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Concept of Slippage Permissibility and The Damage During The Operation Tillage.

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ABSTRACT

The objective of this article review is to highlight and discuss the allowance or permissibility and damages of the tractor wheel slippage in previous studies of field operation tillage in different soil textures and various conditions such as tractor speed, tillage depth, soil moisture and tire inflation, etc. One of the most important indicators that must be taken into account in tractors when pulling agricultural machinery is slippage. Despite the slight differences in the definition of slippage, but they agree on one concept, which is: reducing of movement that has certain permissible limits that may not be exceeded maximum permissible 15 %. Slippage occurs when tire friction with soil and the tires rotate with velocity greater than tractor speed. Moreover, this causes severe damages (especially if slippage exceeds 15 %) for the tire and soil, compact soil, forms a hard pan, destroys soil structure and fertility, waste time and power, more fuel consumption and tire wear. There should be a reasonable and simple percentage of slippage in order to absorb shocks or impacts and maintain the means of transmission in the tractor during the start of the tractor's movement or during the penetration of the plows into the soil, especially at great depths and in hard or clay soil. Many studies have concluded that the best slippage is 8-12 %. Zero tractor tire slip is impossible in operation tillage (this only happens on the road). Most factors affected in the slippage are speed, depth, weight and type of the tractor, tire condition (pressure, size and tread life), soil condition (moisture, soil type and residue), implements and type of field operation.

***Keywords*:** Tractor wheels, Slip, Soil tillage, Plowing implements, Tread tire

INTRODUCTION

Many definitions have appeared to explain the concept of the slippage in the field of agricultural mechanization or agricultural engineering. Tractor tire slip occurs when the tires rotate faster than the ground speed of the tractor. According with ISO 789-9, tractor tire slip is a ration between tire revolution number when moved tractor without load and with load behind tractor (on the hook), at the same distance length. [1] Define the slippage is reduction of moving. Other concept of the slippage by [2] is means how much Tire traveling distance reducing because of the slippage; it is express as percentage by measure the tractor travel speed or calculate tire rotations over set distance. An addition, [3] mentioned that the concept the slip is the ratio of decrease in the distance traveled by the tractor's driving wheels on the soil surface during one revolution, moreover, slippage affected by moisture soil, weight and speed tractor and types of the operation. Slippage represented important key explained relation the tires and soil field and fuel consumption when doing agricultural operation [4] [5].

In Iraq, most lands and fields agricultural still use the implement of primary and secondary tillage. Moreover, many farmers and researchers are using the moldboard, chisel and disc plow, then use disc harrows, cultivators, rollers…ect for prepare the field for seeding or study performance of this implements [6] [7] [8] [9] [10] [11] [12] [13] [14] [15] [16].
[17] mention the tractor wheel slippage at 20-22 % gave highest traction coupling, because of this higher slippage of the tires and soil, it causes the crushing and destroy the soil structure and the loss of its fertility [18] 1[19], and the process of recovery need long time and high expensive. Consequently, the maximum slippage of tractor tires should be such that their impact on the soil is as minimal as possible; this problem was initially solved by adding ballasting on the tractor [20] [21] [22], however, this way leads to increasing the soil compaction. Tractor performance should be 10-15 % as tire slip and not over from this values [23] [24]. An addition, the maximum slippage allowance (permissible) must be not exceeding 15 % [3] [25]. Many studies showed about 20 -50 % losses of tractor power at the interface tire with soil, because the tire slip, moreover, soil and tire deformation [26] [27] [28] [29].
[30] concluded that the mean value of tire slip increased from 11.91% to 29.47% when increasing the tillage depth from 10 to 20 cm. [31] used 2 bottom disc plow in primary tillage at soil moisture 16.7 %, they founded the tire slippage in first and second ploughing were 10.31 % and 12.13 % respectively, addition, recorded 3 bottom disc mounted were 9.92% and 11.93 % respectively. Results of many researchers showed when used ballast weight in wheel and front tractor frame are not solution

reduce tire slip, this way leads to excessive compaction of the soil and damage soil structure, then reduce soil productivity [31] [32].
Normally, tractor tire slippage should not exceed 15 %, otherwise it reduces productivity, destroy the soil and increasing the operation cost [31] [33] [34] [35], while slippage was unacceptable, if low and less than 6 - 7 %, which traction power not utilization and increase energy consumption. Many investigations by researcher's shows best and optimal tire tractor slip in various soil must be in rate 8-12 % [3] [27] [36] [37] [38].
[27] Concluded that the high slippage causes damage in the topsoil layer, stricture and shear deformations. Moreover, single or dual tire tractor slip should not exceed 15 % in operation tillage. [2] reported that the optimal tractor tire slip arrange 8-15 %, it is effect on tire wear and lifetime, moreover, many result showed if tire slip low may be drive train being strained, conversely, high slip leads to tire wearing, wasting fuel and time, also they reported zero tire slip is impossible on the operation field such as tillage or other, but will be desire if the tractor transport on the road or hard surface. [39] used chisel and disc plow in primary tillage and founded when increasing tire pressure and speed of the tractor increased slippage, also, conclude the tractor tire inflation and vertical loads is directly effect in the slippage and fuel consumption during operation tillage. [40] Founded in operation tillage the tire slippage decreased from 9.98 % to 4.39 % when adding ballast from 200 to 500 kg at inflation tire 1.02 kg.cm^{-2}.

The aim of this article review is to highlight and discuss the allowance or permissibility and damages of the tractor wheel slippage in previous study of field operation tillage in different soil texture and various conditions such as tractor speed, tillage depth, soil moisture, tire inflation and others.

Methods of the slippage measurement

Tractor tire slip cannot be measured directly; the most common methods for measuring tractor tire slippage are:

1- Forward speed tractor: This method more using by researchers in the world and give a good and acceptable result, this method summarized of measuring the theoretical speed of the tractor over a set distance, then measuring the practical (actual) speed of the tractor when it performs field work over the same set distance. Slippage calculated by the following equation [41]:

$$Slippage\ (\%) = \left(\frac{Theoritical\ tractor\ speed\ -\ Actual\ tractor\ speed}{Theoritcal\ tractor\ speed} \right) \times 100 \qquad (1)$$

2- Tractor tire rotations: Measuring tractor tire rotations number over set distance by put a mark on the soil and a mark on one of the rear tires of the tractor, then drive a tractor under load with tool (agricultural implement) for ten revolutions of the rear wheel of the tractor. Put another mark on the tractor again without a load (without implement) and count the number of revolutions between the two marks (fig. 1), and calculated the revolutions on the second time (trip), (Table 1). Slippage calculated by follow the equation [42]:

$$Slippage\ (\%) = \left(\frac{no.of\ rotations\ with\ load\ \ -\ no.of\ rotations\ no\ load}{no.of\ rotations\ with\ load} \right) \times 100 \qquad (2)$$

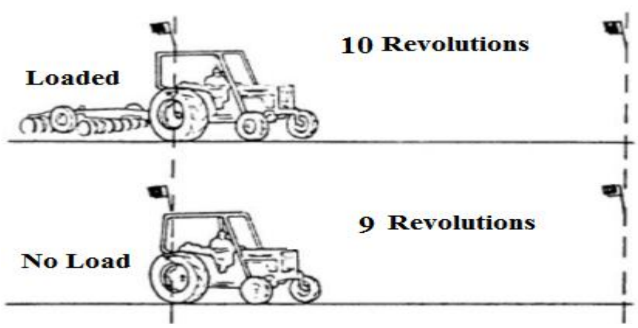

Fig. 1. Measuring the slippage by numbers of tire rotations method.

Table 1. Rear tractor wheel slippage %.

Rotations	Tractor tire rear wheel slippage %	What to do?
10	0	Ballast weight remove
9.5	5	
9	10	Ballast weight proper
8.5	15	
8	20	Ballast weight add
7.5	25	
7	30	

3- Distance: Measure a certain distance traveled by the tractor without a load, then measure the same distance for the tractor with a load to find out the slippage as a percentage. Slippage calculated by follow the equation [43]:

$$Slippage\ (\%) = \left(\frac{Distance\ without\ load\ - Destance\ with\ load}{Destance\ without\ load} \right) \times 100 \qquad (3)$$

4- Doppler radars and sensors electronics.

5- Installation of a 'bolt-on system: Bolt –on tire slippage could be used on the very old tractor, which not has component monitors, this method is old and not used by researchers or farmers at the present time.

6- GPS information: Used inertial measurement unit (IMU), and wheel angle encoders were used to estimate the slip ratio.

7- Visual inspection of the tire tread: Another practical method of knowledge the tractor tire slippage is inspecting tread marks, which leaves behind the tires in the soil surface (fig.2).

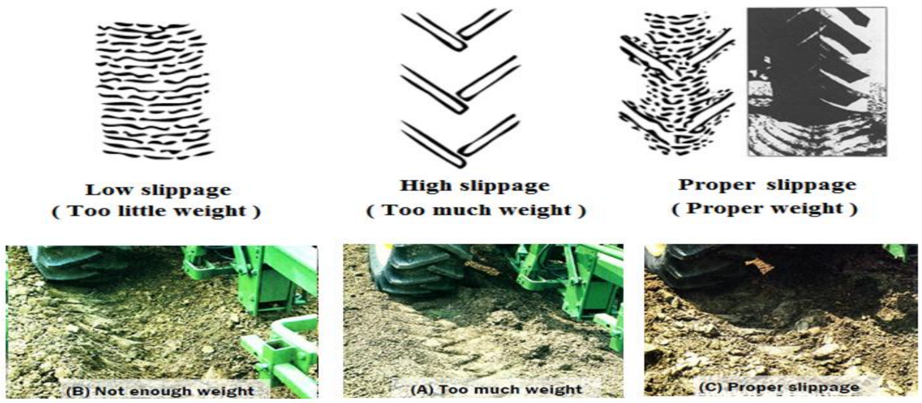

Fig. 2. Tractor tires slippage tread marks in the soil surface and slippage levels.

Tire and track tractor slippage

Concept of the slippage is the ratio (percentage) of the difference between both of the tire speed and the ground speed. The tire should grip the surface soil to improve the traction force. When the tire grips the soil, there are some rotations during which the tire loses speed. The proportion of speed lost is tire slippage, expressed as a percentage. Tire with no slip means no accrue traction, to prove traction, tire must a slip. Moreover, if the traction force increases, tire slip should increase.

Tractor wheels (Tires) and tracks are the most important factor that controls and affects slippage, basic forces acting in tire and tracks in (figure 1 a, b and c).

Tire over hard surface in (fig.1-a) noticed reaction vertical force (*Wd*) is not with under centerline axel, it is horizontal offset (*eh*), which is important and necessary for stability static horizontal offset (*eh*) is calculated by following the equation [1]:

$$eh = \frac{(slr)\ (MR)}{Wd} \qquad (4)$$

Where *slr* is load radius static, *MR* is motion resistance and *Wd* is weight dynamic.

While, in the reality of working, both of them tire and soil surface are deformable (fig.1-b), noticed a vertical (*ev*) and horizontal offset (*eh*), these offset depend on motion resistance (*MR*), tire loaded radius (*slr*) and vertical force resultant (*Wd*), horizontal offset (*eh*) is calculate by follow the equation [1]:

$$eh = \frac{(slr\ -\ ev)\ (MR)}{Wd} \qquad (5)$$

Where *ev* is vertical offset.

Track (crawler or belt) tractor (fig.1-c) is kind of similar to the tire in many aspects, but the load distribution depends on the tractor parameters. According to [44] the dynamic balance or dynamic load (eh) depend on the static distribution, suspension mechanical design over the wheel and tractor weight transfer characteristics.

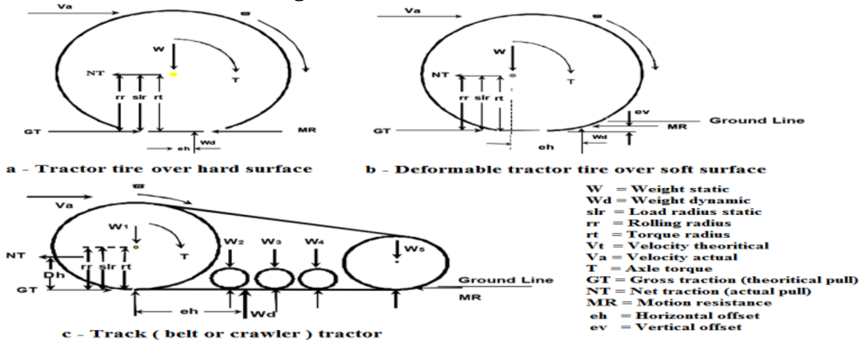

Fig. 3. Distribution forces in tire and track tractor (Zoz and Grisso 2003).

Tire inflation pressure plays an important role in affecting slippage, traction and fuel consumption, whether it is a single or dual tire. Reducing the tire pressure within the permissible limits increases the surface contact area in the soil and tire, which reduces the rate of slippage and improves the traction (pull) force and drawbar power in tractor. However, increasing the tire pressure by an acceptable limit improves the flotation and reduces the tire sinking in the soil. As a comparing between the tires and tracks, the track have more contact area with surface soil, therefore the compacting soil was a lower than from tire in case of the tractors equal in weights.

Optimal tractor tire slippage

The result of many studies have proven that obtaining the best tractor wheel (tire) slippage percentage based on the type of agricultural tractor is possible under certain conditions and limits that must be followed (Table 2 and 3).

Table 2. Optimal tractor tire slippage and tractor weight distribution by axel load.

Type of the tractor	Optimal tractor slippage	Tractor weight distribution	
		Front Axle	Rear Axle
Two Wheel Driver 2WD	10 % -15 %	25 – 30 %	75 – 70 %
Four Wheel Driver 4WD	8 % - 10 %	55 – 60 %	45 – 40 %
Mechanical Front Wheel Drive MFWD	8 % - 12 %	40 – 45 %	60 – 55 %
Crawler (track) tractor *	3 % - 6 %	50 %	50 %

* Crawler (track) tractor slippage should not exceed 12 %.

Table 3. Slippage (%) recommended in various soil condition [45].

	2 Wheel Drive	Front Wheel Drive	4 Wheel Drive	Tracks
Firm surface	10	9	8	1
Tilled soil	12	11	10	2
Soft soil	15	13	12	3

Moreover, tractor tire slippage rates are affected by many factors, which play a major role in decreasing and increasing the slip rates in the tractor wheels during the performance of various agricultural operations:

1. Tractor type: 2WD or 4WD or MFWD, size, horsepower, weight, ballast weight, tire (type, size and pressure) or crawler, weight distribution, loads carried or pulled, required traction force.
2. Soil condition: types, texture, moisture, bulk density, porosity, hardness, penetration resistance, shear strength, plant residues and previous tilt or not, soil slope, compaction and hard pan soil, cohesion and adhesion.
3. Tire condition: type, size, inflation pressure, life tread pattern and remaining, number of tires, dual or single rear tires, rolling resistance.
4. Implement agricultural: type, width, weight, type of contact with soil, metal type, purpose of implement, mounted or pull or sime-pull.
5. Type of field operation: primary or secondary tillage, seeding, fertilize, harvesting… ect.
6. Speed operation: basically, increasing speed result to increase slippage, moreover, operation speed range 3 – 15 $km.h^{-1}$ prefers in agricultural field working.
7. Depth of tillage: basically, increasing the depth leads to increase slippage.
8. Combined implement or single.

Slippage damages

1. More fuel consumption.
2. Time losses.
3. Tractor power (horsepower) lost.
4. Tires wear , fast damage in tread size and life.
5. Compacting and destroy structure soil.
6. Formation the hardpan under soil surface.
7. Reduce soil productivity.
8. Damage mechanism driver transmission tractor.
9. Heavy tire slip will transmit tractor power 60 – 70 % and may be lower reach to 50 %.
10. Increasing the operation cost.
11. Increasing risk of tire stuck especially in sutured moisture clay soil (fig. 4).

Fig. 4. Stuck tire tractor in saturated clay soil.

Many researchers in the world measuring the tractor tire slip on various field conditions for know whether the tractor and plow or implement performing the operation tillage within the permissible tire slip limits (Table 4).

Table 4. Most findings of the slippage by some researchers various in soils conditions.

Reference	Investigation and implement	Soil & moisture	Most findings
[46]	Adding water to tractor tire and using disc plow at difference depth	Clay loam 18.2 %	Adding water in tire get at depth 15, 20 and 25 cm least values 6.47, 7.19 and 9.28 % respectively, while plowing without add water recorded 10.82, 12.08 and 14.23 %. Add water reduce the slippage.
[47]	Chisel and moldboard plow at differ depth and speed	Silty clay loam 16-17 %	Chisel plow got slippage 26.46 % and 41.36 % at depth 15 cm and 22 cm with speed 3.375 km.h^{-1}. Moldboard got 23.15 % and 38.68 % at depth 15 cm and 22 cm with speed 2.571 km.h^{-1}. Higher Tire slip.
[48]	Adding water in tractor tire when tillage by moldboard plow	Clay loam 18.5 %	Adding water reduce tire slip 7.7, 8.8and 9.0 % at depth 15, 20 and 25 cm, respectively, while tire working without water recorded 11.6, 12.4 and 14.6 at the same depth. Add water reduce slip ratio 34% and gave motion tire and tractor stability.
[49]	Disc harrow and rotivator under variable speed	Silty clay loam 18 %	Increased speed 3.0 to 4.7 then to 5.8 km.h^{-1} increased slippage 8.6 to 9.8 then to 11 % respectively for rotivator and 7.5 to 8.9 the to 9.8 % respectively for disc harrow.
[50]	Combined tillage and installation tubes irrigation under soil surface	Silty clay loam 16-18 %	Speed 4.5, 5.5 and 6.5 km.h^{1} gave tractor tire slip 8.5, 11.25 and 13,5 %, respectively, when installation tubes under soil, while recorded 6.36, 9.23 and 12.7% when installation tube above soil surface.
[51]	Chisel used,depth 10, 20 and 30 cm and speed 1.88 and 9.6 km.h^{-1}	Sand 8.6 % 10.3% 11.6 %	Increase moisture, depth and speed leads to increase the slippage. Slippage exceeded the permissible limit (15 %) when field working at speed 9.6 km.h^{-1} with depth 20 and 30 cm until reach to 37.15 %.
[52]	Four bottom reversible plow at depth 17.6 cm	Stubble loam 10 %	Reducing tire inflation 240 to 100 kPa slippage reduced 4.2 % as a rate, added ballast weight 0 to 540 kg slippage decrease rate 2.3 %.
[53]	Moldboard under variables speed tractor and depth	Silt clay 20 %	Raising tractor speed 1.8 – 2.33 – 3.88 to 4.86 km.h^{-1} resulted to increased tractor tire slippage. Moreover, increased depth leads to increase slippage too.
[54]	Moldboard plow at variable depth and speed tractor	-	Plowing at depth 15, 20 and 25 cm recorded tire slip 10.32, 13.61 and 17.15 %, respectively. Speed 2.6 and 3.6 km.h^{-1} got 13.48 and 13.9 % respectively.
[55]	Effect tirepressure and speed on the slip at used moldboard	Silty clay loam 18 %	Increasing tire pressure from 15 to 30 bar leads to increased slippage from 11.90 % t0 25.14 %. Increasing speed tractor from 3 to 6 km.h^{-1} leads to increase slippage from 15.11 % to 21.93 %.
[56]	Add ballast in wheel tractor during used moldboard plow	Clay 14-16 % 18-20 %	Adding ballast 310 kg reduces tire slip 17.44% to 12.44 %. Slip reduced 18.56 % to 14.66 then to 11.60 % when speed reduced from7.7 to 5.6 then to 3.3 km.h^{-1}. Reducing moisture gave 18.79 % to 11.08%.

[40]	Disc plow at difference speed and inflation tire	Silty clay loam 17%	Increase speed 3.4 to 8.2 km.h^{-1} at inflation 1.02 kg.cm^{-2} increased slip 4.55 to 10.98 %. At inflation 1.53 kg.cm^{-2} slip increased 6.83 to 16.48 %, also slip increased 10.95 to 264 % at inflation 2.45 kg.cm^{-2}.
[5]	Simulation predi-cting slippage when used chisel	Clay loame 18 %	Increasing the depth of tillage and peed tractor are directly effect on increased slippage under all condition of experiment.
[57]	Determining the slippage by using a single-frequency GNSS receiver	-	Tractor gear 2 and disc harrow on length 100 m recorded slippage 8.66 %, moreover, comparing with ISO 981 slippage was 11.04 %. Measured slip by GNSS receiver was good method.
[58]	Effect moisture soil and depth on slippage when used disc plow	Silt clay 9-12 % 13-16 % 17-20 %	Increasing moisture increased tire slip 8.72 – 10.67-13.09 %, respectively. Increasing depths 12-17-22 cm increased slippage 7.19- 10.51- 14.86 % respectively. Slippage levels with permissible limits.
[59]	Evolution chisel plow under various tire pressure and speed tractor	Silty clay loam 18 %	Increasing tire pressure from 15 to 20 then to 30 psi leads to increased slippage 9.24- 10.69- 12.18 % respectively. Increasing speed from 3.9 to 4.8 then to 6.1 km.h^{-1} leads to increase the slippage 8.38- 10.69- 14.94 % respectively.
[11]	Investigation tire slip at difference speed tractor	Silty clay	Low speed tractor 5.28 km.h^{-1} got lower tire slip 5.34 %, while higher speed 8.30 km.h^{-1} got slip 11.53 %. Concluded speed effect strongly in tire slip.
[60]	Chisel, moldboard and disc plows at depth 10.15,20 and 25 cm and speed 3,4,5 and 6 km.h^{-1} and tire pressure 120 kPa	Clay and clay loam 8.5% 12.5% 16.5% 20.5%	Maximum slippage was 14.65, 19.00, 19.63 % for chisel, moldboard and disc plows, respectively in clay soil. Additionally, Maximum slippage was 15.14, 19.37 and 19.56 % for chisel, moldboard and disc plows, respectively in clay loam soil. Chisel got less slippage comparing with other plows. Speed and depth were most effective factors in the study.
[61]	Using slider and disk knife on moldboard at different depth	Silty clay 16.22 % 9.73 %	Increased depth 15-20 and 25-30 cm increase tire slip12.96 % to 16.87%. Slider knife recorder 13.86 % while disc got 14.75. Moisture soil 16.22% got slip 13.92%, while moisture 9.73% got slip 15.91%.
[62]	Slatted and normal moldboard tillage at various speed and depth	Silty clay loam 16- 19	Slatted and normal moldboard gave 3.98 % and 4.71 % at depth15 cm and speed 4.14 km.h^{-1}, respectively. While gave 7.63% and 9.12% at speed 7.14 km.h^{1}. Slatted moldboard gave less slippage in all condition. Depth and speed have strong effect on the slippage.

Conclusion

1. Slippage should not exceed 15 % also not less than 6 %, basically, the best tractor tire slippage at average 8 – 12 %.
2. Zero tractor tire slip on field operation is impossible and not acceptable, because of tires, transmission, and other drivetrain components would wear much faster, therefore, the manufacture company tractor against using the heavy traction at speed 6.4 – 8 km.h^{-1} (4-5 miles). Zero slippage only in the hard road (street).
3. At difference condition and various soil types, all types of a tractor tire slippage must be between 10 – 15 %.
4. To reduce slippage, put liquid inside the tire (calcium chloride resist freezing and provide more weight than water). Also can attach iron ballast to tire or to the front frame tractor.
5. Dual tire reduce slippage and increase flotation because give more contact with the soil.
6. Tracks pressure on the soil lower than tires, especially in case of the tractors equal in weights.

Recommendation

Field working of the tractor during conduct the primary and secondary tillage process should be in the range of 6 – 14 %. When the tire tractor slippage reaches 25 % or more, the operation tillage must be stooped and the process should be re-evaluated and make calibrated process.

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مفهوم الانزلاق المسموح والاضرار خلال عملية الحراثة

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الخلاصة
هدف المقالة هو تسليط الضوء ومناقشة سماحية انزلاق عجلات الجرار وأضراره من خلال الدراسات السابقة في عمليات حراثة حقول ذات ترب مختلفة النسجة وظروف مختلفة في سرعة الجرار وعمق الحراثة ورطوبة التربة وضغط انتفاخ عجلات الجرار.. الخ. يعد الانزلاق من أهم المؤشرات التي يجب أخذها في نظر الاعتبار عندما الجرار يسحب الآلات الزراعية. بالرغم من الاختلافات البسيطة في تعريف الانزلاق الا ان الجميع يتفق بأن

الانزلاق هو نقص أو تخفيض في الحركة والذي يجب ان لا يتعدى النسبة المسموح بها كحد اقصى 15 %. الانزلاق يحدث احتكاك بين الاطار (العجلة) والتربة، حيث الاطار يدور بسرعة اكبر من السرعة الارضية للجرار. على اية حال، هذا يسبب أضرار شديدة (خاصة اذا الانزلاق تعدى 15%) للاطار والتربة وكبس التربة وتكوين الطبقة الصماء وتحطيم تركيب التربة وخصوبتها وضياع الوقت والقدرة واستهلاك اكثر للوقود والاطار. يجب ان يكون هنالك نسبة معقولة وبسيطة من الانزلاق لعرض امتصاص الصدمات في وسائل نقل الحركة خلال بدئ حركة الجرار وخلال اختراق المحاريث للتربة وخاصة عند الاعماق الكبيرة في التربة الصلبة والطينية. عدة دراسات استنتجت ان افضل انزلاق يتراوح بين 8 – 12 %. الانزلاق لا يمكن ان يصبح صفراً عند اجراء عملية حراثة (الانزلاق يكون صفراً فقط عند سير الجرار في الطرق الصلبة). اكثر عوامل تؤثر في الانزلاق هي سرعة الجرار وعمق الحراثة ووزن ونوع الجرار وظروف الاطار (ضغط وحجم وعمر بروزات الاطار) وظروف التربة (رطوبة ونوع التربة والبقايا النباتية) والآلات ونوع العملية الحقلية.

الكلمات المفتاحية: عجلات الجرار، انزلاق، حراثة التربة، آلات الحراثة، بروز الاطار.