) and draft 10.78kN. The saving in cost of onion digging/ha with the use of the developed digger in comparison to manual was found to be ₹1170/ha.

Key words: Damage percentage, Digging efficiency, Separation index, Speed ratio

Onion (*Allium Cepa* L.) is one of the important commercial bulbous vegetable crops grown in different parts of the world. In terms of area, India ranks first in the world with over 0.83 million ha (Anonymous 2009) but the productivity of onion in India is around 16.30 tonnes/ha, which is lower than the world average of 19.59 tonnes/ha as well as the Asian average of 18 tonnes/ha (Anonymous 2009). Mechanization of onion harvesting is needed as traditionally, the well-matured bulbs are harvested by hand shovel (*khurpa*) which requires 21.4% of total expenditure of onion cultivation (Jadhav *et al.* 1995). Also, it is necessary to complete the harvesting operation of onion within specified time limits for reduced harvest losses and higher storage life (Srivastava *et al.* 2001, Maw *et al.* 2001). In fact, early harvesting affects the keeping quality of onions adversely and reduces the yield, whereas delayed harvesting leads to infection caused by rot organism (Ashok 2003, Maw and Mullinix 1997, Maw and Mullinix 2005). A combination of machines for harvesting onions including the machine for removing onion leaves and weeds, the pull-type mounted onion digger, and the onion windrow pickup was developed by Penza State Agricultural Academy (Laryushin, *et al.* 2005). The pull-type mounted onion digger intended for two-stage harvesting of onion cultivars with field capacity 0.42–0.6 ha/hr, and digging efficiency is 98.0–98.9% (Laryushin and Laryushin 2009). But, the design was complex and not suitable for small land holdings due to high cost. For onion growers in India an economical partial mechanized onion harvesting would be a mechanical harvester which can dig the onion, help detaching soil and mixture, separating soil mass and finally windrowing the harvested crop which can be picked up manually. Although tractor-drawn elevator type potato diggers have been developed (Vatsa and Thakur 1993) but biometric properties of onion crop are entirely different from the potato. The aim of the study is to develop and evaluate a prototype of tractor-drawn onion digger and study its economic feasibility for adoption.

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[1]Assistant Professor (e mail tapankhura@gmail.com), CAEPHT, Ranipool Gangtok 737135;

[2]Senior Scientist (email maniindra99@gmail.com), Division of Agricultural Engineering;

[3]National Coordinator, NAIP, Room No 319, Krishi Anusandhan Bhavan II, New Delhi 110 012

MATERIALS AND METHODS

The harvester was designed to accomplish digging of onion crop, lifting the soil and onion with leaves from the field and subsequently transferring the digged onion onto a separation unit for removing soil mass from onion and finally windrowing clean onions in the rear for manually picking up with minimum damage to the onion bulbs and leaves.

The observations were taken on different biometric properties relevant to mechanical digging of onion 'Pusa White Round' cultivar at harvesting stage, i e 110 DAS. The mean length of the leaves of randomly selected 50 plants was used for designing the throat height of the digger and length of the conveyor. Similarly, mean depth of bulb with respect to ground surface was determined to decide the depth of harvesting and the equatorial and polar diameter were determined to design the spacing between the rods of the oscillating conveyor (Fig 1). The weight of onion crop was measured at the stage of harvesting which would help designing the capacity of the elevator of the digger (Khura *et al.* 2010).

Six shapes of digging shares, viz straight, convex, concave, triangular fork, inverted V and V-shaped blade, made of mild steel flats having 500 mm width of cut were selected for performance evaluation in soil bin having sandy loam soil with moisture content varying from 12 to 13% and bulk density of 1.35 to 1.45 g/cm^3.

An experimental set-up was designed and fabricated with provision for changing the length, slope and speed ratio (the ratio between the peripheral speed of the elevator and forward speed of travel) of elevator.The operational variables, eg forward speed, speed ratio and slope of the elevator were taken as independent variables. Digging efficiency, separation index and damage percentage were calculated as per the standards (BIS Test code, IS 13818:1993). The experimental unit was test run under actual field conditions by varying elevator length (1.0,1.2 and 1.5 m), slope (15°, 20° and 25°$^)$ and speed ratio (1:1, 1.25:1 and 1.5:1) using factorial randomized block design with three replications of each experiments. The design values were optimized based on the performance in terms of digging efficiency, separating index and bulb damage. Based on optimal design values of digger blade, conveyor slope, speed ratio and length of the conveyor, a prototype onion digger was fabricated.

Finally, the prototype onion digger was evaluated in the experimental fields in an area of 0.5 ha to harvest onion crop varieties 'Pusa White Round' during 2005 and 2006 at IARI research farm and the observations were recorded on number of onion remaining undug, damaged onion and total number of onion from the selected area and fuel consumed in a given time. The depth of operation of 75 mm was selected as 100% of the bulb were within 70 mm depth and this depth. The performance parameters like digging efficiency, separation index, damage percentage, field efficiency and fuel consumption were determined and critical differences were determined to test the influence at 5% and 1% level of significance. The cost associated with existing practice (manual digging) of onion was compared with the cost of operation of developed tractor-drawn onion digger making standard assumptions (Khura 2008).

RESULTS AND DISCUSSION

Biometric parameters of the onion crop were found important in deciding the range of the design variables of the onion digger (Khura *et al.* 2010). The percentage distribution of the onion below the ground surface indicated that 76% onion bulbs were within 0–5 cm and 94% within 0–6 cm, (Fig 1). The minimum equatorial and polar diameter of onion

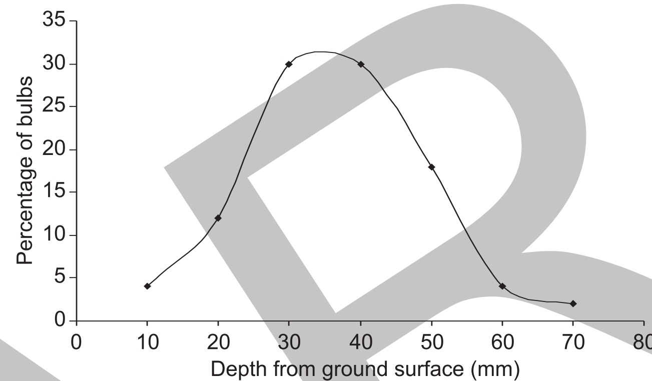

Fig 1 Distribution of bulbs below the ground surface

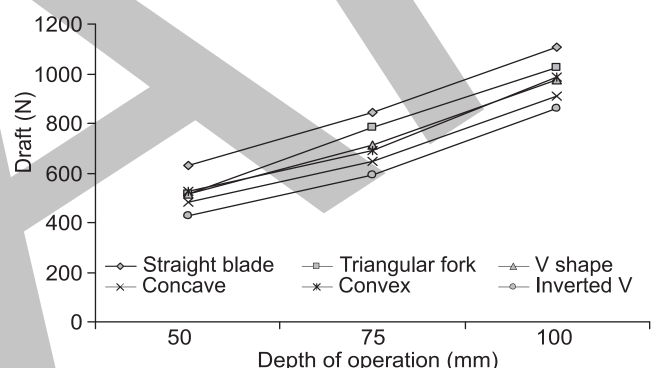

Fig 2 Effect of shape of blade on draft for different depth of operation

was more than 30 mm which helped selecting spacing between the bars of elevator conveyor of separating unit (Maw *et al.* 1996).

Design of digging blade

Influence of shape of blades on draft: All the six different shapes of digging blades experienced different draft, a variation of 42% in draft was observed between straight and inverted V shape blades (Fig 2). The minimum draft of 625.6 N was observed for inverted V shape blade, whereas maximum draft of 860.3N was observed for straight blades for operating depth of 75 mm. In fact, for different shape blades, the regime of soil failure and soil-acting forces are different. Also the tool geometry factors like macro shape, micro shape and surface roughness influenced draft in a significant manner. The degree of confinement of the soil as induced and controlled by the geometry of the cut substantially affected the draft force of the tool. In addition

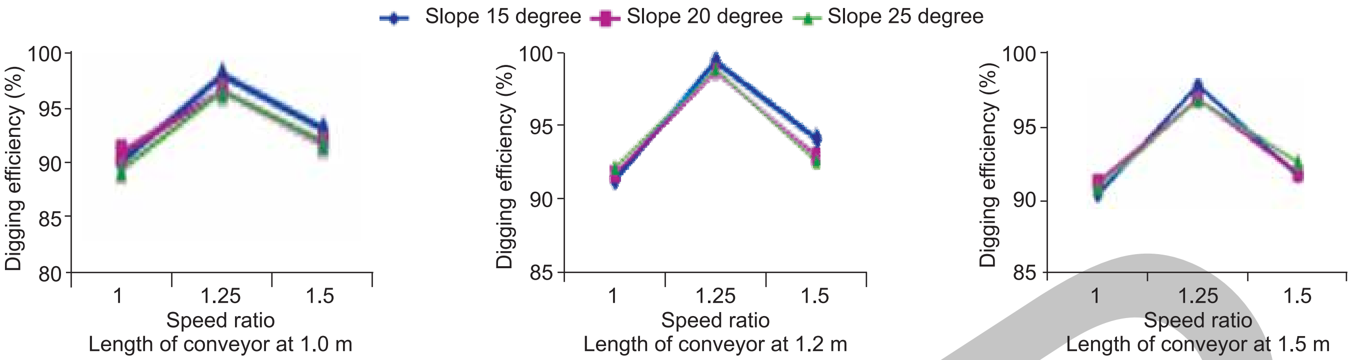

Fig 3 Influence of speed ratio, slope and length of elevator on digging efficiency

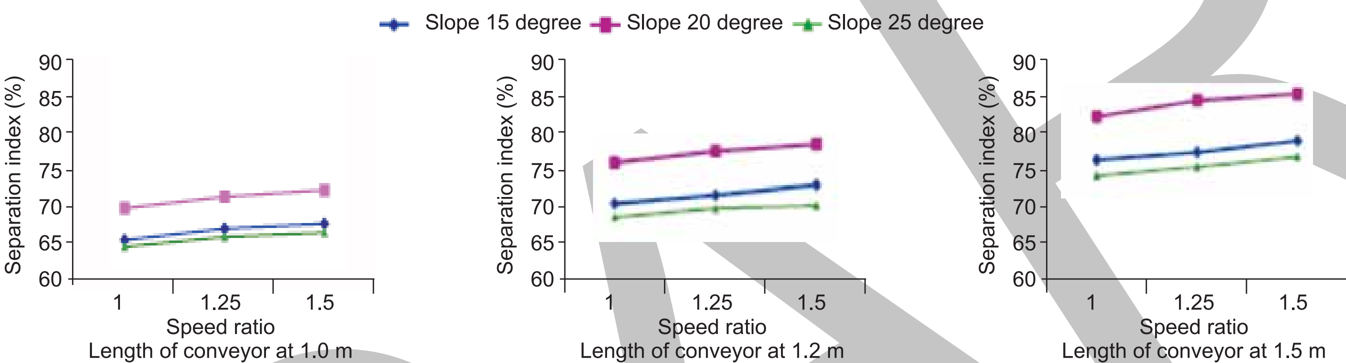

Fig 4 Influence of speed ratio, slope and length of elevator on separation index

to minimum draft, the inverted V type blade was able to give maximum recovery with minimum damage and bruise while digging. (Vatsa and Thakur 1993). Thus, inverted V shaped blade was selected for the design of the onion digger.

Design of separating unit

Influence of slope, length and speed ratio of elevator on digging efficiency: The digging efficiency was observed maximum at slope of 15° for all combination of speed ratio and length of elevator (Fig 3). A minor variation of 0.5%, in the digging efficiency, was observed when the slope of elevator was raised from 15 to 25°. The digging efficiency increased as speed ratio was increased from 1.0 to 1.25 but decreased with further increase in speed ratio. The digging efficiency was maximum at the speed ratio of 1.25 for all combination of variables. The increase in the speed ratio from 1.0 to 1.25, at 15° slope and 1.0 m length of elevator, resulted in 8% increase in digging efficiency but showed a decreasing trend when speed ratio was changed from 1.25 to 1.5 (Fig 3). Thus, a speed ratio of 1.25 was selected for design of the onion digger for increased digging efficiency.

Influence of slope, length and speed ratio of elevator on separation index

The separation index increased with the increase both in

Table 1 Influence of machine variables on separation index and damage percentage

	Length of elevator (m)			Slope of elevator (degree)			Speed ratio (speed of elevator/forward speed)		
	1.0	1.2	1.5	15	20	25	1.0	1.25	1.5
Mean separation index (%)	67.75	72.76	79.09	71.96	77.46	70.18	71.92	73.35	74.32
Coefficient of variation (%)	3.93	4.83	5	6.62	7.21	6.11	7.73	7.83	7.99
Standard deviation	2.66	3.52	3.96	4.76	5.59	4.29	5.56	5.74	5.94
Standard error mean	0.51	0.68	0.76	0.92	1.07	0.82	1.07	1.1	1.14
Damage percentage	2.94	4.88	6.25	3.89	4.71	5.47	3.46	4.68	5.93
Coefficient of variation (%)	51.6	23.94	19.33	52.85	36.87	28.05	44.9	35.18	27.26
Standard deviation	1.51	1.17	1.21	2.06	1.74	1.54	1.56	1.65	1.62
Standard error mean	0.29	0.22	0.23	0.4	0.33	0.3	0.3	0.32	0.31

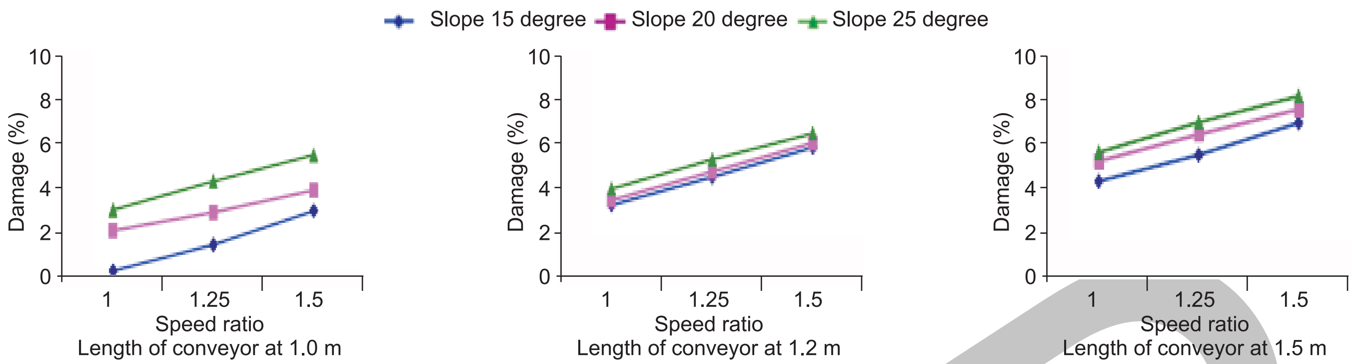

Fig 5 Influence of speed ratio, slope and length of elevator on damage

speed ratio and length of elevator, (Table 1). At 15° slope and 1.25 speed ratio and increase in elevator length from 1.0 to 1.5 m, the separation index increased by 16 % (Fig 4). The maximum separation index was observed for 1.5 m length of elevator for all combinations of speed ratio and slope because with increase in the length the soil-plant material got more conveying time and surface vibration. The slope also influenced separation index and the maximum separation index was observed at 20° slope of the elevator followed by 15° and 25°, respectively. For 1.5 m length of elevator and 1.25 speed ratio, 9% increase in separation index was observed for increase in slope from 15° to 20° however, a 10% decrease was observed when slope was increased from 20° to 25° (Fig 4). At higher slopes of elevator, the soil and bulb had tendency to move faster downward when the elevator was in motion and this caused the material to accumulate at the fag end instead of spreading over the whole length of the elevator which led to reduced separation. Similarly, at less than optimum slope the flow velocity and vibration level got reduced (2.5Hz). The mean separation index was observed as 71.72, 73.35 and 74.32% with coefficient of variation 7.73, 7.83 and 7.99 for three speed ratios, respectively (Table 1).

Influence of slope, length and speed ratio of elevator on damage: The damage of onion tops and bulbs was highly influenced by variations in the length and slope of the elevator and speed ratio of the digger at 1% level of significance. The length of the elevator caused maximum influence, followed by the speed ratio and the slope of the elevator (Table 2). The general mean of damage was 4.69% with standard error 0.35. The interaction of length of elevator with slope influenced the damage at 1% level of significance (Table 2). The increase in length of elevator from 1 to 1.5 m increased the damage of bulb by 1.25 times. The minimum damage was observed for 1.0 m length of elevator for different combination of other variables (Fig 5). Duration of contact of bulb and top with the rubber coated metal surface of the elevator was more for larger length of elevator. Thus, the damage caused by the friction to the onion bulb highly depended on the length of elevator.

Table 2 Influence of machine variables on damage percentage (ANOVA)

Source	DF	SS	Mean square	F value	PC > F
Replication	2	0.56	0.28	2.31	0.1089
Length (L)	2	150.19	75.01	615.40	<.0001**
Slope (S)	2	33.76	16.89	138.40	<.0001**
Speed ratio (V)	2	82.10	41.05	336.39	<.0001**
L*S	4	9.41	2.35	19.28	<.0001**
L*V	4	0.16	0.0396	0.32	0.8609
S*V	4	0.47	0.12	0.96	0.4356
L*S*V	8	0.34	0.04	0.35	0.9403
Error	52	6.35	0.12		
Total	80	283.35			
		General mean= 4.69		Standard error = 0.35	

*P=0.05, **P=0.01

Performance and cost economics of prototype onion digger: The final design values recommended were inverted V shape blade with 1.0 m length, 1.25:1 speed ratio, 1.2 m length of the conveyor and 15° slope of the elevator. The digging efficiency, separating index, and damage percentage obtained during field evaluation were, 97.7%, 79.1%, and 3.5%, respectively. The fuel consumption and draft were 12.8 litre/ha and 10.78 kN, respectively. The cost of onion digging with the prototype digger was ₹ 992/ha.

The saving in the cost of digging of onion with the use of the digger was to the tune of 44% of the cost of manual digging. The damage to bulb was within acceptable limit of less than 5%. The techno-economical evaluation revealed that the field capacity was 0.32 ha/hr and the break even point was 122.20 hr with the pay back period of 3.85 years. The machine is useful for onion cultivating farmers, particularly to those who are engaged in onion cultivation at commercial scale.

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