

Characteristics of locally fabricated sugarcane grab loaders related to transport vehicles

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Abstract: Manual loading of sugarcane is an expensive slow operation which lasts for several hours, therefore, mechanical loading has been urgently required. To overcome the problems of the astronomical prices of self-propelled sugarcane loaders, the tractor attached sugarcane loader was designed and locally fabricated. The constructive and functional parameters of the front loaders mounted on agricultural wheel tractors have to satisfy the requirements of the working process and the dynamic stability and have to correspond to the structures of the tractors they are mounted on. This article aimed to study the geometry loader/vehicle relationship while loading and transporting sugarcane. Vehicles equipped for sugarcane transport include rail transport represented in decauvelle wagons and rail wagons. Road transport equipment such as trailers pulled by tractors and lorry are equipped and operated for sugarcane transport. Locally developed loaders are rigid boom loader type and articulated boom loader type. The geometry of loader/vehicle relationship was developed in the situation of loading to facilitate estimating loading capabilities of each type of the loader. Load density of mechanically loaded sugarcane vehicles may be lower than that when manually loaded. The main reason may refer to the chance given to the labor of the sword to cut the curved cane stalks where manual loading last for longer time. The loader of rigid dual arm of the boom could not be lowered in between the side columns of the sugarcane transport vehicle. The loader operator lifts the sugarcane bundle to a level over the side columns and leaves the cane dropping down forming lower density load. The front link of the articulated loader boom is of a single link that can be easily lowered down in between the side columns of sugarcane transport vehicles so that the cane bundle placed in more compressed form. Load density ranged from 0.298 to 0.304 t/m³. In case of manual loading a labor with a sward stands over the vehicle rearrange and cut the curved cane stalks. Vehicle load density of the mechanically loaded sugarcane ranged from 0.205 to 0.237 t/m³ in case of the rigid boom type loader compared to 0.267 to 0.272 in case of the articulated boom type loader.

Citation: Abdel-Mawla, H. A. 2016. Characteristics of locally fabricated sugarcane grab loaders related to transport vehicles. *Agricultural Engineering International: CIGR Journal*, 18(4):30-39.

1 Introduction

Huang (1989) reported that the hydraulic grab loader attached to a Ford 6600 tractor and able to turn through 360° was described and illustrated. The grab teeth are only 40 cm wide, i.e. less than the width of a furrow, in order to reduce the amount of dirt taken up with the piled cane. Field tests were conducted with four rows of manually cut cane laid in a pile across the ridges of two rows; the average dirt content was 0.7% and a field capacity of 26 t/h was achieved. Although the maximum capacity was 500 kg, a maximum load of 350 kg was better for the sake of stability. The total power rating was

49 kW (compared with an engine rating of 58 kW). The loader moved steadily on the road. Meyer (2000) stated that manual loading of sugarcane is usually carried out when the field conditions are poor, and where the annual tonnage handled does not justify mechanizes system. The main advantage of manual loading is low extraneous matter levels. The main disadvantage of manual loading is that it is expensive and time consuming, resulting in poor vehicle utilization and therefore increases transport costs. In most instances the first step in mechanizing the harvest operation is the acquisition of a mechanical loader. However, any cost savings made during the manual harvesting operation and/or increase in transport payload must justify and cover the costs of owning and operating the loader. In mechanical loading operation cutter performance is significantly improved as the manual cutter can now concentrate putting all his effort into

Received date: 2016-04-12

Accepted date: 2016-09-10

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cutting operation. Time and motion have shown that cutters spend about 30% of their time carrying sugarcane and building stalks in a cut and staking system. Abdel-Mawla (2000) stated that decauville slide lines and wagons are the principal transport system established for sugarcane delivery. The railway slide track which the decauville move expanded among cane fields. Decauville wagons are distributed (at the early morning) on the slide opposite to cane fields according to delivery schedule. Farmers load their cane on the assigned wagons before pull due time. Wagons are pulled to the mill reception and still waiting for unloading. Railway wagons used for transporting cane have similar conditions of the decauville system. The differences may only refer to the larger load of the railway wagon and the larger distance from the fields to the stores (stations) in which railway wagon/s park (Abdel-Mawla 2001). The role of alternative sugarcane delivery systems represented in lorries and tractor-trailers equipped for cane to mill transportation have been increased because of problems that face the main system (decauville slide lines and wagons). Cane transported from fields to stores at the main asphalt roads at which lorries and trailers loaded and travel to the mill. The use of tractor-trailers for direct transport of cane from fields to mill may have advantages especially at cane regions close to the sugar mill. Rehnberg (2008) stated that the wheel loader is a type of engineering vehicle used primarily to move crude materials over shorter distances. As the vehicle is designed without wheel suspension, wheel loader drivers are exposed to high levels of whole body vibration which influences ride comfort negatively. An analytical model is used to study the effect of front and rear suspension characteristics on the pitching response of the wheel loader, showing that a stiffer rear suspension is favorable for reducing pitching but also that a similar effect is attainable with a stiffer front suspension. Results are compared to multi-body simulations which show the same trend as analytical predictions. Colic (2009) developed a dynamic model to perform the hydraulic and

mechanical simulation of the loader system of a backhoe-loader. Instead of deriving and programming the hydraulic and mechanical system equations, physical simulation toolboxes inside MATLAB environment are used to model the hydraulic and mechanical systems of the machine. In conclusion, this dynamic machine model, which includes the hydraulic and mechanical systems, can be used in determining the dynamic loads on the joints and attachments of the backhoe-loader. Then, these dynamic loads may be used as an alternative loading condition for the stress analysis of the attachments. In addition, this model may be integrated into the design process in order to reduce prototyping time and costs during the design process Popescu and Sutru (2009). The loaders mounted at the front-end of agricultural wheel tractors represent cost-effective loading equipment. Computer simulation allows the study of the longitudinal stability of the systems through application for the constructive tractor-loader models. The front loaders mounted at the front-end of agricultural wheel tractors are increasingly employed for the mechanization of material loading and unloading operations into/from transport means or other locations on low and medium agricultural farms. The manipulation of both pallets and box-pallets in agriculture farms can be performed on the relatively short distances (within a hangar or between close locations) and on the vertical up to certain heights, using the forklift equipment mounted on the tractor rear hitch. The constructive and functional parameters of front and rear loaders mounted on agricultural wheel tractors have to satisfy the requirements of the working process and of the dynamic stability and have to correspond to the structures of the tractors they are mounted on. The braking of the tractor equipped with a front and rear loaders during descending a longitudinal slope with the filled bucket or forklift in transport position are in relation to the longitudinal stability of the system the most difficult situation of the traveling process. The authors explained that loaders mounted at the front-end of agricultural wheel tractors represent cost effective loading equipment.

Computer simulation allows the study of the longitudinal stability of the systems through application for the constructive tractor-loader models.

1) The front loaders mounted at the front-end of agricultural wheel tractors are increasingly employed for the mechanization of material loading and unloading operations into/from transport means or other locations on low and medium agricultural farms.

2) The manipulation of both pallets and box-pallets in agriculture farms can be performed on the relatively short distances (within a hangar or between close locations) and on the vertical up to certain heights, using the forklift equipment mounted on the tractor rear hitch.

3) The constructive and functional parameters of front and rear loaders mounted on agricultural wheel tractors have to satisfy the requirements of the working process and of the dynamic stability and have to correspond to the structures of the tractors they are mounted on.

4) The braking of the tractor equipped with a front and rear loaders during descending a longitudinal slope with the filled bucket or forklift in transport position are in relation to the longitudinal stability of the system the most difficult situation of the traveling process.

5) The dynamics of tractor-front end loader and fork lift loader systems can be analyzed by mathematical modeling of the equivalent dynamic models of the real systems, taking into account the exterior forces to which they are subjected in various working situations.

6) Based on the equivalent dynamical models of tractor-front end loader and fork lift loader systems it can be elaborated the mathematical model describing the dynamical behavior of the forklift truck during the descending on a slope by slowing down (braking) of the vehicle and acceleration of the fork while lifting the load.

Abdel-Mawla (2010) stated that mechanical loading of sugarcane in the Nile Valley in Upper Egypt is required to substitute for the decreasing availability of laborers for manual loading. Farmers have been striving to increase the number of loaders available. Practical

procedures can be developed to facilitate the operation of cane loaders with increased efficiency and productivity. Operational strategies which facilitate profitable operation of cane loaders will lead to a significant increase in the proportion of the crop which is mechanically loaded. Each farmer transports the cane from the field to be unloaded opposite to the wagon/s assigned. Several field to store transport vehicles to be used to maintain continuous loader of the loader. Loader operator loads all decauville wagons in the site and then move to the next site. The site should be wide enough to facilitate comfortable maneuver for the loader opposite to each wagon. Adequate quantity of cane should be ready in the site in case of mechanical loading. Loader operator may load several wagons considering loading the cane of each farmer in the wagons assigned. Each farmer should determine the quantity of cane that could be transported during loading and transport the rest of the wagons load at the former day. Worley and Saponara (2011) reported that the front-end loader is an indispensable machine for the off-road construction equipment industry. It is a classic example of a working machine with complex interactions between its subsystems (hydraulic, mechanical, and electrical). Dynamic models of the full-scale vehicle coupled with event-based operator models are currently used to help quantify the overall system performance, efficiency, and operability. However, these models are complex and not always necessary to characterize the response of individual subsystems. There is a great value added to the design process-specially in prototyping of new vehicle platforms-in development of simpler models that can quickly and accurately define first-order measures of system loads and performance. Abdel-Mawla (2012) stated that it seems that each country overcame the problems of the astronomical prices of self-propelled sugarcane loaders by fabricating the tractor attached sugarcane loader that match local conditions and compatible with their locally fabricated tractors. Consequently, a special design of the tractor attached loader should be prepared and fabricated to be

compatible with most prevailing tractor found in the sugarcane production area in Upper Egypt. Mechanizing sugarcane loading as a major farming/industrial activity will release labors from one of the most adverse operations, and develop the technical level of the people, save hard currency, save more job opportunities and secure higher labor income. Abdel-Mawla (2012) discussed the tractor mounted loader performs as cost-effective machine for a wide range of the infield loading. The cost balance of operating the tractor mounted sugarcane loader either in the site or in the field is always positive in achieving higher profit within wide range of operation efficiency. The custom operation of the tractor mounted sugarcane loader achieved the highest profit compared to the other agricultural machines. The cost of fabricating and commercial marketing of the loader is within the financial ability of all the farmers who hold such size of tractor. Abdel-Mawla (2014) reported the dimensions of the tractor-mounted-loader should be relative to the tractor size. The design of the loader bases should be compatible to the type of the tractor on which the loader mounted. Dynamic balance of the tractor-mounted loader in operation is the main condition that determines the size of the loader.

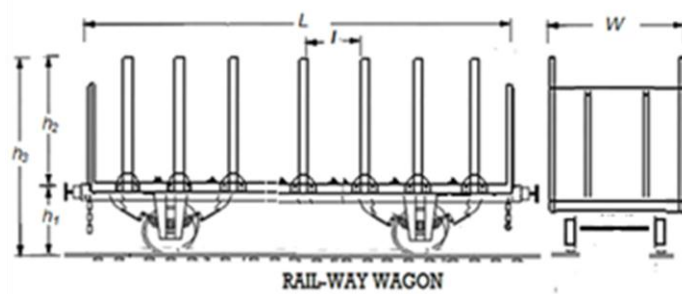
Optimizing the design of the tractor mounted sugarcane loader facilitates fabricating a balanced tractor front mounted loader that may load the transport vehicles to the maximum load height. Necessary measurements and computations were conducted to facilitate optimizing the design of the tractor front mounted loader without the need for counterbalance weights. The technique was used to compute the principle dimensions and to estimate the tractor longitudinal balance of the loader mounted on the medium size tractor. General formula was also developed to facilitate estimating the loader dimensions for a tractor with any size conserving the condition of balance.

2 Material and methods

Characteristics of vehicles used in sugarcane transport are related to mechanical loading:

(1) Rail transport: rail transport represented in:

- a. Decauville system (track, wagons and locomotives) that transport over 40% of sugarcane production. Decauville wagons move on narrow gage rail slide track that expanded among the sugarcane production fields.
- b. Railway wagons that transport about 4% of sugarcane production. Railway wagons move on the public railway line of Upper Egypt. The characteristics of rail transport Equipment are shown in Table 1 and Figure 1.



rail-way wagon

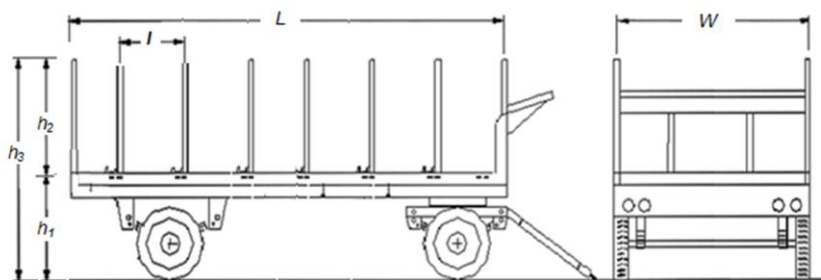
Figure 1 Schematic drawing of railway wagons equipped for sugarcane transport

(2) Road transport: road vehicles that travel on asphalt roads are trailers and lorries equipped for sugarcane transport.

- a. Trailers (Figure 2) pulled by variable medium size agricultural tractors are of two sizes, namely; common size agricultural trailers and large trailers.

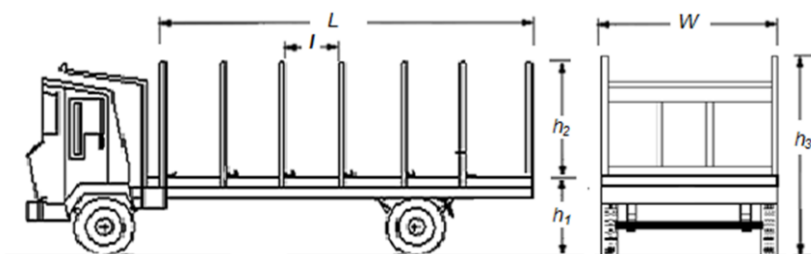
- b. Lorries (Figure 3) of various types equipped with side columns for sugarcane transport.

The most necessary characteristics of sugarcane road transport equipment are related to mechanical loading also presented in Table 1.



agricultural trailer

Figure 2 Schematic drawing of agricultural trailer equipped for sugarcane transport



lorry equipped for sugarcane transport

Figure 3 Schematic drawing of a lorry equipped for sugarcane transport

Table 1 Characteristics of transport equipment related to sugarcane loading

Item	Symbol	Rail transport		Road transport		
		Rail	Decauville	Small trailer	Large trailer	Lorry
Width of loading box/m	W	2.4	1.8	2.0	2.4	2.4
Length of loading box/m	L	8.0	6.0	4.0	6.0	8.0
Height of loading surface from ground/m	h_1	1.30	0.75	1.20	1.5	1.4
Height of side columns/m	h_2	1.75	1.50	1.50	1.75	1.75
Spaces of side columns/m	l	1.0	1.0	1.0	1.0	1.0
Max height of load over columns/m	h_3	1.25	1.00	0.75	1.25	1.25
Max load height from ground surface/m	H_L	4.25	3.25	3.50	4.50	4.50
Saif load/t	S_W	14	10	9	18	16

(3) Characteristics of locally developed sugarcane loaders:

Design criteria of the locally developed tractor mounted sugarcane grab loaders may be presented as follows:

- a. The sugarcane loader should be a tractor front-mounted loader.
- b. The sugarcane tractor mounted loader should be removable, i.e. the farmer can easily remove the loader to release the tractor for other farm operations.

- c. The basis on which the loader mounted should be compatible to the most popular tractor of sufficient power.
- d. The basis should be designed with a manner to maintain maximum support to the tractor chassis against the stresses due to the loader overloading.
- e. The bases should transfer the loader stresses to a position as near as possible to the center of gravity of the tractor.
- f. The loader should be assembled to the basis as front oriented front mounted loader.

- g. The first version of the loader should be a push arm operated type to avoid the complication of other possible designs.
- h. The loader should be powered by the tractor hydraulic system (to avoid the need of additional hydraulic pump or hydraulic tank).
- i. As a first version, the loader was capable to load cane to height up to 3.8 m. Next versions could be developed for loading at more heights considering the experience of operating the first version and more training of operators for the safety against tractor overturn probability.
- j. The loader arm should be strong enough and at the same time of reasonable weight.
- k. The grab should be of simple design strong enough and of light weight as much as it could be.
- l. The loader-grab should be hinged to the front end of the arm and clamped to a hydraulic link where it could be turned down for discharge at any position of the arm.
- m. Operator should have clear view of the lowered grab while collecting cane pile and clamping.

Figure 4 shows the most effective parameters of the locally developed tractor mounted sugarcane loader from which two types namely, rigid boom dual arm loader and articulated boom loader were fabricated. Table 2 shows the most important characteristics related to loading operation on sugarcane transport vehicles.

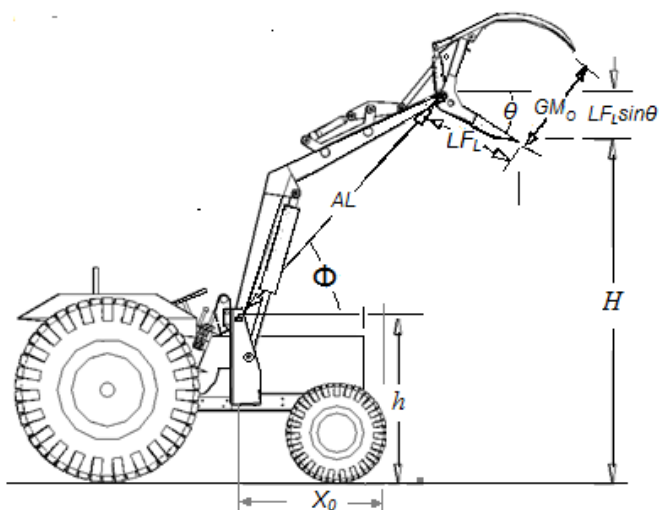


Figure 4 Configuration of the locally developed tractor mounted sugarcane loaders

Table 2 Characteristics of locally developed tractor mounted sugarcane grab loaders related to loading operation on sugarcane transport vehicles

Item	Symbol	Tractor mounted	
		Rigid boom	Articulated boom
Boom base height/m	h	1.9	1.9
Boom length/m	A_L	3.1	4.5
Boom loading left angle/(°)	β	60	70
Max height at grab LF horizontal /m	H_{max}	4.4	5.9
Max loading height at grab LF discharge angle 45°	H	3.8	5.3
Length of the lower fork of the grab/m	G_L	1.0	0.8
Tilt angle of the boom at max loading height/(°)	θ	60	70
Max grab open/m	MG_0	1.0	1.2
Avg. grab load/kg	G_w	300	400

(4) The characteristics of mechanically loaded sugarcane represented in vehicle load weight and load density were compared with that of manually loaded vehicle were estimated. Vehicle load dimensions were measured where load volume were computed. The data concerning vehicle load weight were recorded according the data of mill reception balance. Load density was then computed considering the load volume of each vehicle load and load weight as recorded from the sugar mill reception data.

The experiments were carried out in several loading sites in Nagh-Hammady sugarcane production area in Upper Egypt. The experimental activities included recording the data of each of the sugarcane transport vehicles either manually or mechanical loaded at five locations in the sugarcane production area in Upper Egypt. The average of three replicates was considered for each of the sugarcane transport vehicles that were mechanically loaded by each of the locally manufactured loader types. Data of manually loaded similar vehicles were collected at other locations where manual loading existed.

3 Discussion and conclusion

3.1 Mechanical loading capabilities based on loader/vehicle geometry

Operational dimensions related to the optimum positions for loading a sugarcane bundle over a transport vehicle are presented in Figure 5. While loading, the tractor should maneuver to become in certain position with respect to the vehicle considered for sugarcane loading. The tractor operator should maneuver to bring the tractor oriented where the longitudinal axis of the tractor perpendicular to the vehicle box longitudinal axis. The relative size of both loader and the vehicle box should maintain reasonable reach of the loaded cane bundle to the far side of the vehicle. The height of the lowest point of the grab at the situation of loading should

be equivalent to the height of load expansion over the vehicle box. At the situation of discharge, the grab lower fork should be oriented down with sufficient inclination angle θ and the clamping cylinder should be completely closed. The maximum stretch length of the loader boom cylinder should maintain a loader boom lift angle Φ that conserve minimum distance X_1 of reasonable value between the front end of the tractor and the vehicle body. Minimum reach of the grab over the trailer box X_3 is to have the grab boom articulation point over the vehicle box side and the full length of the grab will be over the vehicle. Figure 5 shows the operational dimensions of the loader relative to the transport vehicle. Table 3 show the relative operational dimensions of the loader at the situation of loading estimated for the most prevailing tractors found in the sugarcane area.

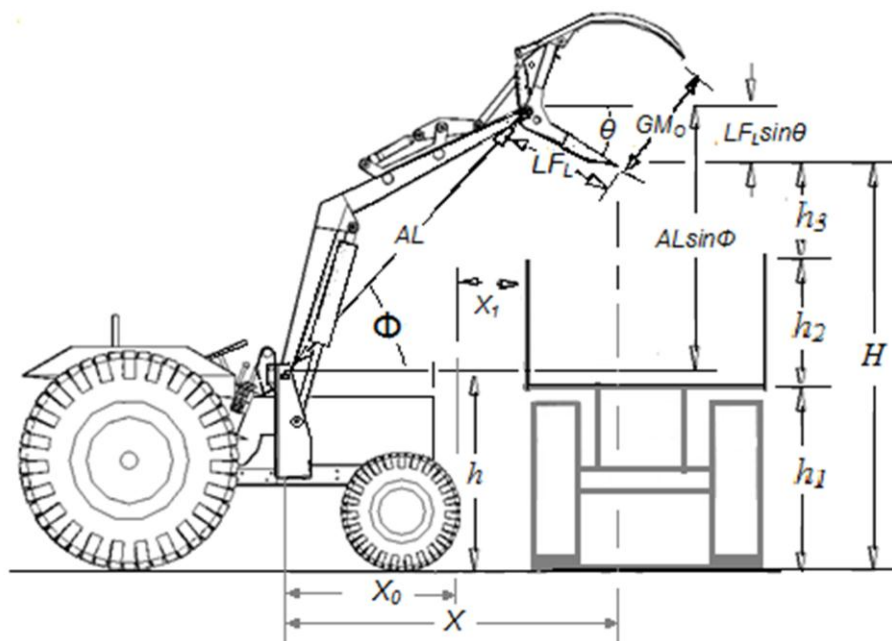


Figure 5 Geometry of loader/vehicle relationship at loading situation

Table 3 presented the most important dimensions of both of the transport vehicles and the locally fabricated sugarcane grab loaders based on the loader/vehicle geometry at loading situation. Maximum loading heights over each vehicle side columns were computed for each of the two loaders. Actually, the maximum loading height depends mainly on the height of the vehicle loading surface. Because of lower ground clearance of the

decauville wagons, the rigid boom type loader can raise the height of loading up to 1.35 m over the side columns. The articulated boom loader type may raise the load to up to 2.85 m over the side columns. Practically, the full height of the load should not exceed 3.0 m over the vehicle surface as recommended by the sugarcane transport experts and the farmers as safe load height. The rigid boom loader may raise the sugarcane load to up to 1.10 m, 0.85

m, and 0.65 m for rail wagons, small trailer and lorry, respectively. The articulated boom loader may raise the sugarcane load to up to 2.25 m, 2.035 m and 2.15 m for rail wagons, small trailer and lorry, respectively. The data show that the rigid boom loader maximum loading height may be always less than the upper limit of manually loaded vehicle and the articulated boom loader type is capable to raise the load up to or more than the upper limit of the manually loaded vehicle. Accordingly, the advices should

be announced to the loader operator not to exceed the height of load recommended for safe load dimensions. Therefore, the articulated boom loader type may be capable for loading vehicles standing on a level higher than the plan of the site. In most cases, the decauvelle tracks constructed on ridges and the paved roads on which road transport vehicles stand are of higher level than the site plan.

Table 3 Dimensions related to loading situation

Item	Symbol	Computation	Rigid boom dual arm loader	Articulated boom loader
Horizontal distance from the boom base hitch point to the front end of the tractor front wheel	X_0	According to the tractor For prevailing tractors	135	135
Lift angel made by the line AL	Φ	$\Phi = 75-30 = 45$	60^0	70^0
Distance between the front end of the tractor front wheel and the vehicle at loading situation/cm	X_1	$AL \sin 60 - X_0$ $327 \cos 60 - 135 = 28.5$	30	30
Max loading height at grab discharge tilt angle/m	H	$H = h + AL \sin \Phi - LF_L \sin \Theta$ $= 190 + 327 \sin 60 - 88 \sin 45$ $= 410$	410	5.3
Surface loading height of the vehicles/m	h_1	For Decauvelle wagons	0.70	
		Rail wagon	1.30	
		For the traditional trailer	1.20	
Side columns height	h_2	For lorry	1.40	
		For all transport vehicles	1.75	
Max Load height over the side columns $h_3 = H - (h_1 + h_2)$	h_3	For Decauvelle	1.35	2.85
		For rail wagon	1.10	2.25
		For S. trailer	0.85	2.35
		For L. trailer	0.65	2.15
Maximum reach of the loader grab across/inside the trailer	X	For lorry	0.65	2.15
		$X = (AL \cos 60 + LF_L \cos 45) - (X_0 + X_1)$ $= 226 - 165 = 61$	61	1.4

3.2 Load characteristics of manually loaded vehicle

In manual loading and in case of sufficient cane available, the farmers load the vehicle to a height up to 3 m over the vehicle surface. Also a labor with a sword standing over the load working continuously to rearrange the cane and cut the curved cane stalks to maintain higher load density. Table 4 presented load characteristics of manually loaded sugarcane transport equipment. The data

show that at load height equivalent to 3.0 over the vehicle surface, sugarcane loads were 9.0 t and 15.0 t and load densities were 0.298 t/m^3 and 0.308 t/m^3 for decauvelle and rail wagons respectively. The road transport vehicles safe loads were 8.0 t, 16.0 t and 14.0 t with load densities of 0.303 t/m^3 , 0.323 t/m^3 and 0.304 t/m^3 for agricultural trailer, large trailer and lorry respectively.

Table 4 Load characteristics of manually loaded sugarcane transport equipment

Sugarcane transport vehicles	Loading surface dimensions (W×H)/m	Vehicle surface height/m	Load height from ground/ m	Avg. load height surface/m	over	Ave load/t	Load density/(t/m ³)
Decauville	1.8 × 6	0.7	3.4	2.8		9	0.298
Railway wagons	2.4 × 7	1.3	4.2	2.9		15	0.308
Agricultural trailer	2 × 4	1.2	4.5	3.3		8	0.303
Large trailer	2.4 × 6	1.3	4.5	3.3		16	0.323
Lorry	2.4 × 6	1.4	4.5	3.2		14	0.304

3.3 Load characteristics of the mechanically loaded sugarcane vehicles

In case of manual loading that lasts for longer time, the labors have the chance to arrange the cane and using a sword for cutting the curved cane to make the vehicle load in compacted form. Figure 6 shows the weight of mechanically loaded transport vehicle compared to that of manual loading. Comparing the data of vehicle loads it was clear that mechanically loaded vehicle may hold up to 40% less weight in case if loaded by the rigid boom type loader and up to 20% less weight in case if loaded by the articulated boom loader.

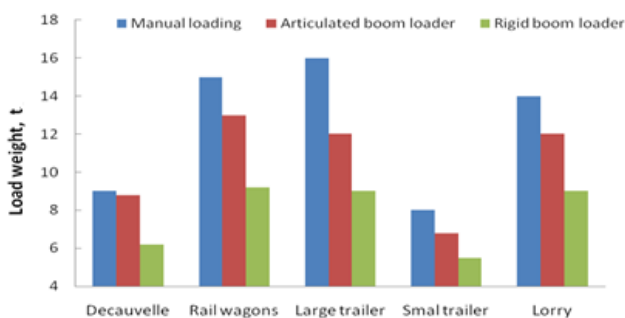


Figure 6 Vehicle loads of mechanically loaded vs manually loaded vehicles

It has been observed that load density of mechanically loaded sugarcane vehicles is lower than that of manually loaded sugarcane transport vehicles for all the imported and the locally fabricated sugarcane loaders. The main reason may refer to the chance given to the labor of the sword to cut the curved cane stalks where manual loading lasts for longer time. Figure 7 shows that the load density of the mechanically loaded vehicles is lower in case of the rigid boom type loader which is

mainly because of the structure of the loader boom. The loader of rigid dual arm of the boom could not be lowered in between the side columns of the sugarcane transport vehicle. The loader operator lifts the sugarcane bundle to a level over the side columns and leaves the cane dropped down with gravity that resulted in a lower density load. Load density reduction ranged from -0.058 t/m³ to -0.098 t/m³ compared to manual loading density as a result of using the rigid boom type loader. The front link of the articulated loader boom is a single link that can be easily lowered down in between the side columns of sugarcane transport vehicles so that the cane bundle placed in more compressed form. The reduction of load density in that case may only refer to the short chance given to the man of a sword to deal with curved cane stalks. The data show that in case of operating the articulated boom loader, the reduction of load density compared to manual load ranged from 0.02 t/m³ to up to 0.05 t/m³.

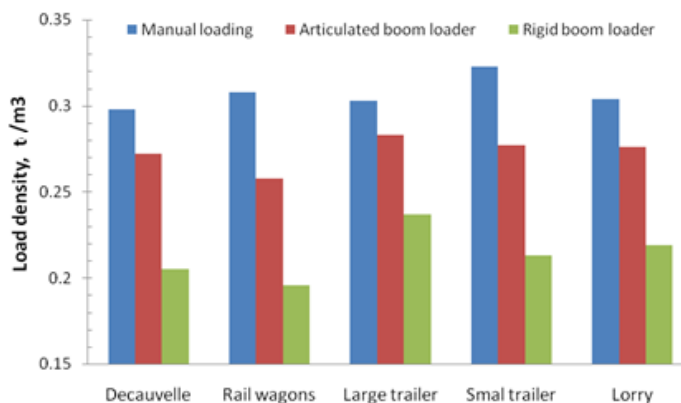


Figure 7 Load density of mechanically loaded vs manually loaded vehicles

Acknowledgements

The author would like to announce that the paper was developed through a project financed by the Egyptian Scientific and Technology Fund (STDF).

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