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An Optimization Study on Corn Silage Mechanization in Ege University Agricultural Research Farm

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Abstract: One of the biggest challenges in forage mechanization is optimizing the production chain. As the main goal in forage production is finishing the process in a short time, optimization becomes a very important factor. There are many ideas and methods for optimization. Some of them focuses on logistics and some on compaction. But the majority concentrates on the harverster as it is the most important element and of course the most valued machinery. The power of the forage harvester effects all the elements in the production chain (logistics, compaction and labour). In this study the data obtained from the practical field conditions were optimized and evaluated in order to point out the difference between the planned and unplanned production. The study took place in the corn fields of Ege University Agricultural Faculty Research Farm in Menemen. There were 7 fields which individally analysied in means of size, shape, labour, distance to compaction site and machinery used. The study revealed the economic aspects of practical production and produced 2 scenerios one of which was well optimized and the other is disoptimized and had worse conditions than the practical work. The optimized production proved that there were significant waste of fuel, time and labour force. Especially the extensive use of fuel means more "CO_2" emissions in the environment and having negative effect in means of the global warming. The result showed that it is not possible to produce economic and quality forage feed without a detailed optimization. It is also important to follow the aspects of this optimized production in the practical condition which only can be done together with experienced labour and well maintaned machinery.
Key words: Corn silage mechanization, optimization, quality silage, cycle analysis

INTRODUCTION

Economic and enviromental constrains are causing dairy farmers to continue their search for ways of improving and enhancing production efficiency. The inflation affected prices for milk and meat have been unstable and declining while production costs continue to increase in Turkey. Production efficiency must improve to enable a sustainable and competitive animal industry for the future. Corn silage is one of the most popular forages fed to dairy cows in Aegean Region. It has good agronomic characteristics, yields high concentrations of nutrients, ensiles well and incorporates easily in to TMR. In order to have efficient and quality corn silage it is very critical to optimize the production chain. The production chain consists of harvest, transport, compaction and ensiling. As harvesting is the first and the most important stage, it has a significant effect on the ending product. Methods of harvest management can also affect the nutritive value of corn growth for silage.

In forage harvesting systems, there are equipment interactions as the crop moves from the field to the silo site. The harvester needs to interact with the transport units to align and either unload or switch containers. Also the transport units need to interact at the unloading site to align and unload (Harrigan, 2003). A small optimisation or re-arregeanment can effect all the process and reduce income and save the environment by saving fuel.

New methods of CO2 emission reduction calculation and search new methods and technologies of transport biofuels production is very important subject for academic and practice. It is now believed that the generation of fossil fuels (mineral) has exhausted its effectiveness, and it was time for a new generation of transportation fuels, based on raw materials of vegetable origin (Marek Klimkiewicz, Remigiusz Mruk, Jacek Słoma, Janusz Wojdalski; 2013).

One of the way to reduce CO2 is using energy crops, engines with higher level of effectiveness (Piotr Borowski; 2011). According to Akyuz study, the application of hybrid systems also reduces the CO2 emission. And to achieve satisfactory level of energy independence is using differentiated sources production or supply. Innovations focus on refining conventional engine technologies, improving aerodynamics of vehicles, reducing rolling resistance and decreasing the weight of cars. The industry is also developing hybrid vehicles as well as combustion and fuel-cell hydrogen engines in various forms, which will contribute to cutting CO2. Biofuels can significantly help to reduce CO2 emissions from cars (Piotr Borowski; 2013).

Four different factors have influence on the capacity of forage harvest operations depending on field conditions and the operation. These factors are power, throughtput capacity, speed and traction. Forage harvester power depends on throughput, moisture content, lenght of cut, crop type and knife sharpness (Srivastava et al., 2006). In order to minimize production cost and increase quality, it is important to investigate those factors and their sub-components. A well matched pull-type forage harvester (PTFH) and tractor or a well designed self-propelled forage (SPFH) harvester should result in power and throughput yielding a similar upper bound on capacity.

MATERIALS and METHOD

In this study, a closely examined corn silage production chain was optimised in order to point out the difference between systems in means of economics and quality of the final product. As new technology and information spreads everyday life, a periodic study of farm activities is required to maintain current situation and compare with the new advances. So the study focused on identifying forage harvester throughput and cycle times for chopped corn silage for a range of harvest systems commonly used on Aegean Region dairy farms. The harvesting process need a harmony with the continuing processes, so identifying transport vehicle travel speed and cycle times in the loading, transport and unloading of chopped corn silage is also very important. The study took place in Ege University, Agricultural Faculty, Agricultural Research Farm (Menemen Research, Practice and Production Farm). The harvest took place in 7 fields which sized 11 ha in average (78,8 ha in total) (Figure 1). The transport distance ranged from field to storage site between 0,2 to 1,4 km. Complete harvesting and hauling cycles were observed at each field to determine rates that represent harvest productivity achieved on Research farm.

Figure 1. The harvested fields
(Field number and size in hectares)

An average harvested crop dry matter was determined by collecting 500 g sample from each load. The samples were dried in a forced air oven at 60^{O}C for 72 h (ASAE Standards, 2001). An average dry matter based on these samples was used in calculating harvester throughput (Table 1). Forage harvester throughput was defined as the mass of silage processed and delivered to the transport vehicle per unit time (t-DM h^{-1}). Forage harvester time included silage processing, maneuvering on the headlands and waiting for transport vehicles (Figure 2).

Figure 2. The two row PTFH switching trailer

Time required for each process was recorded by an observer either riding with the machine operator or stationed nearby with a clear view of all harvest and transport operations. Harvester throughput was based on the time the silage material was seen actually flowing through the machine and the mass of silage collected. Time in turning on the headlands, waiting for transport vehicles and other delays were recorded as support time in determining harvester efficiency. Harvest delays from machine adjustment and maintenance were recorded as downtime. The hauling cycle was divided into discrete time units for data collection which were manuevering the transport vehicle near the storage bunker, unloading, traveling to the field, manuevering in the field, loading and returning to the storage bunker. Hauling distance was measured from the point the transport vehicle entered farm road near the storage bunker to the point it exited farm road near the harvest field. Time spent for alignment between transport vehicle and harvester,also alignment for unloading were not included in the measure of travel time and distance, they were recorded as support time. Packing a bunker silo increases silage density, excludes oxygen, promotes fermentation and improves the quality of the stored feed (Ruppel et al., 1995; Muck and Holmes, 2000). In order to size a tractor for bunker silo packing is that a tractor can pack about twice its weight in silage per hour (Tyson et al., 1996). In this study, packing intensity was measured as a ratio of the mass of silage delivered to storage (as-fed t h^{-1}) to the mass of the tractor(s) used in distributing and packing the pile. Silage flow rate was measured as the harvester throughput (t h^{-1}) multiplied by the harvester efficiency. Packing tractor weight was estimated as 73,2 kg PTO-kW^{-1}. Forage harvester cutter unit was set at 12 mm theoretical lengt of cut (TLC) and processor role clearance was set at 2,2 mm. Silage weight estimated based on transport vehicle volume and dry matter. The fuel consumption online measurements for all the processes were made with "Kracht VC-Gear Type Flow Meter" device (Figure 3). The measuring device had a wireless connection to a laptop on the field transferring online data to Squirrel View Software. After that the saved data was processed and mean values were used in the study in order to have at most realistic situation. The distance measurements were made with laser distance measurement device FatMax-TLM300.

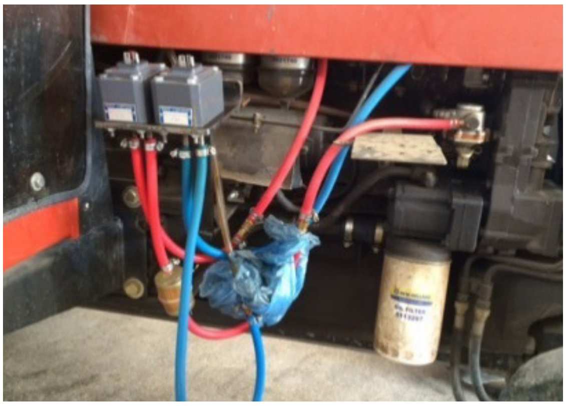

Figure 3. The fuel consumption measuring device

Corn silage harvest included two parallel machinery operations; harvesting and processing the silage, transporting the chopped material and placing it in storage. During the harvest there were two harvest method (A and B) used. Method A was that the chopped material was blown to the trailer hitched to the harvester and changed with the empty one but in method B the harvester and the trailer drawn alongside and as the trailer filled up, the empty trailer followed the process and replaced continuously (Figure 4).

There were two PTFH with different capacities (one and two row) and three tractor-drawn trailers used in both system. The dry matter (DM), TLC, fuel consumption, power requirement, in&out field speed of trailers and all time requirements were calculated and stored in order to have a realistic optimisized values. In order to point out the importance of the minor changes and their effect on the whole process there were two scenarios created for the total ensiling process. All the machinery and equipment were used the same except the harvesting systems. In a worse scenario all the fields were harvested with system A and in order to have the opposite effect all the fields were harvested with system B. Although the selection of harvester and transport vehicle depend on the field size and distance to silo, it is not an easy process in practical conditions especiallly in big farms. It might become harder to organize the machinery serts as there are many proceeding simultaneous work.

Figure 4. The two row PTFH working with system A

Table 1. Corn silage harvest motion-time study performance on seven fields (Practical conditions)

	Fields						
	1	2	3	4	5	6	7
Field size (ha)	13,81	9,93	19,28	7,59	7,06	11,95	8,56
Field yield (t ha^{-1})	62,8	58,8	60,2	55	54,2	66,8	61,5
Harvester							
Type, size and method	PTFH,2R,A	PTFH,2R,B	PTFH,2R,B	PTFH,1R,A	PTFH,1R,A	PTFH,2R,A	PTFH,1R,B
Power (kW)	50	50	50	32	32	50	32
Field capacity (ha h^{-1})	0,46	0,46	0,46	0,18	0,18	0,46	0,18
Crop processor*	yes	yes	yes	no	no	yes	no
Throughput as harvested (t h^{-1})	22,43	22,11	23,29	8,74	8,61	22,12	9,77
DM (%)	27	25	30	28	32	35	34
DM (t h^{-1})	6,06	5,53	6,97	2,44	2,75	7,74	3,32
Harvester efficiency (%)	94,04	95,69	95,28	97,48	95,61	92,50	98,57
Harvester fuel consumption (L h^{-1})	16,25	9,09	9,11	9,86	12,93	10,33	4,48
Harvester fuel consumption (L)	628	240	455	471	575	373	241
Transport							
Distance to storage (km)	1,146	1,397	1,358	0,841	0,842	0,794	0,225
Vehicles	2-tractor drawn	2-tractor drawn	2-tractor drawn	2-tractor drawn	2-tractor drawn	2-tractor drawn	2-tractor drawn
Number of loads	69	65	93	46	42	64	58
Total volume (m^{3})	44,9	30,1	44,9	30,1	30,1	30,1	30,1
Transport fuel consumption(L load^{-1})	1,44	1,39	1,84	1,16	1,1	1,19	0,85
Transport fuel consumption (L)	99	90	171	53	46	76	49
Storage							
Structure	Bunker	Bunker	Bunker	Bunker	Bunker	Bunker	Bunker
Packing tractor (kW)	64	64	64	64	64	64	64
Fill rate, as-fed (t h^{-1})	21,09	21,16	22,13	8,52	8,23	20,46	9,63
Fill rate:tractor wt. Ratio	4,45	4,52	4,73	1,82	1,75	4,28	2,05
Pack time (min t^{-1})	2,84	2,84	2,71	7,04	7,29	2,93	6,23
Storage fuel consumption (L h^{-1})	4,11	4,18	3,96	3,61	3,77	4,04	3,68
Storage fuel consumption (L)	169	115	208	177	175	158	201

*Processor role clearance was set at 2.2 mm

RESULTS and DISCUSSION

Harvester throughput in every field was determined based on the time the crop was actually flowing through the machine and the silage mass delivered to the transport vehicle. There was a significant capacity difference between harvesters. The transport vehicles were used in relation with harvester capacity.Silage mass was estimated based on the volume (m^3) and dry matter (dry basis) of the silage in the transport vehicle. Corn silage dry matter ranged from %25 to %35. Harvester throughput ranged from 2,44 tDM h^{-1} to 7,74 tDM h^{-1}. The highest harvester effciency was achieved in field 7 (%98) with harvesting system B. The highest fuel consumption for harvesting was measured in field 1 (628 L) as it was one of the biggest land size, for transporting field 3 had the highest value of 171 L (93 loads) and for ensiling again field 3 had the highest value of 208 L. The total system process between the fields showed that field 1 had the highest amont of costs (1659 €) requering 1,91 € t^{-1} input value for cost per mass. This result showed that even field 3 had the highest land size it still had lower costs (1543 €) rather than field 1 (Table 2).

Table 2. Corn silage harvest economical analysis on seven fields (Practical conditions)

	Fields							
	1	2	3	4	5	6	7	**Mean**
Field size (ha)	13,81	9,93	19,28	7,59	7,06	11,95	8,56	**11,16**
Fuel consumption (€):								
Harvesting	1162	444	842	871	1063	690	447	**788**
Transport	184	167	317	99	85	141	91	**155**
Storage	313	213	384	327	324	292	372	**318**
Total	1659	825	1543	1297	1473	1122	910	**1261**
Cost per mass (€ t^{-1}):								
Harvesting	1,34	0,76	0,73	2,09	2,78	0,86	0,85	**1,34**
Transport	0,21	0,29	0,27	0,24	0,22	0,18	0,17	**0,23**
Storage	0,36	0,37	0,33	0,78	0,85	0,37	0,71	**0,54**
Total	1,91	1,41	1,33	3,11	3,85	1,41	1,73	**2,11**

In order to identify the importance of optimisation two different scenarios were created and there were significant difference between them (practical conditon, worse and better scenarios) (Table 3). The value of 2,11 € t^{-1} for practical conditons was worsen by applying harvest system A and in opposite situation it was improved by applying harvest system B to all 7 fields. In the worse scenario the transport fuel consumption had a dramatic fall (0,19 € t^{-1}) but the harvester efficiency and harvester's fuel need increased as the harvester need to haul the trailer attached behind. This increased harvesting fuel needs (1,81 € t^{-1}). The worse scenario had 1519 € total cost and 2,42 € t^{-1} cost per mass. The better scenario had the highest value for transport fuel consumption (0,28 € t^{-}1) but had the best harvesting efficiency and lowest fuel need for harvesting and storing rather than the other systems. This showed that it was possible to consume less fuel and save more time by increasing harvesting efficiency.

Table 3. Economical Results of Different Scenarios

	Worse	**Practical**	Better
	Mean	**Mean**	Mean
Field size (ha)		**11,16**	
Fuel consumption (€):			
Harvesting	1123	**788**	508
Transport	127	**155**	176
Storage	270	**318**	228
Total	1519	**1261**	913
Cost per mass (€ t^{-1}):			
Harvesting	1,81	**1,34**	0,77
Transport	0,19	**0,23**	0,28
Storage	0,41	**0,54**	0,34
Total	2,42	**2,11**	1,38

CONCLUSIONS

The followings were concluded from the study:

- The system B had a fluent process rather than system A but had higher transporter fuel consumption.
- The harvester should be kept busy in order to increase the utilization of the total system.
- The worse scenario had the highest cost of 1519 € followed by practical conditions 1261 € and lowest in best scenario with 913 €.
- The lowest fuel consumptions for the whole systems in terms of carbon dioxide emmissions, best scenario had the lowest mean value of 492 L.
- The best scenario had 1,38 € t^{-1} value and that was the most economical production by saving more than 650 € according to worse conditions. Lowest fuel consumption and better timeliness were other advantages.
- It should be taken under consideration that better scenario had high amount of fill rate at the silo. The compaction for ensiling should be monitored in order to improve silage quality.
- The economic benefits can be a sign of a quality silage but it might be also the opposite way as the ensiling processes has specific requirements in order to have a healthy fermentation period.
- The further research should be conducted to compare fuel consuption and level of carbon dioxide emmision depending on the type of fuel use.

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