Al-Muthanna J. For Agric Sci Online ISSN:2572-5149
Print ISSN: 2226-4086
Vol. 13 , Issue 1. 2026

https://muthjas.mu.edu.iq/ http://doi.org/10.52113/mjas04/13.1/5

Effects of Tractor Forward Speed and Tire Inflation Pressure on Operator Whole-Body Vibration, Seed Row Alignment, and Fuel Efficiency Under Semi-Arid Soil Conditions

Jarullah Maher[1], Assad Ibrahim Alhayali[2]

mti.lec146.jarullah@ntu.edu.iq mti.lec149.assad@ntu.edu.iq

1, Department of Anesthesia Techniques - Medical Technology Institute - Northern Technical University - Mosul - Iraq

2, Department of Therapeutic Nutrition Techniques - Nimrud Technical Institute - Northern Technical University - Mosul - Iraq.

(Abstract)

Tractor operating conditions strongly affect operator comfort, seeding quality, and energy efficiency, especially in semi-arid soils with high surface roughness. This study evaluated the effects of forward speed, tire inflation pressure, and soil roughness on whole-body vibration (WBV), seed row alignment accuracy, fuel consumption, and effective field capacity during seeding operations. Field experiments were conducted using a Turkish-manufactured New Holland tractor driven by a trained operator (90 kg) in a Randomized Complete Block Design And with three repeats. Forward speed (3–6 km·h□¹), tire pressure (0.8–1.6 bar), and soil roughness (smooth to rough) were systematically varied. WBV was quantified using RMS and VDV following ISO 2631, while seeding accuracy was assessed via mean lateral deviation and zig-zag frequency. Fuel consumption and field capacity were also recorded.

Results showed that RMS and VDV increased with speed and soil roughness, from 0.85 ± 0.05 to 2.15 ± 0.07 m·s□² and 12.5 ± 1.2 to 31.5 ± 1.5 m·s¹·□□, exceeding recommended exposure limits under extreme conditions. Concurrently, mean lateral deviation rose from 3.2 ± 0.3 to 10.8 ± 0.5 cm and zig-zag frequency from 2.0 ± 0.2 to 6.2 ± 0.3 per 100 m. Fuel consumption ranged 4.2 ± 0.1 to 5.3 ± 0.2 L·h□¹, while field capacity increased 0.8 ± 0.05 to 1.3 ± 0.08 ha·h□¹.

Intermediate tire pressure (~1.2 bar) combined with moderate speed and smooth-to-moderate soil conditions achieved the most balanced performance, optimizing productivity while maintaining acceptable vibration exposure and seeding precision. These findings provide practical guidance for improving tractor operation and operator safety under semi-arid conditions.

Keywords: Whole-body vibration; tractor operating parameters; tire inflation pressure; seed row alignment; fuel consumption; field capacity; semi-arid soils

(Introduction)

Agricultural mechanization plays a decisive role in improving field productivity, operational efficiency, and the overall sustainability of modern farming systems, particularly in semi-arid regions where soil surface irregularities and mechanical stresses are pronounced [1]. Tractors remain the central power units for most field operations, including tillage and seeding; therefore, their operational stability and dynamic behavior directly influence both operator well-being and the quality of agricultural practices [2].

One of the most critical occupational challenges associated with tractor operation is whole-body vibration (WBV), which is transmitted to the operator through the seat, steering system, and tractor chassis during field operations. Prolonged exposure to WBV has been strongly linked to operator fatigue, reduced task performance, and long-term musculoskeletal disorders, especially spinal injuries [3,4]. Several studies have demonstrated that vibration magnitude is highly dependent on operating speed, soil surface roughness, and tractor–soil interaction characteristics [5]. Under rough field conditions, vibration levels may exceed internationally recommended exposure limits defined by ISO 2631-1, posing significant health risks to operators [6].

The transmission of vibration to the operator is also influenced by tractor seat design and suspension characteristics. Scarlett et al. [7] reported that suspension seats can significantly reduce vibration transmissibility; however, their effectiveness diminishes at higher operating speeds and under severe surface roughness. More recent investigations by Mehta et al. [8] confirmed that seat vibration transmissibility varies considerably with excitation frequency and operating conditions, emphasizing that vibration control cannot rely solely on seat design but must consider the entire tractor–soil–operator system. A comprehensive review by Koirala et al. [9] further highlighted that WBV exposure among tractor operators remains a global concern, particularly in developing regions where field conditions are harsh and mechanization technologies are less advanced.

Beyond operator health, tractor dynamic stability and vibration behavior have direct implications for seeding performance, especially seed row alignment accuracy. Accurate seed placement and straight row formation are essential for achieving uniform crop emergence, efficient nutrient utilization, and optimal yield [10]. Deviations in seed row alignment increase intra-row competition and complicate subsequent field operations, such as mechanical weed control and harvesting. Studies focusing on planter performance have shown that mechanical stability and consistent soil–implement interaction are

key factors governing seed placement accuracy [11].

Advances in precision agriculture, particularly GPS-based guidance and auto-steering systems, have significantly improved seed row alignment by minimizing human steering errors [12]. Stombaugh and Shearer [13] demonstrated that GPS-guided agricultural vehicles achieve superior row straightness compared with manual steering. However, in many semi-arid regions, conventional tractors without advanced guidance systems remain dominant, making tractor stability, vibration behavior, and operator control accuracy critically important. Zhang et al. [14] emphasized that improving operational precision under such conditions remains a major objective of precision agriculture research worldwide.

Several studies have attempted to link tractor operating parameters with both operator comfort and machine performance. Tire inflation pressure, in particular, has been identified as a key variable influencing tractor ride comfort, vibration transmission, and traction efficiency. Langer et al. [15] reported that inappropriate tire pressure significantly increases vibration exposure and reduces driver comfort, while Depauw et al. [16] demonstrated that tire inflation pressure alters the dynamic response of the tractor, affecting both ride quality and vehicle stability. These dynamic changes can indirectly influence the directional stability of mounted or trailed implements, including seed drills.

Recent research has also shown that reducing operator workload through improved guidance systems can enhance both operational accuracy and operator comfort [17]. Gonzalez-de-Soto et al. [18] demonstrated that vision-based guidance systems reduce steering corrections and operator workload, which may indirectly reduce vibration peaks caused by abrupt corrective maneuvers. Despite these advancements, limited experimental studies have simultaneously evaluated the combined effects of tractor speed, tire inflation pressure, and soil surface roughness on operator vibration exposure, seed row alignment accuracy, and fuel efficiency under semi-arid soil conditions.

Therefore, the present study aims to address this research gap by experimentally investigating the individual and interactive effects of key tractor operating parameters—namely forward speed, tire inflation pressure, and soil surface roughness—on whole-body vibration exposure, seed row alignment accuracy, and fuel consumption during seeding operations under semi-arid conditions. The findings of this study are expected to provide scientifically grounded recommendations for optimizing tractor operation, enhancing operator safety, and improving seeding quality in challenging dryland agricultural environments.

(Materials and Methods)

1. Study Site and Soil Characteristics

The field experiments were conducted in semi-arid agricultural lands in Al-Rashidiya area, Nineveh Governorate, Mosul, Iraq, during the [2024]. This location is characterized by a semi-arid climate with low annual rainfall and relatively high soil temperatures, typical of northern Iraq. Prior to field operations, soil samples were collected and analyzed to determine texture, organic matter content, and moisture level using standard laboratory procedures [1,2].

Prior to field operations, soil samples were collected from the 0–30 cm soil layer at multiple locations across the experimental field. Soil texture was determined using the hydrometer method described by Bouyoucos [3], while soil moisture content and organic matter were measured following standard laboratory procedures. Based on the obtained results, the soil was classified as loamy sand. Surface roughness was subsequently categorized into three levels (smooth, moderately rough, and rough) according to micro-topographical measurements of the soil surface, following methodologies commonly applied in tractor vibration and soil–machine interaction studies [4 , 5] .

Table 1. soil Physical and Chemical Properties of the study site.

soil properties	
Value	Soil type
64%	Sand
16%	Clay
2.8%	Organic matter
13%	Moisture

The soil was classified as semi-arid loamy sand, with roughness levels later categorized into three classes (smooth, moderately rough, and rough) based on surface micro-topography measurements.

2. Machinery, Equipment, and Operator

All experimental trials were conducted using a 75 hp Turkish-manufactured New Holland agricultural tractor equipped with a mechanical transmission system and coupled to a standard seed drill. This tractor category is widely used in semi-arid farming systems and has been frequently employed in vibration and performance evaluation studies [6,7].

The tractor was operated by a trained and experienced driver weighing 90 kg, selected to represent an average tractor operator in practical field conditions. Operator mass was kept constant throughout the experiments to minimize variability in vibration transmission, as recommended in whole-body vibration assessment standards and previous studies [8,9].

The following instruments were used for data acquisition:

A tri-axial accelerometer for measuring whole-body vibration exposure in accordance with ISO 2631-1 [10].

A high-precision GPS receiver combined with ground-based measuring tools for assessing seed row alignment accuracy.

A calibrated fuel flow meter for recording real-time fuel consumption during each experimental run.

3. Treatments and Experimental Design .

The experiments were arranged according to a (RCBD) Randomized Complete Block Design with three replications per treatment to reduce the effects of field variability and ensure statistical reliability, as commonly adopted in agricultural machinery performance studies [11].

Three independent operating parameters were evaluated:

1. Tractor forward speed: 3, 4.5, and 6 $km \cdot h^{-1}$

2. Tire inflation pressure: 0.8, 1.2, and 1.6 bar

3. Soil surface roughness: smooth, moderately rough, and rough

Each treatment combination was tested along a 100 m straight test track. This distance was selected to ensure sufficient data collection for vibration exposure, seed row deviation, and fuel consumption while maintaining consistent operating conditions [12].

The experiments were arranged using a Randomized Complete Block Design (RCBD) with three replications for each treatment combination.

Three independent variables were evaluated:

1. Tractor forward speed: 3, 4.5, and 6 km/h

2. Tire inflation pressure: 0.8, 1.2, and 1.6 bar

3. Soil roughness: smooth, medium, and rough

Each experimental run was conducted over a 100-meter test track to allow accurate measurement of vibration exposure, seed row alignment, and fuel consumption.

4. Measurement Instruments and Data Acquisition

Operator whole-body vibration was measured in accordance with ISO 2631-1 standards using a calibrated tri-axial accelerometer. The accelerometer was rigidly mounted on the tractor seat directly beneath the operator to record vibration exposure along the longitudinal (x), lateral (y), and vertical (z) axes. Vibration signals were continuously collected during each experimental run and processed to obtain the frequency-weighted Mean square root acceleration (RMS, m/s^2) and Evaluate the vibration dose (VDV, $m/s^{1.75}$).

Seed row alignment accuracy was evaluated along a 100 m seeding track by measuring the lateral deviation from the theoretical centerline at fixed intervals. The zig-zag rate (zig-zag/100 m) was calculated based on the number of significant directional changes observed along the seeding path, providing an indicator of row straightness and placement consistency.

Fuel consumption was determined using a calibrated fuel flow measurement system installed in the tractor fuel line, enabling real-time monitoring of fuel usage during field operations. Effective field

capacity (ha/h) was calculated based on the actual covered area and the corresponding operating time for each treatment.

All measuring instruments were calibrated prior to field experimentation, and data acquisition was conducted under steady-state operating conditions to ensure data reliability and repeatability.

5. Measured Parameters

4.1 Operator Vibration

Whole-body vibration was measured according to the procedures outlined in ISO 2631-1, using a triaxial accelerometer mounted on the tractor seat and the operator's chest.

The following vibration indices were recorded:

- Mean square root acceleration (RMS)
- Evaluate the vibration dose (VDV)

4.2 Seed Row Alignment Accuracy

Seed placement accuracy was evaluated using:

- Mean lateral deviation (cm)
- Maximum deviation (cm)
- Zig-zag frequency (zig-zag/100 m)

Measurements were taken along the full 100-m seeding track using GPS and ground-measuring tools.

4.3 Fuel Consumption and Field Productivity

Fuel consumption was measured using a calibrated fuel flow meter installed in the tractor fuel supply system. Effective field capacity was calculated based on the actual area covered during each run and the corresponding operating time, using the following equation [13] .

Field Productivity = Area Covered (ha) \ Operating Time (h)

6. Statistical Analysis

All collected data were subjected to statistical analysis using SAS software. Analysis of variance (ANOVA) was performed to evaluate the effects of tractor forward speed, tire inflation pressure, and soil surface roughness, as well as their two-way and three-way interactions, on vibration exposure, seed row alignment accuracy, and fuel consumption.

Treatment means were compared using Duncan's Multiple Range Test (DMRT) at a significance level of $P < 0.05$. This statistical approach is consistent with methodologies adopted in similar tractor performance and vibration studies [11]

(Results and discussion)

1. Operator Whole-Body Vibration (RMS and VDV)

Table(1) Effect of tractor forward speed, tire inflation pressure, and soil surface roughness on whole-body vibration exposure (mean ± SD)

Speed (km/h)	Tire pressure (bar)	Soil roughness	RMS a_w (m/s²)	(m/s¹·□□)VDV

3	0.8	Smooth	0.04 ± 0.78	1.0 ± 11.9
3	1.2	Smooth	0.05 ± 0.85	1.2 ± 12.5
3	1.6	Smooth	0.06 ± 0.94	1.3 ± 13.8
4.5	0.8	Medium	0.06 ± 1.25	1.3 ± 18.4
4.5	1.2	Medium	0.05 ± 1.38	1.4 ± 20.1
4.5	1.6	Medium	0.07 ± 1.55	1.5 ± 22.3
6	0.8	Rough	0.06 ± 1.85	1.4 ± 26.7
6	1.2	Rough	0.05 ± 1.98	1.6 ± 29.1
6	1.6	Rough	0.07 ± 2.15	1.5 ± 31.5

***The mean in a column followed by different letters differs significantly at P < 0.05 (DMRT).**

Table 1 demonstrates that whole-body vibration (WBV), expressed by RMS and VDV indices, was significantly affected ($P < 0.05$) by tractor forward speed, soil surface roughness, tire inflation pressure, and their interactions. The lowest vibration exposure was recorded under smooth soil conditions at low operating speed (3 km·h□¹), where RMS values remained within acceptable occupational exposure limits (0.85 ± 0.05 m·s□²), in accordance with international vibration exposure guidelines [2,3].

In contrast, operation on rough soil at high forward speed (6 km·h□¹) combined with elevated tire pressure (1.6 bar) resulted in a marked increase in vibration magnitude, with RMS reaching 2.15 ± 0.07 m·s□² and VDV increasing to 31.5 ± 1.5 m·s¹·□□. These values exceed recommended daily exposure thresholds, indicating a potential occupational health risk for operators during prolonged field operations [3,6].

Soil surface roughness emerged as the dominant factor governing vibration transmission, as irregular terrain induces higher excitation forces that propagate through the tractor structure to the seat–operator interface. Forward speed acted as an amplifying parameter by increasing the frequency and magnitude of these excitations, a phenomenon consistent with established vibration transmission theory [2,5]. Similar relationships between terrain irregularity and WBV intensity have been widely reported in tractor dynamics studies [5,6].

The interaction between tire inflation pressure and soil roughness was also statistically significant. Higher tire pressure reduced tire compliance, limiting its ability to absorb surface irregularities and thereby increasing vibration transmissibility. Conversely, an intermediate pressure (1.2 bar) provided partial damping due to improved tire–soil contact characteristics. These findings align with previous investigations emphasizing the importance of tire flexibility in mitigating WBV exposure [12,13].

A simple regression model was developed to quantify the combined effect of tractor forward speed and soil hardness on RMS vibration exposure:

RMS = 0.3 *Speed (km/h) + 0.6 Soil Hardness Index

The model confirms that soil hardness is the dominant factor influencing operator WBV, with speed acting as an amplifying variable."

2. Seed Row Alignment Accuracy

Table (2) Effect of operating parameters on seed row alignment accuracy

Speed (km/h)	Tire pressure (bar)	Soil roughness	Average lateral (deviation cm)	Maximum deviation (cm)	Zig-zag rate (zig-zag/100 m)
3	1.2	Smooth	0.3 ± 3.2	0.4 ± 5.0	0.2 ± 2.0
4.5	1.2	Medium	0.4 ± 6.1	0.5 ± 9.3	0.3± 3.9
6	1.2	Rough	0.5 ± 9.6	0.6 ± 12.8	0.4 ± 5.5
6	1.6	Rough	0.5 ± 10.8	0.6 ± 14.2	0.3 ± 6.2

As shown in Table 2, seed row alignment accuracy—quantified by mean lateral deviation, maximum deviation, and zig-zag frequency—was significantly influenced by all examined operating parameters. Mean lateral deviation increased from 3.2 ± 0.3 cm under smooth soil conditions and low speed to 10.8 ± 0.5 cm when operating on rough soil at 6 km·h□¹. A similar trend was observed for maximum deviation and zig-zag frequency, which reached 14.2 ± 0.6 cm and 6.2 ± 0.3 zig-zags per 100 m, respectively, under the most severe operating conditions.

The deterioration in row straightness can be primarily attributed to increased vibration-induced instability and reduced steering precision. Elevated WBV levels adversely affect the operator's ability to maintain steady steering inputs, resulting in frequent corrective maneuvers and increased lateral oscillations of the tractor–implement system [2,8]. Furthermore, rough soil conditions generate irregular traction forces acting on the seed drill, exacerbating directional instability and contributing to higher lateral deviations [9,10].

The absence of automatic guidance systems during the experiments amplified the influence of operator-induced variability. Previous studies have demonstrated that manual steering under high vibration environments leads to lower directional accuracy compared with guided systems, particularly in semi-arid fields characterized by pronounced surface irregularities [10,14].

3. Fuel Consumption and Field Productivity

Table (3) Fuel consumption and effective field capacity under different operating conditions

Speed (km/h)	Tire pressure (bar)	Soil roughness	Fuel consumption (L·h□¹)	Field capacity (ha·h□¹)

3	1.2	Smooth	0.1 ± 4.2	0.05 ± 0.80
4.5	1.2	Medium	0.2 ± 4.8	0.06 ± 1.05
6	1.2	Rough	0.2 ± 5.1	0.07 ± 1.25
6	1.6	Rough	0.2 ± 5.3	0.08 ± 1.30

Table 3 indicates that both fuel consumption and effective field capacity were significantly affected by tractor speed, tire inflation pressure, and soil surface roughness. Fuel consumption increased from 4.2 ± 0.1 L·h□¹ at 3 km·h□¹ on smooth soil to 5.3 ± 0.2 L·h□¹ at 6 km·h□¹ on rough soil. This increase is mainly attributed to higher rolling resistance, increased wheel slip, and elevated engine load under rough terrain and high-speed conditions [5,13].

Effective field capacity increased with forward speed, ranging from 0.8 ± 0.05 to 1.3 ± 0.08 ha·h□¹. However, productivity gains achieved at higher speeds were partially offset by increased fuel consumption and reduced seeding accuracy. Inappropriate tire inflation pressure further intensified energy losses, as excessive pressure reduced traction efficiency, while insufficient pressure increased rolling resistance [12,13].

These results clearly demonstrate that maximizing forward speed alone does not ensure optimal operational efficiency. Instead, a balanced combination of moderate speed, appropriate tire inflation pressure, and favorable soil surface conditions is required to achieve acceptable productivity while minimizing fuel consumption and maintaining seeding precision. This approach is consistent with the principles of efficient and sustainable agricultural mechanization [1,5].

(Conclusion)

1. Tractor forward speed, tire inflation pressure, and soil surface roughness exert significant and interactive effects on operator vibration exposure, seed row alignment accuracy, and fuel consumption under semi-arid soil conditions.

2. The highest vibration exposure (RMS = 2.15 m·s□²; VDV = 31.5 m·s¹·□□) and greatest row deviation (10.8 cm) occurred at 6 km·h□¹ on rough soil, exceeding internationally recommended vibration exposure limits.

3. An intermediate tire inflation pressure of approximately 1.2 bar, combined with moderate operating speed and smooth-to-moderately rough soil conditions, provided the most balanced performance in terms of operator comfort, seeding precision, and fuel efficiency.

4. Fuel consumption ranged from 4.2 to 5.3 L·h□¹, underscoring the economic and environmental importance of selecting appropriate operating parameters.

5. The results offer practical guidance for improving tractor operation, enhancing operator safety, and optimizing seeding performance in semi-arid agricultural environments

(Recommendations)

1. Future studies should evaluate the effects of the same operating parameters on different tractor models, tire types, and soil textures to enhance the generalizability of the findings.

2. Operator skill level, body posture, and weight distribution should be examined for their role in modulating whole-body vibration exposure.

3. Development of predictive modeling tools—such as machine learning-based vibration and deviation estimators—could support precision tractor operation under varying field conditions.

(References)

[1] Negrete, J. (2019). The role of agricultural mechanization in food security. *Journal of Agricultural Research Adcances*, *1*(3), 12-15.

[2] Griffin, M. J. (2012). *Handbook of human vibration*. Academic press.

[3] AN, N., & SI, S. (2007). Mechanical vibration and shock–evaluation of human exposure to whole body vibration–part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems. *Mechanical Vibration and Shock–Evaluation of Human Exposure to Whole Body Vibration–Part 4: Guidelines for the Evaluation of the Effects of Vibration and Rotational Motion on Passenger and Crew Comfort in Fixed-Guideway Transport Systems*.

[4] Pusty, T., Więckowski, D., Dębowski, A., Wesołowski, M., & Barta, D. (2025). Experimental Study of the Effect of Tire Pressure and Cab Height of a Tractor-Trailer Driver on Driving Comfort. *Transport and Telecommunication*, *26*(2), 175-184.

[5] Cutini, M., Deboli, R., Calvo, A., Preti, C., Brambilla, M., & Bisaglia, C. (2017). Ground soil input characteristics determining agricultural tractor dynamics. *Applied Engineering in Agriculture*, *33*(4), 509.

[6] Caffaro, F., Preti, C., Micheletti Cremasco, M., & Cavallo, E. (2017). Three-axial evaluation of whole-body vibration in agricultural telehandlers: The effects of an active cab-suspension system. *Journal of occupational and environmental hygiene*, *14*(10), 758-770.

[7] Mehta, C. R., & Tewari, V. K. (2000). Seating discomfort for tractor operators–a critical review. *International journal of industrial ergonomics*, *25*(6), 661-674.

[8] Kabir, M. S. N., Ryu, M. J., Chung, S. O., Kim, Y. J., Choi, C. H., Hong, S. J., & Sung, J. H. (2014). Research trends for performance, safety, and comfort evaluation of agricultural tractors: A review. *Journal of Biosystems engineering*, *39*(1), 21-33.

[9] Strasser, R. S. (2017). *Development of a test stand for the evaluation of row crop planter automatic downforce systems and the evaluation of a row crop planter electronic drive singulation seed meter* (Doctoral dissertation, Kansas State University).

[10] Zaman, Q. (Ed.). (2023). Precision agriculture: Evolution, insights and emerging trends.

[11] Etezadi, H., & Eshkabilov, S. (2024). A comprehensive overview of control algorithms, sensors, actuators, and communication tools of autonomous all-

terrain vehicles in agriculture. *Agriculture*, *14*(2), 163.

[12] Pusty, T., Więckowski, D., Dębowski, A., Wesołowski, M., & Barta, D. (2025). Experimental Study of the Effect of Tire Pressure and Cab Height of a Tractor-Trailer Driver on Driving Comfort. *Transport and Telecommunication*, *26*(2), 175-184.

1), 6.

[13] Zabrodskyi, A. (2023). *The effect of maintaining operating parameters of agricultural tires to minimize soil compaction* (Doctoral dissertation, Vytautas Magnus University).

[14] Emmi, L., Fernández, R., & Gonzalez-de-Santos, P. (2023). An efficient guiding manager for ground mobile robots in agriculture. *Robotics*, *13*(