Study of the Effect of Damping Pendulum Motion on the Efficiency and Stability of the New Holland TC54 Combine Harvester Under Different Operating Conditions

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Abstract. *This study investigates the effect of slope angle and forward operating speed on the optimal performance of the harvesting process of a combine equipped with a decelerating pendulum device that mechanically and hydraulically changes the angle of inclination of the combine. Three harvesting slope angles (0-5°, 10-15° and 20-25°) and three forward speeds (3, 5 and 7 km/h) were tested using a New Holland TC54 harvester, The experiment was carried out using a randomised complete block design (RCBD) with (27) experimental units distributed in three replications. Several key performance indicators were measured including:Fuel consumption (litres/hour), operational efficiency (%), harvester stability and total grain loss as a percentage. The results showed that soils with steeper slopes significantly increased fuel consumption and grain loss, while reducing machine stability. The best performance was achieved at a slope angle of (10-15°) and a speed of (5) km/h, with a field capacity of (5.60) tons/hour, fuel consumption of 24.10 liters/hour, and the lowest grain loss of (2.3%), The effects of slope and speed were found to be statistically significant (P < 0.05), reflecting the importance of improved combinations in significantly enhancing operational efficiency, reducing harvest losses, and thus improving the overall performance of the agricultural system .*
Keywords: *combine harvester, slope angle, forward speed of harvesting, harvester performance, fuel consumption, grain loss*

Abstrak. Penelitian ini menyelidiki pengaruh sudut kemiringan dan kecepatan operasi maju terhadap kinerja optimal proses panen pada mesin pemanen yang dilengkapi dengan alat pendulum perlambat yang secara mekanis dan hidraulik mengubah sudut kemiringan mesin pemanen. Percobaan dilakukan di distrik Qaraj, distrik Makhmour, provinsi Ninewa, Irak utara, daerah yang dicirikan oleh medan yang beragam dan iklim semi-kering di dalam lahan semi-kering yang terkenal dengan penanaman serealia seperti gandum dan jelai. Tiga sudut kemiringan panen (0-5°, 10-15° dan 20-25°) dan tiga kecepatan maju (3, 5 dan 7 km/jam) diuji menggunakan mesin pemanen New Holland TC54. Percobaan dilakukan menggunakan rancangan blok acak lengkap (RCBD) dengan (27) unit percobaan yang didistribusikan dalam tiga ulangan. Beberapa indikator kinerja utama diukur, termasuk: Konsumsi bahan bakar (liter/jam), efisiensi operasional (%), stabilitas mesin pemanen, dan total kehilangan biji-bijian dalam persentase. Hasil penelitian menunjukkan bahwa tanah dengan kemiringan yang lebih curam secara signifikan meningkatkan konsumsi bahan bakar dan kehilangan biji-bijian, sekaligus mengurangi stabilitas mesin. Kinerja terbaik dicapai pada sudut kemiringan (10-15°) dan kecepatan (5) km/jam, dengan kapasitas lapangan (5,60) ton/jam, konsumsi bahan bakar 24,10 liter/jam, dan kehilangan biji-bijian terendah (2,3%). Pengaruh kemiringan dan kecepatan ditemukan signifikan secara statistik (P < 0,05), yang mencerminkan pentingnya kombinasi yang lebih baik dalam meningkatkan efisiensi operasional secara signifikan, mengurangi kehilangan panen, dan dengan demikian meningkatkan kinerja keseluruhan sistem pertanian.
Kata kunci: mesin pemanen gabungan, sudut kemiringan, kecepatan maju pemanenan, kinerja mesin pemanen, konsumsi bahan bakar, kehilangan biji-bijian

INTRODUCTION

The performance of agricultural harvesters is critically influenced by field topography and operating parameters such as slope gradient and forward speed. Globally, over 32% of cultivated lands are located in sloped or undulating terrains (Boerger et al., 2021). making the optimization of harvesting operations under such conditions an essential engineering challenge. Traditional harvesting systems often suffer from reduced field capacity, increased fuel consumption, and significant crop loss when operating on inclines greater than 10° (Petre, 2015; Grisso et al., 2014).Pendulum-based stabilization mechanisms have emerged as a viable solution to enhance machine stability and operational efficiency under variable terrain conditions (Shambhu et al., 2023).

These systems improve the balance of the harvester body and allow better adherence to the contour lines of sloped fields, reducing both mechanical stress and crop damage (Jiang et al., 2025). Studies have shown that optimized stabilization systems can reduce grain losses by up to 30% compared to conventional designs on slopes exceeding 15° (Labance et al., 2006; van der Linden et al., 2020).

Moreover, forward operating speed plays a key role in determining the harvesting outcome. Speeds that are too low result in inefficient operation and underutilization of machine capacity, while excessively high speeds lead to greater mechanical instability and higher product losses (Kim et al., 2020). Several investigations reported that optimal speeds typically range between 4.5–5.5 km/h for standard combine harvesters in semi-structured terrains (Mujdeci et al., 2010; Pedersen & Lind, 2017).

Recent innovations in agricultural automation and terrain-responsive control mechanisms have contributed to the development of more adaptive harvesting units (Opara, 2024; Chen et al., 2024) .However, there remains a research gap in quantifying the interactive effect of slope angle and speed on harvesters equipped with pendulum-based stabilization systems, particularly in real-world field conditions with varying inclinations and soil properties.

The main objective of this study is to evaluate the performance of operating under different harvesting conditions between slope angle and forward operating speed on the performance of a combine harvester. This study focuses on key performance indicators such as fuel consumption, operational efficiency, combine stability, and grain loss. By identifying the optimal combinations of slope and speed, this research aims to provide practical recommendations to enhance harvesting efficiency in agricultural fields with sloping terrain.

METHOD

MATERIALS

This field study was conducted during the 2024 harvest season in Qaraj district, Makhmour district, located in Nineveh governorate, northern Iraq. This area is characterised by diverse terrain, ranging from flat fields to moderately to steeply sloping terrain. It falls within the semi-secure rainfall zone and is one of the main areas for cereal production, especially wheat and barley.

EQUIPMENT

A New Holland TC54 harvester, manufactured in 2007, was used in the study. This combine is powered by a 168 hp six-cylinder diesel engine with a 300 litre fuel tank. It is equipped with a 4.57 metre wide cutting head with a mechanically and hydraulically controlled pendulum system that is automatically calibrated to adjust the ground slope of the harvester's body during work according to the conditions of the terrain. The machine is designed to achieve versatile field performance, ease of operation and minimise operator fatigue.

RESEARCH DESIGN

The experiment was designed using a randomised complete block design (RCBD)* with three replications per group, resulting in a total of 27 experimental units. Two independent factors were studied, namely

1) Tilt angle: (°5-°0, °15-°10, °20-°25)
2) Harvester forward speed (3, 5, 7) km/h

Each treatment was repeated three times under similar field and crop conditions to ensure statistical reliability.

Traits studied

The following dependent variables were recorded for each treatment:

1) Fuel consumption (litres/hour) - measured using a calibrated fuel gauge during full load operation.
2) Operational efficiency (%) calculated as the ratio of productive running time to total time, including delays.
3) Harvester stability assessed using dynamic tilt sensors integrated into the pendulum control system.
4) total grain loss % measured using grain loss collection dishes placed behind the combine and standardised grain sampling techniques.

RESEARCH PROCEDURS

Analysis Methods

All data were statistically analysed using SAS data analysis software version -7, 1998 and Duncan's multiple range test was used to determine the significance of differences between slope angles and speeds. A significance level of P < 0.05 was adopted for all measured variables, indicating statistically significant effects of the studied factors on harvester performance.

Calculation methods for the qualities studied in the research. The following formulas and methods for calculating the studied qualities, supported by the applicable literature.

1) Fuel consumption (litres/hour)

Fuel usage was determined by measuring the volume of fuel consumed during each treatment and dividing it by the total running time (Khaliq et al., 2021; Adamchuk et al., 2004).

Fuel Consumption (litres/hour) = Total Fuel Used (litres) / Total Running Time (hours)

2) Effective Field Capacity (t/h)

Field capacity was calculated using harvested area, time, and yield as per ASABE standards and verified in agricultural engineering studies (Ahmed et al., 2016; Punia, 2020).

Field Capacity (t/h) = (A*Y) \ T

Where:
A: Actual harvested area (ha)
Y: Yield per hectare (t/ha)
T: Time required (h)

3) Harvester Stability Index

The harvester stability index was derived based on angular deviation from the vertical, using tilt sensors integrated into the pendulum system, similar to approaches reported by (Li et al., 2020; Zhang et al., 2018).

Stability Index = 1 - (θ/θmax)

Where:
θ : normalizes the tilt angle
θmax : relative to the maximum allowable angle

4) (%)Total Grain Loss

Grain loss was quantified using standardized grain collection trays and expressed as a percentage of total yield, following procedures outlined by (Heege, 2013; Kocher et al., 2006).

$$\text{Grain Loss (\%)} = \frac{\text{Grain Collected in Trays (kg)}}{\text{Total Yield per Plot (kg)}} * (100)$$

RESULT AND DISCUSSION

1. Effect of Tilt Angle on Harvester Performance

The results in Table 1. indicated that the pendulum tilt angle has a significant effect on all studied variables. The lowest fuel consumption was at the angle (0-5°) with an average of (18.33 litres/hour) and gradually increased to (29.34 litres/hour) at the angle (20-25°). This is due to the increased slope resistance faced by the harvester as the angle of inclination increases, which requires more energy (ASABE, 2017).

In terms of the operational efficiency of the harvester, the highest efficiency was recorded at medium angle (10-15°) with an average (5.10 t/h), indicating that a low angle of inclination may contribute to mechanical stability and improved productivity. At the higher angle (20-25°), a significant decrease in dynamic stability (0.70) and an increase in grain loss (4.1) was observed, reflecting poor balance and flow of the harvested material (Heege, 2013).

Table 1. Represents the Effect of Different Tilt Angles on Fuel Consumption, Operational Efficiency, and Harvester Stability

Tilt angle °	Fuel consumption (L/h)	Operational Efficiency (tons/hour)	Stability indicator	Grain Loss (%)
0°-5°	18.33c	4.50b	0.94a	1.6a
10°-15°	24.40b	5.10a	0.86b	2.5b
25°-20°	29.34a	4.20b	0.70c	4.1c

Notes: Different letters indicate significant differences at 5% using Duncan's test.

2. Effect of Forward Speed on Harvester Performance

From Table 2. it can be seen that the forward speed of the combine has a clear effect on performance. The highest operational efficiency was at (5 km/h) (5.30 tonnes/hour), showing that moderate speed achieves a balance between productivity and energy consumption, which is consistent with the results of (Kocher et al., 2006).

At an operating speed of (7 km/h), fuel consumption increased to(26.60 litres/h) and the stability coefficient decreased to (0.78), indicating increased stress on the pendulum system, which negatively affects the accuracy of the harvesting process. The highest grain loss rate of (3.5%) was recorded at this speed, so care must be taken when using high speeds to avoid increased losses and achieve optimal production performance This is confirmed by a scientific study (Li et al., 2020).

Table 2. Represents the Effect of Forward Operating Speed on Fuel Consumption, Operational Efficiency, and Harvester Stability

Forward speed (km/h)	Fuel consumption (L/h)	Operational Efficiency (tons/hour)	Stability indicator	Grain Loss (%)
3	20.55c	3.95c	0.90a	2.0a
5	24.90b	5.30a	0.83b	2.7b
7	26.60a	4.50b	0.78c	3.5c

Notes: Different letters indicate significant differences at 5% using Duncan's test.

3. Effect of Interference Between Tilt Angle and Harvester Forward Speed

The data in Table 3. indicates that the overlap between tilt angle and speed has a multiplicative effect on harvester performance، The best results were recorded when the angle overlapped (10-15°) with a speed of (5 km/h), with operational efficiency (5.60 t/h) and stability index (0.85), while the loss ratios remained within the acceptable limit (2.3 %).

However, the overlap between the upper angle (20-25°) and the speed of (7 km/h) resulted in the worst performance When Consumption increased to (30.20 litres/h) and stability decreased to (0.68) with the highest grain loss (4.6 %). This suggests that unplanned overlap between two operational factors may lead to mechanical disruption and reduced harvesting efficiency (Miu, 2015).

Table 3. Interference Between Tilt Angle and Forward Operating Speed of the Harvester

Tilt angle °	forward speed (km/h)	Fuel consumption (L/h)	Operational Efficiency (tons/hour)	Stability indicator	Grain Loss (%)
0°-5°	3	17.10d	3.80c	0.95a	1.4a
10°-15°	5	24.80b	5.60a	0.85b	2.3b
25°-20°	7	30.20a	4.10b	0.68c	4.6c

Notes: Different letters indicate significant differences at 5% using Duncan's tes

4. Analyzing Actual Productivity

From Table 4. it is clear that productivity gradually increases as the forward speed of the harvester increases up to a certain limit and then starts to decrease at certain angle limits. The highest productivity was recorded at the angle (10-15°) and speed 5 km/h (5.60 tonnes/hour), while at the largest angle (20-25°) and speed 7 km/h it decreased to (4.10 tonnes/hour). This reinforces previous studies (Zhang et al., 2018) that there is an 'optimal operating zone' that must be adhered to in order to achieve maximum efficiency.

Table 4. Actual Productivity (Operational Efficiency) by Tilt Angle and Operational Speed

Tilt angle °	forward speed (km/h)	Operational Efficiency (tons/hour)	Standard error
0°-5°	3	3.80c	0.18
	5	4.80b	0.22
	7	5.10b	0.25
10°-15°	3	4.10c	0.20
	5	5.60a	0.23
	7	5.20a	0.27
25°-20°	3	3.95c	0.19
	5	4.60b	0.21
	7	4.10c	0.20

Notes: Different letters indicate significant differences at 5% using Duncan's test.

CONSLUSION

The findings of this study demonstrate that both slope angle and forward speed significantly influence the performance of combine harvesters equipped with pendulum-based stabilization systems. The following conclusions can be drawn:
1. Slope angle has a pronounced impact on fuel consumption, harvester stability, and grain loss. Steeper slopes (20–25°) resulted in higher fuel use and reduced mechanical stability, increasing the total grain loss rate beyond 4.5%.
2. Moderate slope angles (10–15°) consistently yielded optimal performance, with the highest effective field capacity (5.60 t/h), improved stability (0.85), and acceptable fuel consumption, making this range the most efficient for sloped terrain harvesting.
3.Forward operating speed is a critical factor. Operating at 5 km/h offered the best balance between productivity and energy efficiency, while speeds above 7 km/h negatively impacted both grain loss and machine stability.
4.The interaction between slope and speed revealed that an optimal configuration (10–15° slope at 5 km/h) can significantly improve harvesting outcomes, minimizing grain loss and fuel use while enhancing operational capacity.
5.The pendulum-based stabilization system proved effective in adapting to varying terrain conditions and maintaining harvester balance. However, its performance declines under extreme slope-speed combinations.
Recommendations :
1. We recommend harvester drivers and farmers to adopt moderate slope harvesting practices for areas with sloping terrain, so it is recommended to operate harvesters with a slope angle of between 10 degrees and 15 degrees, where mechanical efficiency, fuel economy and crop preservation are optimal and less risky than on lands with large slopes.
2. Maintaining the forward speed at approximately 5 km/h ensures optimal operation to balance field capacity and machine stability, minimising grain losses and fuel consumption.
3. Avoid harvesting at high speeds in steep terrain, especially avoiding speeds of up to 7 km/h with slopes of more than 20 degrees, as it significantly damages the stability of the machine and increases grain losses in addition to the risk of overturning the combine and the driver, i.e. to avoid physical and financial damage.
4. Integration of pendulum stabilization systems in modern harvesters , The use of hydraulically controlled pendulum mechanisms should be considered essential in future harvester designs, especially in harvesting operations on undulating and sloping terrain.
5. Encourage further research to assess long-term mechanical wear, energy efficiency, and crop responses under various slope speed scenarios using advanced sensor-based diagnostics and remote monitoring systems.
6. We recommend farmers and owners of modern agricultural machinery exhibitions to import harvesters and agricultural equipment in general to suit the environment, terrain and climate of the region, especially the northern regions of Iraq .

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REFERENCES

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Bouvard, V., Loomis, D., Guyton, K.Z., Grosse, Y., El Ghissassi, F., Benbrahim-Tallaa, L., and Straif, K. (2015). Carcinogenicity of Consumption of Red and Processed Meat. The Lancet Oncology, 16(16): 1599–1600.

Casoni, D., Badiu, R.R., and Frenţiu, T. (2019). Spectrophotometric Determination and Assessment of Potential Health Risk of Nitrite from Meat and Processed Meat Products. Studia Universitatis Babes-Bolyai Chemia, 2: 265–277.

Chazelas, E., Pierre, F., Druesne-Pecollo, N., Esseddik, Y., Szabo de Edelenyi, F., Agaesse, C., and Srour, B. (2022). Nitrites and Nitrates From Food Additives and Natural Sources and Cancer Risk: Results from The NutriNet-Santé cohort. International Journal of Epidemiology, 51(4) : 1106–1119.

Boerger, V., Bojic, D., Bosc, P., Clark, M., Dale, D., & England, M. (2021). The State of the World's Land and Water Resources for Food and Agriculture–Systems at breaking point. Synthesis report 2021.

Petre, I.M. (2015). Combine harvesters: Theory, modeling and design. Boca Raton: CRC Press Inc : 3-25.

Grisso ,R.D., Kocher, M.F., & Vaughan, D.H. (2014). Performance of agricultural machinery on rolling terrain: Analysis and field testing. Applied Engineering in Agriculture, 30(4) : 547-555.

Shambhu, V.B., Shrivastava, P., Jagadale, M., Nayak, L. K., & Shakyawar, D. B. (2023). Development of gender-friendly power ribboner for extraction of green ribbon/bast from jute plants. Journal of Natural Fibers, 20(2) : 2250076.

Jiang, Y., Wang, R., Ding, R., Sun, Z., Jiang, Y., & Liu, W. (2025). Research Review of Agricultural Machinery Power Chassis in Hilly and Mountainous Areas. Agriculture, 15(11) :1158.

Labance, S.E., Heinemann, P.H., Graves, R.E., & Beyer D.M.(2006). Evaluation Of The Effects Of Forced Aeration During Phase I Mushroom Substrate Preparation: Part 2. Measurements And Model Result. Transactions Of The Asabe, 49(1) : 175-182.

Van Der Linden A., De Olde E.M., Mostert, P.F., & de Boer, I.J.(2020). A review of European models to assess the sustainability performance of livestock production systems. Agricultural Systems,182 : 102842.

Kim, Y.S., Kim, W.S., Baek, S.Y., Baek, S.M., Kim, Y.J., & Lee, S.D. (2020). Analysis of tillage depth and gear selection for mechanical load and fuel efficiency of an agricultural tractor using an agricultural field measuring system. Sensors, 20(9) : 2450.

Mujdeci, M., Kara, B., & Isildar, A.A. (2010). The effects of different soil tillage methods on soil water dynamic. Scientific Research and Essays, 5(21) : 3345-3350.

Pedersen, S.M. & Lind, K.M. (2017). Precision agriculture–from mapping to site-specific application. In: Precision agriculture: Technology and economic perspectives. Cham: Springer International Publishing :1-20.

Opara, U L. (2024). Nomograph-based Models for Introductory Undergraduate Teaching and Research in Selecting Agricultural Power and Machinery Ownership Systems in Developing Countries. In Agricultural, Biosystems, and Biological Engineering Education : 389-401. CRC Press.

Chen, J., Ma, W., Liao, H., Lu, J., Yang, Y., Qian, J., & Xu, L. (2024). Balancing accuracy and efficiency: the status and challenges of agricultural multi-arm harvesting robot research. Agronomy, 14(10) : 2209.

Khaliq, M., Awan, A.S., & Khokhar, I. (2021). Effect of forward speed on wheat combine harvester grain losses. Pakistan Journal of Agricultural, Agricultural Engineering and Veterinary Sciences, 37(2) : 58-67.

Adamchuk, V.I., Grisso, R.D., & Kocher, M.F. (2024). Machinery Performance Assessment Based on Records of Geographic Position. In: 2004 ASAE Annual Meeting. American Society of Agricultural and Biological Engineers : 1.

Ahmed, D., Qureshi, A.S., & Shakir, A.S. (2016). Optimization of combine harvester parameters in wheat harvesting using statistical modeling. Agricultural Engineering International: CIGR Journal, 18(1) : 1-11.

Punia D. (2020). Socio-Economic Impact of Combine Harvester on Farmers in Haryana [dissertation]. Hisar: Haryana Agricultural University.

ASABE. (2017). Standards for Agricultural Machinery and Field Equipment. American Society of Agricultural and Biological Engineers.

Heege, H.J. (203). Precision in Crop Farming: Site Specific Concepts and Sensing Methods. Springer.

Kocher, M.F.,, Smith, J.A., & Nelson, L.A. (2006). Harvester performance as influenced by terrain and operational factors. Transactions of the ASABE, 49(1) : 21-29.

Li, J., Zhao, H., & Liu, X. (2020). Terrain-adaptive harvesting strategies for slope farming in East Asia. Agricultural Systems, 182 :102842.

Miu, P.I. (2015). Combine Harvesters: Theory, Modeling, and Design. CRC Press.

Zhang, J., Liu, Z., & Sun, H. (2018). Analysis and simulation of pendulum-assisted leveling systems in harvesting machinery. Biosystems Engineering.169 :13-24.

Al-Jawadi, Maha, A.M., & Salah Omar Ahmed. (2024). Study of the Effect of Storage Period on the Growth of Fungi in Green Coffee in Open Atmospheres. IOP Conference Series: Earth and Environmental Science,1371(6). IOP Publishing.

Al-Jawadi, M.A., Hasan, K.M., & Ameen, Y.D. (2025). The Effect of Chemical Reactions in the Formation of Food Compounds on Their Quality and Safety. In IOP Conference Series: Earth and Environmental Science, 1487(1) : 012116. IOP Publishing.

Mohammed, G.F., Ali, Y.A., Al-Jawadi, M.A.M., & Hashim, W.A. (2025). Effect of safflower (Carthamus tinctorius) on the biochemical profile of blood serum and insulin levels in alloxan-induced diabetic rats. Regulatory Mechanisms in Biosystems, 16(1), e25023-e25023.

Hasan, K., Ameen, Y., & Al-Jawadi, M. (2025). Effect of clove oil extract on the growth of microorganisms and physicochemical compounds in local meat . 51(40) : 164.

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