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DETERMINATION OF FORWARD SPEED EFFECT ON PLANTING UNIFORMITY IN A SUGARCANE BILLET PLANTER

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ABSTRACT Today's agriculture industry has become highly dependent on new technologies which result in better performances in terms of quality and quantity. In other words, new technologies contribute to higher productivity in agriculture sector of developing economies. Sugarcane as an industrial crop plays an important role in many countries. Precision planting in sugarcane plantations worldwide is a main concern mainly because saving in billets planted could decrease production costs and increase the profit in the form of an increase in sugar production from the billets being saved. This research was conducted to determine the effect of forward speed on planting uniformity in a sugarcane billet planter. The machine was designed and developed for precision planting and was able to pick single billets from a secondary hopper and place them on the furrow with a desired overlap of around 15 centimeters. Ground-driven power train was used to run the metering units, hence providing a constant billet overlap planting pattern according to the changes of forward speed. The planter was evaluated in the field based on the percent filling of the cupboards, over–overlapping and under-overlapping planting patterns as affected by planting speed, cane variety and angle of the chain conveyor structure from vertical line. The aim of this field evaluation was to determine the best operation speed and level of billet consumption rate. A split-split plot experiment with a completely randomized design was used to determine effect of speed of planting and angle of the chain conveyor on percent filling of cupboards, over-overlapping and under-overlapping indexes. Data obtained from experiments were analyzed using SAS statistical software. Results indicated that effect of speed of planting and angle of chain conveyor to vertical line on three parameters had a significant difference so that with an increase in speed of planting and decrease in angle of chain conveyor, under-overlapping decreased and percent filling of the cupboards and over–overlapping increased. Effect of the interaction of the cane variety and chain conveyor on under-overlapping and percent filling of cupboards was observed to be significantly different. For the best working condition, a planting speed of 2 km hr^{-1} for both cane varieties gives the best results. A Vertical angle of 30 and 25 degrees was found to be best suited for with and without debris varieties, respectively.

Keywords: Sugarcane; Planting Uniformity; Billet Planting

INTRODUCTION

Sugarcane is an important crop worldwide. Currently about 60% of the world's supply of sugar comes from sugarcane while the remaining 40% is produced from sugar beet. The top producers of sugar cane are Brazil and India. According to FAO (2009), sugarcane is cultivated in an area of about 27 million hectares with an average production of 75 ton ha^{-1}. Traditionally sugarcane has always been planted manually. However to reduce the cost of planting and drudgery and to enhance proper placement of fertilizer, machinery for sugarcane planting has been developed. These machines are basically of two types widely known as billet planters and cutter planters. In billet planters, pre cut sugarcane stalks of desired length commonly 25-50 centimeters are fed into the machine. The billets may be cut manually or mechanically. In the cutter planters, whole cane is fed by one or more labor for each row planting. Labors feed the stalks to the cutting unit, which cuts the fed cane in pre-determined length and carries it to the furrow.

Equal space between planted billets and proper overlap are two important performance characteristics of billet planters and cutter planters which could contribute to elimination of the cost of plant thinning operations and additional planting operations for filling the gaps created after main planting operation. Various factors may cause improper spacing of the billets which include inability of the metering units to pick up the billets from the secondary holding hopper or on time release of them to be placed on the furrows which ultimately results in greater spacing of the billets. Additionally, picking up several billets by the metering units results in less spacing of the billets. Moreover, form of the picking cupboards on conveying belt or chains of the metering unit, external coefficient of friction of the billets and the holding tank, velocity of the conveying chain carrying billets and other factors may affect the spacing of the billets on planting rows. Non-uniformity of billets' spacing generally depends on delivery method of billets to furrow surface and forward speed.

Subrata Kumar et al. (2008) fabricated a semi-mechanized sugarcane cutter planter. In this machine, whole stalk sugarcane fed by laborers sitting on the machine was cut automatically into pieces before dropping into furrows. It also used a furrow opener, applied fertilizer and fungicide and also covered the billets and pressed them with soil automatically. This planter was operated by a 35 hp tractor and had 2 units. The billet length was 31.8 cm with an average overlap of 6.48 cm observed at a speed of 2.5 km hr^{-1}. In Louisiana a sugarcane planter is used which works based on the plan suggested by Miren in 1995. This machine is equipped with a trailer containing billets which are hold in an almost vertical position. A conveyor chain on the bottom of the trailer carries the billets and feeds them to the metering unit. The metering unit consists of a drum equipped with holding grippers for transferring billets to ground surface. The drum and conveyor chains are hydraulically driven by hydraulic motors. An automatic two row billet planter has been developed in Taiwan equipped with a metering unit which has two conveying belts. The first belt is in the holding tank with 40 cupboards connected to it which transfers the billets to second belt for delivery to ground surface. An electronic eye is used to count the billets as planting operation goes on. The billet consumption of this machine is reported to be 8.5 ton ha^{-1} with a row distance of 1.5 meters. In Pakistan a sugarcane planter was developed which was powered by a 50 Hp tractor to reduce labor dependency in sugarcane plantations. Furrow opening, billet transfer to soil surface and covering the billets were all done by this machine which was equipped with an automatic metering unit receiving its power from a ground driven wheel. The planter was able to place 61 billets of 50 cm length in a distance of 25 meter with an inter-row distance of 90 cm. Uniformity of planting is a crucial aspect of precision planters. Billet planters which plant billets one by one follow the same rule as other precision planters as stated by Peters and Larsen (2002). They first determined the rate of billet consumption based on climate and geographical location of Florida in the US and then evaluated five different billet planters' performance which had different types of mechanism applied for billet transfer to ground surface (Figure 1).

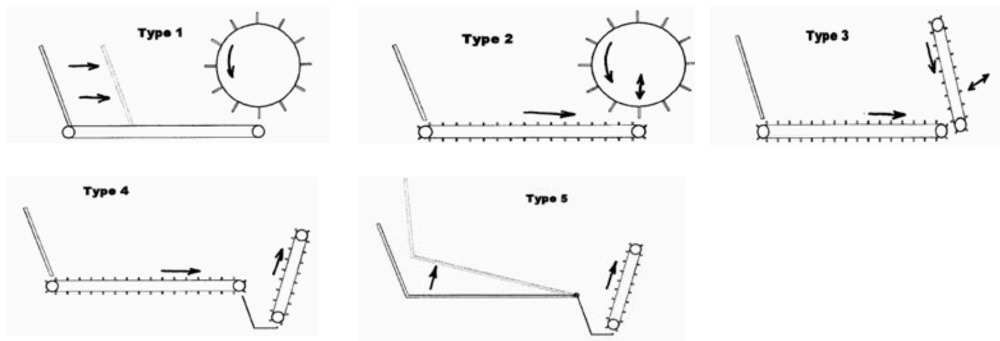

Figure 1. Mechanisms used in five different planters evaluated by Peters and Larsen (2002).

The first planter had a conveying belt on the bottom of the tank and its metering unit consisted of a spiked tooth drum for picking and separating billets. An inclined plate at the edge of the conveying belt was placed to direct and guide billets towards the drum. The second planter was similar to first one except that a conveying chain was used instead of conveying belt. In third planter two conveying chains, one on the bottom of the tank and another as the metering unit chain were used. A secondary tank was also provided for the chain to pick billets from. The metering chain was hitched to the tank so that its vertical angle could be changed accordingly. The fourth planter main tank had a conveying chain to move billets to a secondary tank same as the third one, except that the metering chain was fixed to the main tank. The fifth planter had a lifting hydraulic ram to gradually lift it for feeding billets to a secondary tank. As billets were moved to the secondary tank, a conveying chain picked and transferred them towards the drop chute. The five planters were compared to manual planting and the results were presented in figure 2. As it is shown, the least non-uniform pattern of planting belongs to the first type of planter (spiked tooth drum type metering with feeding belt) and as expected the highest uniformity was observed with manual planting since in this method of planting farmers have the most control and attention over planting operations.

The main objectives of this research were:

1- To determine best forward speed at which highest rate of planting uniformity is achieved.

2- To determine maximum filling index of billet cupboards and overlap pattern as affected by forward speed and type of cane variety.

MATERIALS AND METHODS

A two row precision billet planter with overlap planting pattern was designed and fabricated in the Farm Machinery Department technical workshop of Isfahan University of Technology (IUT) as shown in figure 3. Two metering units were designed based on

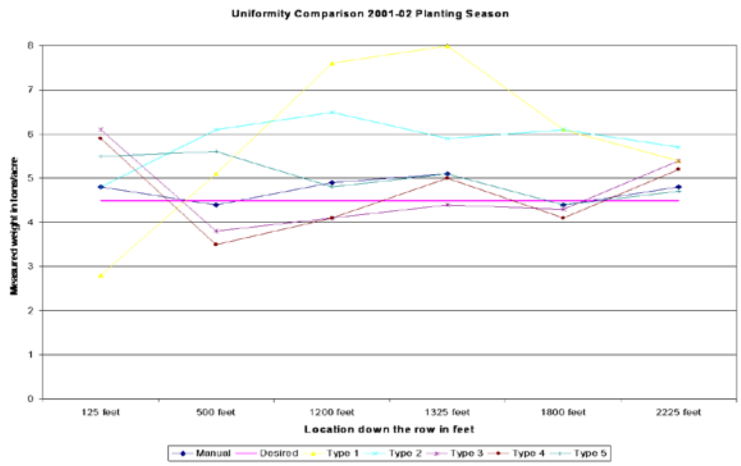

Figure 2. Comparative field performance results of five planters evaluated by Peters and Larsen (2002).

the Populin and Populin (1976) suggested plan and placed on a chassis with a ground driven power train system. Each metering unit was consisted of an upper and lower chassis which were hinged together at the middle part. This could enable the change of the vertical angle of the upper chassis. A series of cupboards were attached to conveying chains on chassis for picking single billets from a secondary holding tank. In case more than one billet was picked up by a cupboard, as that cupboard passed the point of deflection of upper chassis, it would drop down and therefore, only one billet would be transferred to soil surface. The metering units were placed face to face on the planter chassis and the secondary tanks were placed between them. Two furrow openers in the front of metering units were used to provide a furrow for placing billets inside with a distance of 50 cm. required power for rotation of metering units’ chains was provided from ground driven wheels through a differential with a gear ratio which was selected based on a predetermined overlap length. A clutch system was used to connect and disconnect the power flow to metering units while two hydraulic rams lowered and raised the planter drawbar for working in the field or putting the planter in transport position.

The planter was able to plant 50 cm length billets with an overlap of around 13.85 cm based on the gear ratio in the power train and space between each two cupboards on the metering unit chains and thus, change in the forward speed could not affect the overlap length. The overlap pattern of planting of sugarcane billets lowers the risk of missing germination at nodes and therefore minimizing the cost of filling the gaps by labor in the later stages of plant growth.

Field evaluation of the planter was done in experimental farm of the IUT in 2008. For the purpose of evaluation of the fabricated sugarcane planter, two factors of percent filling of cupboards and desired overlap pattern as affected by forward speed, angle of the metering unit conveying chain and variety of the cane were considered in a randomized experimental design with three levels of forward speed (2, 3 and 4 km hr^{-1}), angle of the metering unit as to vertical line with two levels (25 and 35 degrees) and variety of cane with two levels (with and without debris). Due to some restrictions such as lack of sugarcane billets it was decided to perform the experiments in a split- split design. Experiments were performed in three replications in experimental plots of 10*250 meters. After completion of each experiment as shown in figure 4, a measuring tape was used from the beginning to the end to record coordinates of each billet dropped on soil surface on a 240 meter length swath.

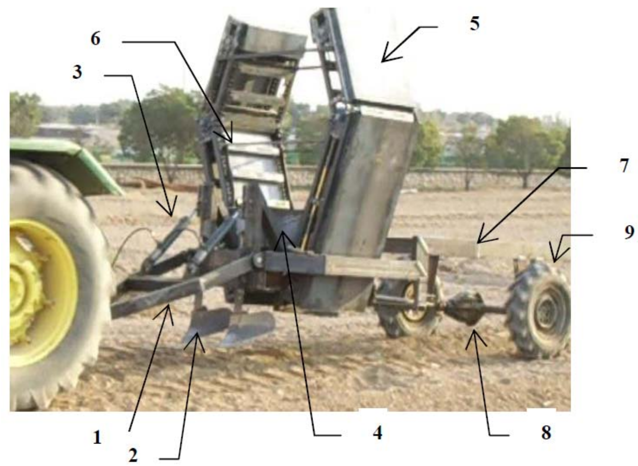

Figure 3. Different parts of evaluated billet planter: 1- Drawbar, 2- Furrower, 3- Hydraulic cylinder, 4- Billet hopper, 5- Metering unit, 6- cupboard,7- Chassis, 8- Differential, 9- Ground wheel

As shown in figure 4, at 2 km speed, billets were placed in the middle of the furrow and the overlap pattern was as desired, however with an increase in forward speed, not only the billets placement in the center of the furrow deviated but also the overlap pattern was not appropriate and even some billets were placed on the shoulders of the furrow.

Figure 4. Effect of forward speed on uniformity of planting

Measurement of Overlap Pattern

Billets placed in the furrows followed one of the patterns shown in figure 5.

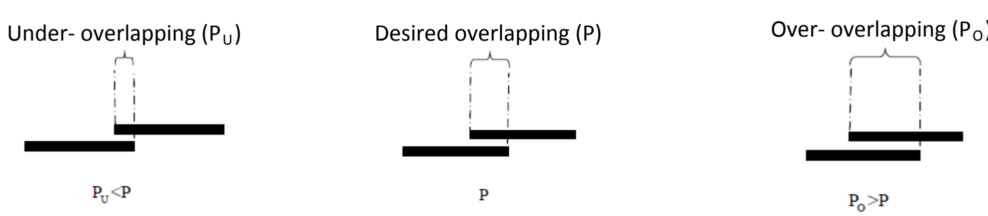

Figure 5. Billets position after being dropped on the furrows

According to figure 6, if end coordination of ith billet equals $(x_2)_i$ and beginning coordinates of next billet to be $(x_1)_{(i+1)}$, the overlap would be:

$$p_i = (x_2)_i - (x_1)_{(i+1)} \quad (1)$$

If the overlap of two consecutive billets is more than 13.85 cm it is said to have an over-overlap and if it is less then it is said to have an under-overlap.

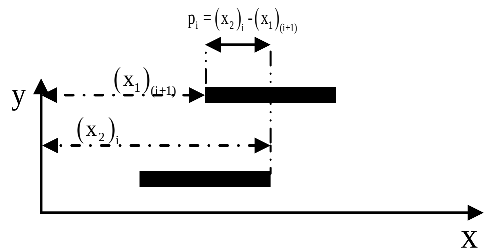

Figure 6. The method of overlap calculation

Measurement of Filling Percentage

An important parameter in evaluation of precision planters which plant one by one either seeds or billets is the filling index of the cupboards receiving from the holding tank. After each experiment number of billets on the furrow was counted on a distance of 240 meters which based on the design of the metering units and the power train should have been 664 billets as seen in equation 2. The equation is used to calculate the filling index of each metering unit in which N is the number of the billets placed on the furrow.

$$\text{Filling} = \left(\frac{N}{664}\right) \times 100 \quad (2)$$

After each experiment ideally an overlap of 13.85 cm must have been obtained, but due to some factors such as wheel slippage and reduced efficiency of the clutch in transferring power in higher speeds, desired overlap was not attained. Data collected was entered in files using Excel software and rate of overlap was calculated. The overlaps between 10- 15cm were considered desired and appropriate enough to meet agronomic criteria for proper growth of sugarcane. SAS software was used to analyze data statistically for determination of significance of factors affecting performance of the planter. LSD test was performed further for comparison of mean data having significant effect at 5 percent probability level.

Measurement of Uniformity of Planting Operation

This planter was designed to plant billets on a row in double lines with 50 cm apart. The actual widths of the rows are 90 cm currently in sugarcane plantations in Iran. The field capacity of the planter with a field efficiency of 80 percent and forward speed of 3 km hr^{-1} is 0.39 ha/hr. If average length and weight of the billets are 50 cm and 217.5 gram, respectively, then the planter theoretically would be able to plant 33942 billets with a total weight of 7.38 ton ha^{-1} with an overlap of 13.85 cm. After each experiment for determination of uniformity of planting in three forward speeds of 2, 3, and 4 km hr^{-1}, number of billets in 10 meter distances for both metering units were counted and mean values obtained for each pass. Assuming average weight of billets and number of them dropped on the ground, billet consumption per hectare and uniformity of planting was calculated.

RESULTS AND DISCUSSION

Table 1 presents the results of the analysis of variance of the effects of selected factors on filling and overlapping percent. As it is indicated, effect of the speed of planting had a very significant effect on experimental factors. Effect of angle of chain conveyor was significant at 1 percent level for filling percentage. No significant effect of variety on experimental factors was observed. This may be due to proper design of cupboards which can pick and carry both with and without debris cane varieties and also the fact that billets enter the cupboards properly and have reasonable balance as they are carried away and maintain high filling index. However, interaction effect of angle of chain conveyor and variety was significant at 1 percent level for filling percentage.

Table 1: ANOVA table for experimental factors

Source of variation	df	Sum of Squares	
		Filling percent	Overlapping percent
Variety (V)	1	262.83	69.39
V error	4	120.00	14.86
Main plot	5		
Angle of chassis (A)	1	243.55**	14.31
V*A	1	303.60**	50.74
A error	4	3.05	19.58
Sub-plot	6		
Speed (S)	2	1063.52***	245.02***
V*S	2	56.77	16.63
A*S	2	15.45	12.77
V*A*S	2	9.25	22.67
S error	16	23.44	8.92
Sub-sub-plot	24		
error	35		

Table 2 presents results of mean comparison of filling and overlapping percent as affected by experimental factors. As it is shown difference between primary levels of speed (2 and 3 km hr^{-1}) was not significant, but with increase in speed of planting to 4 km hr^{-1}, the difference was significant at 5 percent level. An increase in speed from 3 to 4 km hr^{-1} decreased filling and overlapping percent by 13.7 and 8.8 percent, respectively. On the other hand, an increase in angle of chassis from 25 to 30 degrees decreased filling percent by 5.2 percent which was significant. Percent filling of cupboards at 25 degree angle of upper section of metering unit compared to 30 degree angle was higher. The explanation for this condition is that at 25 degree angle maybe more than one billet sits in the cupboard and also as the conveying chain rotates and any given cupboard passes the point of deflection where the lower and upper chassis are joined together, possibility of detachment of extra billets from the cupboard diminishes as compared to 30 degree angle. Transfer of more than one billet by each cupboard would increase filling percentage statistically.

Table 2- Mean comparison of filling and overlapping percent as affected by experimental factors.

Experimental factors		Filling percent	Overlapping Percent
Speed of planting (km hr^{-1})			
	2	96.67[a]	19.32[a]
	3	92.35[a]	16.74[a]
	4	78.63[c]	10.53[c]
Angle of chassis (degree)			
	25	91.81[a]	16.16[a]
	30	86.61[b]	14.90[a]
Variety			
	Without debris	86.51[a]	14.14[a]
	With debris	91.91[a]	16.92[a]

Figure 7 shows the change in filling percentage of cupboards based on the change in forward speed. As speed increases both filling percentage and percent overlap pattern decreases. This may be because with higher speed levels there is not enough time for the cupboards to catch a billet and pass by the billets holding hopper empty. Additionally, because of wheel slippage at higher speeds, the desired overlapping pattern decreases. Therefore, parts of the field remains unplanted and should be replanted manually which increases production costs.

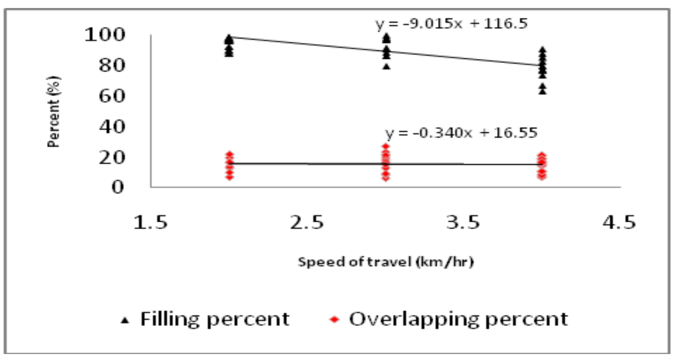

Figure 7. Graph of filling percentage changes of cupboards (triangles) and overlap pattern (diamond) affected by forward speed

Uniformity of planting for 2 km hr^{-1} is shown in figure 8. As seen in the figure in the middle way between 55-165 meter distances the uniformity of billet placement on the furrow is closer to desired condition. The points above the horizontal line represent higher amount of billet consumption more than 7.38 ton ha^{-1} desired level and points below the line represent lower consumption. Figure 9 presents the uniformity of planting for 3 km hr^{-1} forward speed. Most data points are located below the desired level of billet planting indicating that higher speed results in reduction of cupboards filling index or percentage at those points which the planter has passed by. Also, the overlap of consecutive billets put on the soil surface has decreased as compared to desired level of overlap.

In figure 10 the condition of uniformity of planting at 4 km hr^{-1} is shown. As it is evident the uniformity is much distorted compared to 2 and 3 km hr^{-1} speeds indicating in some points planting has not taken place at all and gaps exist in that points.

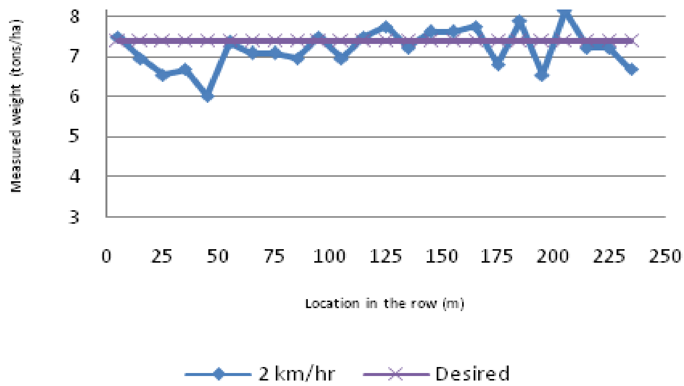

Figure 8. Uniformity of planting at 2 km hr^{-1} forward speed compared with desired level of billet consumption

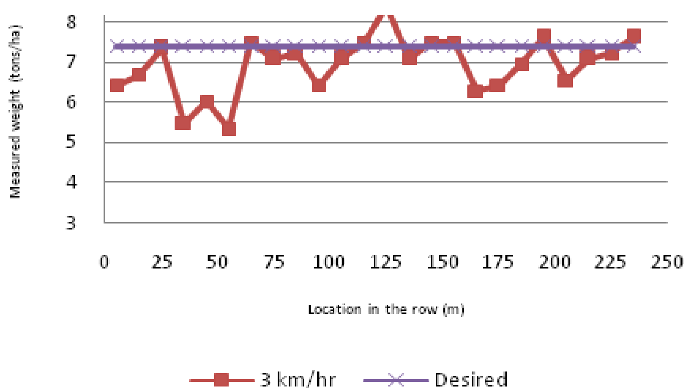

Figure 9. Uniformity of planting at 3 km hr^{-1} forward speed compared with desired level of billet consumption

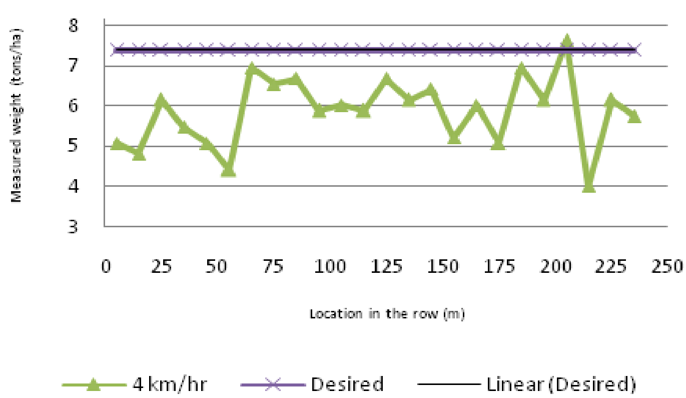

Figure 10. Uniformity of planting at 4 km hr^{-1} forward speed compared with desired level of billet consumption

A general comparison of planting uniformity at 2, 3 and 4 km hr^{-1} forward speed as related to desired level of planting and billet consumption is presented in figure 11. As indicated before, planting conditions at 2 and 3 km hr^{-1} are closer to desired condition, but at 4 km hr^{-1} the uniformity of planting is reduced.

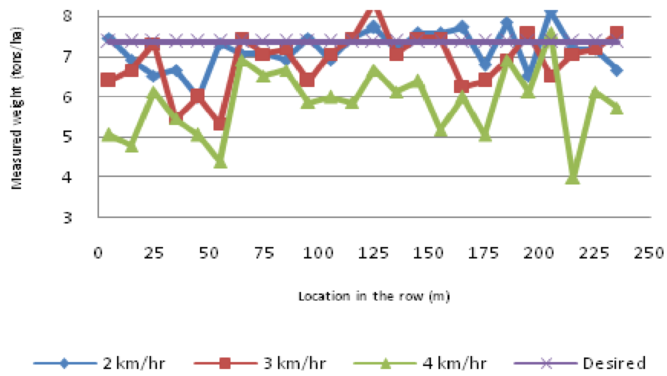

Figure 11. Comparative uniformity of planting billets at 2, 3 and 4 km hr^{-1} forward speeds

CONCLUSION

The results of field tests on a new billet planter designed and fabricated indicated that an increase in speed of planting would reduce filling index of cupboards and desired overlap of consecutive planted billets. In this research an increase from 2 to 4 km hr^{-1} would result in a decrease of 18 and 8.8 percent filling index and desired overlap, respectively. An increase in the angle of the chassis of metering unit from 25 to 30 degrees would decrease filling index by 5.2 percent. For the best working condition, a planting speed of 2 km hr^{-1} for two cane varieties planted gives the best results. A vertical angle of 25 degrees was found to be best suited for with and without debris varieties. It is concluded that this billet planter with operating speed of 2 km hr^{-1} and 25 degree for angle of the chassis of metering unit would provide a very desirable condition for proper planting of sugarcane billets and different varieties with or without debris.

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