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# Study of Some Operational Factors of Forage Harvesters Claas Jaguar 870: A Pathway to High-Quality Corn Silage and *In Vitro* Digestibility

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## ABSTRACT

This study was conducted in Gopal, Duhok, Iraq. The land was planted in July 2024 for fall harvesting, with a corn seed hybrid (Polen-Turkey) that is specified for whole plant corn silage. This study aimed to detect the effects of mechanical parameter adjustments on the performance of a self-propelled forage harvester and the resulting quality of whole-plant corn silage. The experiment tested three forward speeds (3, 5, 7 km $h^{-1}$), two cutting speeds (knife speed 1128.7 and 1229.6 rpm, which corresponded to engine fixed rpm at 1900 and 2050 rpm, respectively), and three cutting lengths (10, 20, 30 mm) in a factorial RCBD design. Results indicate that the finer cutting length (10 mm) combined with higher cutting speed (2050 rpm) optimized silage quality, yielding superior bulk density (311 kg $m^{-3}$), lactic acid content (76.5 g kg $^{-1}$ DM), kernel processing (72.8%), and *in vitro* digestibility, while maintaining ideal pH levels (3.4-3.6). Also, at these settings, wheel slippage (6.14%), field efficiency (71.30%), and productivity (1.41 ha $h^{-1}$) are achived, which is the optimal setting for machine performance and silage quality in comparison to alternative operational settings. Conversely, larger cuts (30 mm) improved field efficiency (74.17%) but compromised silage quality with lower density (238-242 kg $m^{-3}$), higher pH (4.13-4.27), and reduced *in vitro* digestibility. Forward speed played a key role, where 5 km $h^{-1}$ balanced productivity and quality, while 7 km $h^{-1}$ maximized output at the expense of increased wheel slippage. The study concludes that optimal settings depend on operational priorities: fine cuts (10 mm) with moderate speed (5 km $h^{-1}$) for high-quality silage. These findings provide specific recommendations to enhance corn silage production, therefore influencing animals feed efficiency and overall performance.

## 1.Introduction

Mechanization in agriculture has contributed to improved fieldwork, efficiency, and productivity. The traditional methods of harvesting became less dependable because mechanized harvesters perform different tasks simultaneously, such as cutting, chopping, and transporting crops at a faster speed. Modern machines are equipped with advanced technologies that operate with higher efficiency and accuracy under various conditions in the field and crop types. Farmers benefit from these developments in machinery, which reduces labor intensity and speeds up their work. Silage makers benefit from modern forage harvesters to produce better quality silage, as its quality mostly depends on the mechanical processing of the crop, such as cutting length, kernel processing, and uniformity of cut size (Shinners, 2003).

Several factors that affect silage quality, including harvesting practices, plant characteristics, the ensiling process and storage conditions (de Oliveira et al., 2017). The mechanical practices of harvesting plants have a direct effect on the final quality, as adjustments to the machine and its design play a crucial role in the quality of chopped crops. Mechanical factors, cutting size, processing corn kernels, and distribution uniformity had a significant impact on the ensiling of corn silages and then the final quality of silage (Belov, 2019). The physical properties of chopped silage and the quality of ensiling determine the fermentation process, which in turn enhances the nutritional quality of silage, which positively influences animal consumption and performance (Acosta Aragón et al., 2012). Despite the development of self-propelled harvesting machines, local silage makers depend on personal information and skills to operate the machines, which affects silage quality. Scientific research focusing on the operational setting related to corn silage quality under local conditions is less documented.

This study aims to bridge this gap by evaluating the effects of various mechanical settings on forage harvester performance and the resulting silage quality. Identifying optimal machine configurations, this research seeks to enhance silage nutritional value, improve livestock feeding efficiency, and support sustainable ruminant farming practices.

## 2. Materials and Methods

This study was carried out in Gopal-Duhok-Iraq (Latitude: 36.4997, Longitude: 43.8669) (Figure 1). The land was planted in 2024, in the fall season, with a corn seed hybrid (Polen-Turkey) that is specified for whole plant corn silage. This study investigates the effects of three operational parameters; forward speed (3, 5, 7 km $h^{-1}$), cutting speed (knife speed 1128.7 and 1229.6 rpm, which corresponded to engine fixed rpm at 1900 and 2050 rpm, respectively), and cutting size (10, 20, 30 mm) on mechanical performance (wheel slippage %, field efficiency %, productivity ha $h^{-1}$) and silage quality using a normal factorial RCBD. The 18 treatment combinations (3×2×3) are randomly applied within blocks according to field variability, with each combination evaluated for mechanical performance during operation and subsequent silage quality after ensiling. The Claas Jaguar 870 forage harvester with a header of the CLAAS Forage Harvester Type 492 is used in this research (Figure 2). The CLAAS Forage Harvester Type 492 header has four 750-mm-diameter low-speed feeder house drums. This size optimizes cutting for efficient forage handling and high-quality cuts. This cutterhead has 24 knives for precision cutting and harvesting efficiency. The regular blade segments are 2.5 mm thick, while those near the cleaner are 3.5 mm thick for endurance and sharpness. The harvester weighs 1795 kg and top speed that allows fast operation across broad regions is 20 km $h^{-1}$. The harvester's oil bath-lubricated transmission and safety clutch improve reliability and reduce maintenance.

The mechanical parameters were calculated by the following equations:

- Coefficient of the width % = (Actual width / Theoretical width) *100 (Hussein, 2015)
- Coefficient of the speed % = (Speed with load / Speed without load) * 100 (Hussein, 2015)
- Wheel slippage % = (Speed without load – Speed with load) / Speed without load) * 100 (Hussein, 2015)
- Field efficiency % = (Coefficient of width * Coefficient of speed) * 100 (Hussein, 2015)

Parameters that were taken for evaluating silage quality were (bulk density, kernel processing score, particle size percentage, pH, and lactic acid content). The bulk density was performed as described by (Sucu et al., 2016). Corn Silage Processing Score (CSPS) is a water separation technique that has been developed and used to separate kernel fractions. This simple technique exploits differences in buoyancy between the kernels and stover and processing score measured according to (Shinners and Holmes, 2013). Particle size percentage of silages was conducted and calculated according to established methods (ASABE, 2017). Calibrated the pH meter using standard buffers (pH 4.0 and 7.0), immersed the electrode in the extract, and recorded the stabilized reading. Properly rinse the electrode after use (Holmes and Muck, 2007). *In vitro* digestion for silages was conducted according to established methods Tilley and Terry (1963).

- Productivity (ha $h^{-1}$) = (Speed * Width *Field efficiency) / 10000 (Hussein, 2015)

The collected data was subjected to the computer software called SPSS version 25 (SPSS Inc., Chicago, IL, USA) to perform a three-way factorial ANOVA within an RCBD framework. Duncan's or Tukey test was used to confirm the differences among the compared average data at the significant level of probability $P \leq 0.05$.

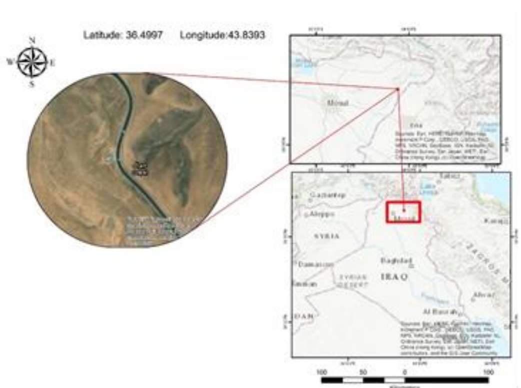


**Figure 1:** Study Location (Gopal Village-Duhok Governorate-Kurdistan Region-Iraq)

**Figure 2:** Forage Harvester (Class-Jaguar 870)

## 3.Results and Discussion

The data in the (Table 1) reveal significant effects of cutting size, cutting speed, and forward speed on wheel slippage, field efficiency, and productivity in forage harvesting. Smaller cutting sizes (10 mm) combined with higher forward speeds (7 km $h^{-1}$) resulted in the highest productivity (1.99 ha $h^{-1}$) but also increased wheel slippage (7.31–7.33. Lower forward speeds (3 km h-1) minimized wheel slippage (5.09–5.47%) but yielded the lowest productivity (0.76–0.80 ha $h^{-1}$). Field efficiency peaked (74.17%) at larger cutting sizes (30 mm) and higher speeds (2050 rpm, 7 km $h^{-1}$).

These results agree with the results obtained by Tian et al. (2019) reported that increased operational speeds enhance productivity but exacerbate wheel slippage, attributing this to greater torque demand and belt wear. This supports the current findings, where higher forward speeds improved output but increased wheel slippage. A tire wheel slippage rate of 7% is considered good for tractors and combine harvesters, as indicated by accredited studies of Gamal et al. (2024). Additionally, Shinners et al. (2009) demonstrated that larger cutting sizes reduce energy consumption by minimizing crop resistance, which supports the higher field efficiency observed with 30 mm cuts in this study. However, Miu (2015) argued that finer cuts (10 mm) improve silage compaction and fermentation, suggesting that productivity gains may justify the efficiency trade-off in certain scenarios. Critically, Savoie et al. (2004) emphasized that mid-range speeds often strike the best balance, as resulted in this study, where 5 km $h^{-1}$maintained moderate wheel slippage while preserving productivity. These comparisons highlight the contextual nature of optimal settings, while larger cuts and moderate speeds favor efficiency, finer cuts and higher speeds may be preferable for quality-sensitive operations (Valge et al., 2021).

**Table 1:** Effect of operational parameters on the forage harvester's performance

| Cutting Size mm | Cutting Speed (rpm) | Forward Speed km $h^{-1}$ | *Wheel slippage% | Field Efficiency% | Productivity ha $h^{-1}$ |
|---|---|---|---|---|---|
| 10 | 1900 | 3 | 5.17 e | 68.01 hi | 0.79 f |
| | | 5 | 6.55 ab | 70.28 f | 1.38 d |
| | | 7 | 7.31 a | 73.79 c | 1.99 a |
| | 2050 | 3 | 5.09 e | 68.19 g | 0.80 f |
| | | 5 | 6.14 bc | 71.30 d | 1.41 c |
| | | 7 | 7.33 a | 73.92 bc | 1.85 b |
| 20 | 1900 | 3 | 5.44 cde | 68.20 g | 0.80 f |
| | | 5 | 6.25 b | 70.90 e | 1.38 cd |
| | | 7 | 7.28 a | 73.84 c | 1.88 b |
| | 2050 | 3 | 5.40 de | 67.92 ij | 0.79 fg |
| | | 5 | 6.55 ab | 71.31 d | 1.39 cd |
| | | 7 | 7.12 a | 74.06 ab | 1.99 a |
| 30 | 1900 | 3 | 5.47 cde | 67.85 j | 0.76 g |
| | | 5 | 6.25 b | 70.84 e | 1.34 e |
| | | 7 | 6.99 a | 73.83 c | 1.88 b |
| | 2050 | 3 | 5.23 e | 68.14 gh | 0.78 fg |
| | | 5 | 6.08 bcd | 71.42 d | 1.41 c |
| | | 7 | 7.32 a | 74.17 a | 1.87 b |

[a,b,c] Means with differing superscripts within the same column are significantly different (*P*<0.05). *Less value is better

Optimizing mechanical processing parameters, such as cutting size, cutting speed, and forward speed, plays a crucial role in determining silage quality and is presented in table (2). Finer cutting (10 mm) combined with higher cutting speeds (2050 rpm) and moderate forward speeds (5 km $h^{-1}$) yielding the most favourable outcomes, including increased bulk density (311.17 kg $m^{-3}$), optimal lactic acid production (76.54 g $kg^{-1}$ dry matter), and enhanced kernel processing (72.78%), which collectively improve starch accessibility and fermentation efficiency. These conditions also maintained a lower pH range (3.37–3.63), indicating stronger acidity and better preservation, as lactic acid bacteria thrive in tightly packed, finely chopped material with reduced oxygen exposure (Muck and Holmes, 2000). In contrast, larger cutting sizes (30 mm) resulted in poorer silage quality, evidenced by reduced bulk density (238.17–242.67 kg $m^{-3}$), higher pH (4.13–4.27), and lower lactic acid concentrations (56.95–59.67 g $kg^{-1}$ dry matter), suggesting compromised fermentation due to inadequate compaction and increased aerobic spoilage risks (Shinners et al., 2000). The coarser particle size percentage associated with larger cuts (54.23–62.22%) further highlights the negative impact on feed digestibility and animal intake, as finer particles are generally more palatable and nutritionally accessible. These findings align with established silage production principles, emphasizing that proper mechanical processing not only enhances fermentation but also maximizes the nutritional value of silage for livestock .Additional factors such as harvest moisture content and microbial inoculants to further refine silage management practices, but the current results underscore the importance of optimizing harvester settings to achieve high-quality silage with improved preservation and feed efficiency (Kung Jr et al., 2018, Muck and Holmes, 2000).

**Table 2**: Effect of operation parameters on the quality and physical properties of whole plant corn silage

| Cutting Size mm | Cutting Speed (rpm) | Forward Speed km $h^{-1}$ | Bulk density kg m-3 | *pH | Lactic Acid (g $kg^{-1}$ DM) | Kernel Process % | Particle Size Percentage % |
|---|---|---|---|---|---|---|---|
| 10 | 1900 | 3 | 315.17 a | 3.53 g | 75.55 ab | 70.57 b | 69.07 bc |
| | | 5 | 308.67 c | 3.63 ef | 76.44 a | 72.23 ab | 65.43 fg |
| | | 7 | 307.17 d | 3.63 ef | 74.15 abc | 71.27 ab | 66.00 efg |
| | 2050 | 3 | 304.00 e | 3.37 h | 76.54 a | 70.56 b | 65.02 g |
| | | 5 | 311.17 b | 3.43 gh | 75.69 ab | 72.78 a | 66.53 def |
| | | 7 | 307.00 d | 3.47 gh | 74.98 ab | 71.28 ab | 70.67 a |
| 20 | 190 | 3 | 271. | 3. | 67. | 65.89 | 67.76 cd |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | | 33 g | 83 c | 27 abcde | c | |
| | | 5 | 270.33 g | 3.77 cd | 68.87 abcd | 65.61 cd | 67.20 de |
| | | 7 | 268.50 h | 3.77 cd | 63.25 cde | 64.14 d | 69.35 ab |
| | 2050 | 3 | 274.00 f | 3.63 ef | 66.87 abc | 64.63 cd | 69.61 ab |
| | | 5 | 274.67 f | 3.73 cde | 69.48 abcd | 65.53 cd | 70.42 ab |
| | | 7 | 273.50 f | 3.67 de | 64.25 bcde | 64.47 cd | 70.12 ab |
| 30 | 1900 | 3 | 242.67 i | 4.13 b | 58.62 de | 56.23 e | 54.23 k |
| | | 5 | 239.67 j | 4.14 b | 56.95 e | 56.85 e | 56.17 j |
| | | 7 | 241.33 i | 4.27 a | 57.78 de | 55.66 e | 59.25 i |
| | 2050 | 3 | 238.17 k | 4.27 a | 59.02 c | 55.78 e | 59.46 i |
| | | 5 | 242.00 i | 4.17 ab | 58.94 de | 55.17 e | 62.22 h |
| | | 7 | 242.17 i | 4.13 b | 59.67 de | 56.61 e | 61.24 h |

a,b,c Means with differing superscripts within the same column are significantly different (*P*<0.05).

The data in table (3) revealed significant interactions between cutting size, forward speed, and digestion parameters, aligning with established principles of ruminant nutrition. The superior performance of 10 mm cutting size across IVDM, IVOM, and NDF digestibility ($P \leq 0.05$) underscores the importance of reduced particle size in enhancing microbial access and enzymatic breakdown, as supported by Mertens (1994), who demonstrated that reduced particle size increases surface area for microbial colonization, thereby enhancing enzymatic hydrolysis of cellulose and hemicellulose. Conversely, larger particles (20–30 mm) limit microbial access, leading to lower IVDMD. Hara and Tanigawa (2010) reported that particle size reduction can lead to better feed efficiency and improved milk production, as smaller particles are more readily fermented in the rumen. Studies have indicated that shorter chop lengths can improve fiber digestibility and overall feed intake in dairy cattle, as they facilitate better ruminal fermentation. However, it is essential to balance the benefits of shorter chop lengths with the potential for increased wear on the harvester and the energy costs associated with processing the crop more finely (Johnson et al., 2003).The results demonstrate that smaller cutting sizes (10 mm) combined with slower forward speeds (3 km $h^{-1}$) optimize *in vitro* digestibility (IVDM, IVOM) and NDF degradation, while higher speeds (5–7 km $h^{-1}$) and larger particles (20–30 mm) significantly reduce nutrient availability ($P \leq 0.05$). These findings highlight the importance of precision forage processing to maximize ruminal fermentation efficiency and feed quality.

**Table 3:** Effect of operation settings on *in vitro* dry matter disappearance and fibre digestion.

| Cutting Size mm | Cutting Speed (rpm) | Forward Speed km $h^{-1}$ | IVDM % | IVOM % | NDF digestibility % |
|---|---|---|---|---|---|
| 10 | 1900 | 3 | 67.61 a | 68.98 a | 38.76 a |
| | | 5 | 64.50 c | 65.61 bc | 25.82 bcd |
| | | 7 | 66.08 abc | 67.30 ab | 28.43 bc |
| | 2050 | 3 | 66.40 ab | 67.95 a | 37.92 a |
| | | 5 | 65.70 bc | 65.71 bc | 26.22 bcd |
| | | 7 | 66.75 ab | 68.39 a | 29.57 b |
| 20 | 1900 | 3 | 62.01 de | 64.97 c | 37.48 a |
| | | 5 | 52.34 h | 53.13 g | 23.57 cd |
| | | 7 | 61.65 de | 62.38 e | 27.45 bc |

| | | | | | |
|---|---|---|---|---|---|
| | **2050** | **3** | 61.50 de | 64.28 cd | 36.57 a |
| | | **5** | 53.68 h | 52.98 g | 24.35 bcd |
| | | **7** | 62.60 d | 61.99 e | 28.41 bc |
| **30** | **1900** | **3** | 62.36 de | 63.22 de | 36.10 a |
| | | **5** | 56.47 f | 57.89 f | 20.93 d |
| | | **7** | 60.72 e | 61.70 e | 27.33 bc |
| | **2050** | **3** | 60.81 de | 62.75 de | 35.71 a |
| | | **5** | 56.77 f | 58.07 f | 21.41 d |
| | | **7** | 61.31 de | 61.48 e | 26.37 bcd |

[a,b,c] Means with differing superscripts within the same column are significantly different (*P*<0.05).IVDM (*in vitro* digestion of dry matter), IVOM (*in vitro* digestion of organic matter), NDF (Neutral detergent fiber).

The data in table (4) demonstrate that VFA concentrations varied significantly with both cutting size and fermentation time. At 0 hours, the smallest cutting size (10 mm) had the highest initial VFA concentration (9.33 mmol 100 ml $^{-1}$), followed by 20 mm (7.52 mmol 100 ml-1) and 30 mm (6.74 mmol 100 ml$^{-1}$), indicating that finer particle sizes may promote faster initial fermentation due to increased surface area for microbial activity (Yang and Beauchemin, 2005). In all treatments, VFA production increased from the beginning to peak at 36 hours. Small-size cutting at 10 mm showed the highest value (26.37 mmol 100 ml$^{-1}$) compared to the other cuts at 36 hours. However, larger cuts (20 mm and 30 mm) tend to produce higher VFA at 48 hours (13.1 and 13.59 mmol 100ml$^{-1}$) compared to the 10 mm size (12.19 mmol 100ml$^{-1}$). Based on these results, it indicates that a small particle size could be fermented earlier and a larger particle size requires a longer time. The fermentation profile of small particle size and large particle size has a direct effect on the VFA production (Khan et al., 2012).

**Table 4**: Effect of cutting size on volatile fatty acid (VFA) production during a 48-hour fermentation period.

| Cutting Size (mm) | VFA (0 h) mmol 100 ml $^{-1}$ | VFA (12 h) mmol 100ml $^{-1}$ | VFA (24 h) mmol 100ml $^{-1}$ | VFA (36 h) mmol 100ml$^{-1}$ | VFA (48 h) mmol 100ml$^{-1}$ |
|---|---|---|---|---|---|
| **10** | 9.33 a | 12.37 a | 15.01 a | 26.37 a | 12.18 b |
| **20** | 7.52 b | 12.00 ab | 13.99 b | 24.09 b | 13.31 a |
| **30** | 6.74 c | 11.81 b | 13.48 b | 24.93 b | 13.59 a |

[a,b,c] Means with differing superscripts within the same column are significantly different (*P*<0.05). VFA (volatile fatty acids).

## 4.Conclusions

This study's results indicate that mechanical parameters could have an effect on the self-propelled forage harvester and corn silage quality. The study revealed that harvester performance was optimized at 5 km h$^{-1}$ forward speed, achieving balanced productivity and field efficiency with minimal wheel slippage. For silage quality, the best results came from a 10 mm cutting length and 2050 rpm cutting speed, producing higher bulk density, lactic acid content, kernel processing, and digestibility while maintaining ideal pH. The best overall setting combined these parameters: 10 mm cut, 2050 rpm, and 5 km h-1 forward speed, ensuring both high machine efficiency and premium silage quality. For farmers, we recommend prioritizing these settings for optimal feed preservation and animal nutrition.

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