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# Assessment of Tractor Power Variation on Soil Properties under Maize Cultivation in Nkwadi Agricultural Volunteerism Program/Kasai Oriental Province, Democratic Republic of Congo

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## Abstract

In tropical regions, reconciling agricultural intensification and protection of soil properties for sustainable agricultural productivity is a major challenge in the context of agricultural tractors becoming heavier and more powerful. As part of the Agricultural Volunteer Program in Nkwadi, Kasai Oriental Province in the Democratic Republic of Congo (DRC), JOHN DERRE tractors of 215, 120 and 75 hp are used in the intensive production of maize, starting with tillage. This study compares soil chemical, physical, and organic-matter indicators before and after two maize-growing seasons managed with 75, 120, and 215 hp tractors in Nkwadi, DRC. The results of this research show that chemically, the acidity of the soil before the first pass and after the second pass remained high with some stability under the 75 and 120 hp tractors after the second pass. The macroelements except $NO_3^-$ under the 75 hp tractor experienced a decrease in the soil. However, the organic matter content has been increased under the effect of all the tractor power; effect due to the burial of maize debris after harvests of the order of 41.83% under the 215 hp, 170.69%

under the 120 hp and 227.08% under the 75 hp. As far as physical parameters are concerned, the general trend shows changes in texture according to the power levels of tractors and according to the depth of ploughing of the soil. With the different contents of organic matter associated with the different silt contents under different levels of tractor power, modifications are observed in the structural stability by the beating indices and the M.O/clay ratio. The higher tractor power is associated with stronger acidification, nutrient changes, lower structural stability, and greater soil degradation. It appears that the 75 hp tractor is the most suitable option for shallow soil operations at the site.

## Keywords

Agricultural Tractors, Agricultural Mechanization, Power Level, Soil Properties, Corn Production

## 1. Introduction

In tropical regions, reconciling agricultural intensification with the protection of natural resources such as soil is a major and difficult challenge [1]. And there are many studies that highlight the harmful consequences of the intensification of poorly controlled motorization on the chemical, physical and biological properties of soils and ecosystems [2]-[4] in particular by: 1) the irreversible deterioration of their functioning, in particular by an increase in hypoxia and/or engorgement [5]; 2) morpho-structural changes in soil [6] with an increase in bulk density or a decrease in soil porosity due to loads applied from the outside or inside [7]; 3) increased resistance to soil penetration [8]; 4) reduced infiltration, drainage and gas exchange conditions [9]; 5) the deformation of the soil by the compaction of the subsoil (below the plough sole) of agricultural soils under the effect of mechanical pressure with the load of the machinery [10] with the number of passages of the gear, even if the first passes are responsible for most of the compaction [11]; 6) the disturbance of soil fauna activities following compaction [12] and 7) scalping of surface horizons, which removes nutrient- and biobiodiversity-rich organic layers that can trigger the erosion process after the removal of "mulch", the rutting resulting from the creep of the soil under pressure [13].

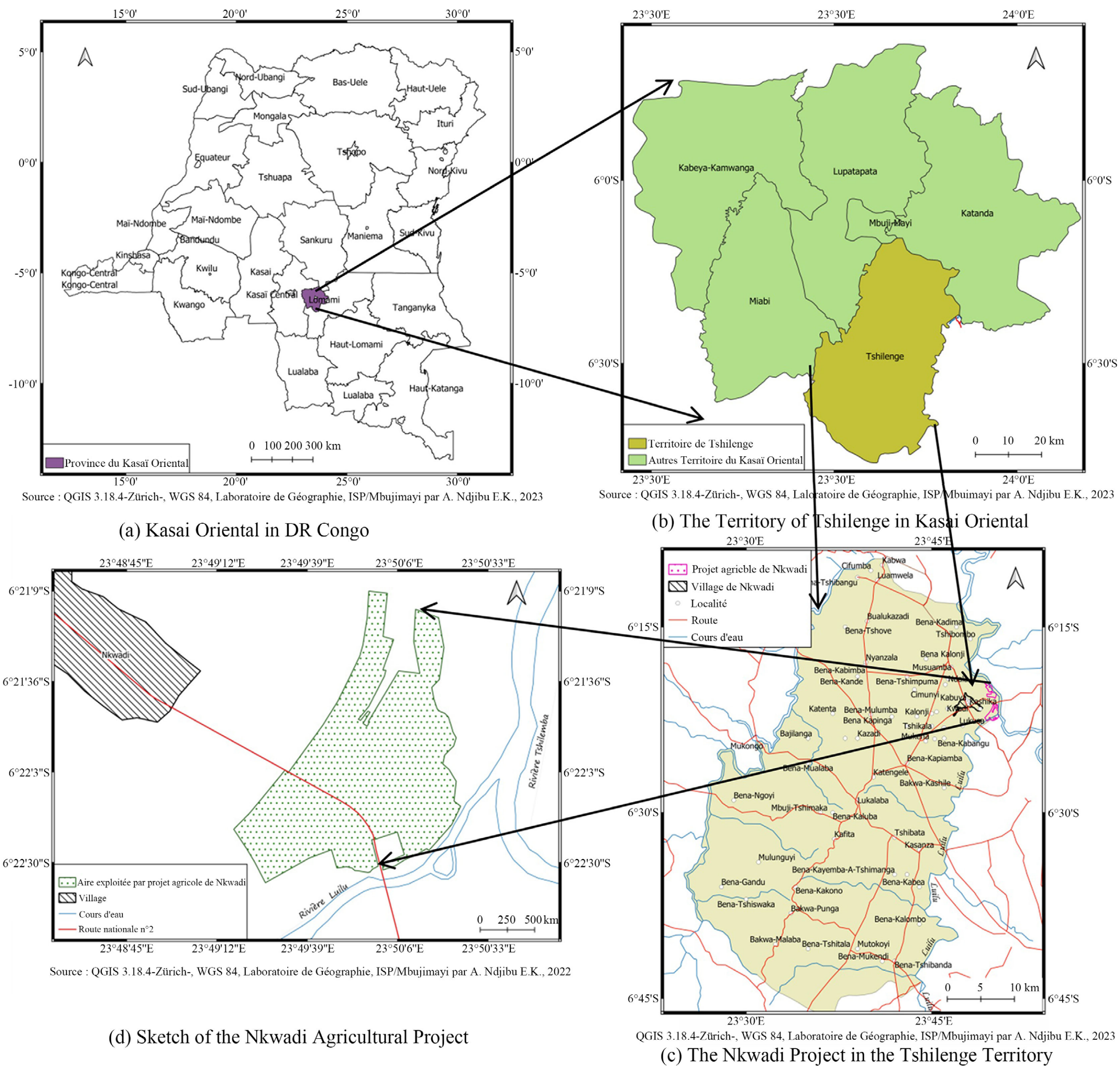
Given that the restoration of degradation of the physical, chemical and biological properties of soils is always difficult, costly and rarely sustainable [8] and that these degradations affect the main functions of the soil (production, water quality, greenhouse gas emissions); the development of means of prevention by the control of agricultural motorization by equipment of adequate power remains a priority for researchers.

The objective of this research is to study the changes brought about by intensive motorization practiced on the ground in Nkwadi, in the center of the Democratic Republic of Congo (DRC) during two agricultural seasons (2020/2021 and 2021/2022). In particular, it is a question of comparing the effects on the physical, chemical and biological properties of the soil under the passage of three tractor power levels (75 hp, 120 hp and 215 hp) in order to identify and popularize the level that causes less harmful effects on the soil for the sustainability of the crop.

## 2. Materials and Methods

### 2.1. Characterization of the Study Area

The study was carried out in Nkwadi in the valley of the confluence of the Tshilemba and Luilu (Kalelu) Bena Biaya rivers between 6˚21'1.41" and 6˚22'37.72" south latitude and 23˚49'17.31" and 23˚22.75" east longitude. This area is located at an altitude of 542.72 m, about 48 km from the city of Mbujimayi, in the Territory of TSHILENGE, Kasai Oriental Province, DRC (**Figure 1**).




(a) Kasai Oriental in DR Congo

(b) The Territory of Tshilenge in Kasai Oriental

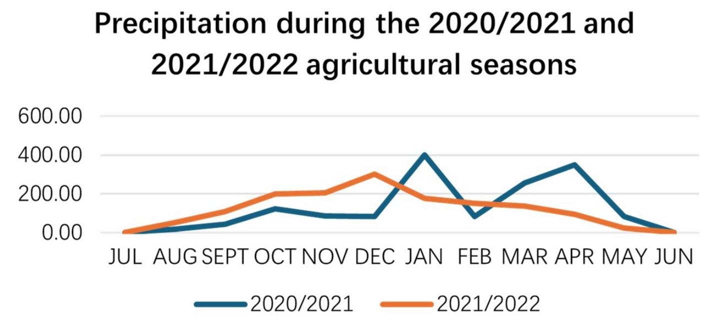
(c) The Nkwadi Project in the Tshilenge Territory

(d) Sketch of the Nkwadi Agricultural Project

**Figure 1.** Map of the PVA Nkwadi base site.

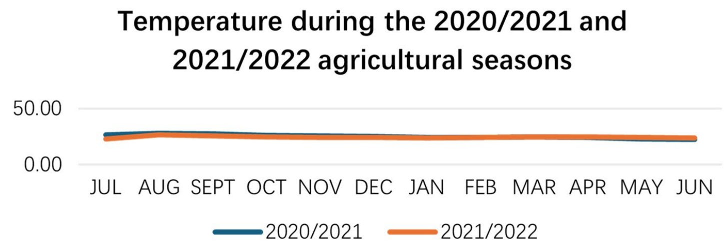
The climate in this site belongs to the AW3 type of the KÖPPEN classification. It is a humid tropical climate where the daytime temperature of the coldest month is above 18˚C with three months of dry season and two growing seasons; season A and B.

The rainfall regime allows for two agricultural seasons per year. The first (season A) begins with the resumption of rains in September and ends in January with the decrease in rainfall. The second (season B) begins in February when the rains become more abundant and ends in May (dry season). Figures 2-4 show the climatological parameters at the Nkwadi site during the period of the trials that took place during two crop years (2020/2021 and 2021/2022). It should be noted that during these two seasons, the work on the Nkwadi base was only carried out in great rain season (A). Referring to Figure 2, it should be noted that it was the 2021/2022 growing season that was rainier, with peak rainfall between October and December, than the 2020/2021 growing season.




Source: NASA/POWER Source Native Resolution Monthly and Annual (2025).

**Figure 2.** Variations in rainfall during the 2020/2021 and 2021/2022 agricultural seasons in mm.

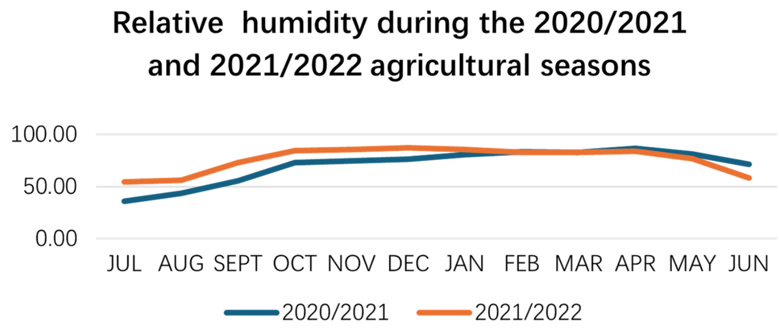



Source: NASA/POWER. Native Resolution Monthly and Annual (2025).

**Figure 3.** Temperature variations during the 2020/2021 and 2021/2022 crop years in ˚C.

From Figure 3, it appears that the temperature had remained constant during the two seasons, except for the month of January 2020/2021 when a remarkable drop of about 5˚C in temperature was recorded.

Figure 4 shows that relative humidity follows the same trend during both agricultural campaigns, peaking between October and December. However, the 2021/2022 campaign exhibits higher humidity compared to the 2020/2021 campaign during the "A" cropping seasons, which run from August to January.




Source: NASA/POWER. Native Resolution Monthly and Annual (2025).

**Figure 4.** Relative humidity variations during the 2020/2021 and 2021/2022 crop years in %.

## 2.2. Materials

### 2.2.1. Agricultural Tractors

The various JOHN DEERE brand tractors were used, including 1) the Model 5075 E with 75 hp (56 kw) developing a nominal speed of 2400 rpm with a wheelbase of 2050 mm and weighing 2425 kg; 2) the Model 6120 B with 120 hp (88.2 kw) with a rated speed of 2400 rpm, with a wheelbase of 2060 mm and weighing 4640 kg; and 3) the Model 7215J with 215 hp (158 kW) rated and maximum power at engine speed at 1900 rpm of 237 hp (174 kW) with 183 hp (134 kW) as power to the PTO, developing the maximum torque speed of 1550 rpm and a nominal speed of 2100 rpm with a wheelbase of 2807 mm and weighing 11,800 kg.

### 2.2.2. Experimental Management

**1) Experimental design**

The trial was conducted using a two-factor split-plot design with three replications. The timing of soil parameter observations served as the main factor, comprising two levels: a) before tractor passage and b) after tractor passage. Tractor power served as the second factor, with three horsepower levels: T1 (75 hp John Deere tractor with a 3-disc FIELDKING plow and a 20-disc FIELDKING harrow), T2 (120 hp John Deere tractor with a 3-disc FIELDKING plow and a 24-disc FIELDKING harrow), and T3 (215 hp John Deere tractor with a 5-disc FIELDKING plow and a 32-disc FIELDKING harrow).

In practical terms, each experimental unit measured 4 m in width by 9 m in length, resulting in a gross area of 36 $m^2$. Plots were separated by 6 m intervals to minimize interference between treatments. Blocks were spaced 12 m apart, while a 4 m distance was maintained between the blocks and the field edges to reduce edge effects and ensure the representativeness of the results.

This work was monitored during two agricultural seasons, 2020/2021 and 2021/2022 in season A. It should be noted that during these two seasons, the work on the Nkwadi base was only carried out in season A. Figure 5 presents the Experimental design for this study.

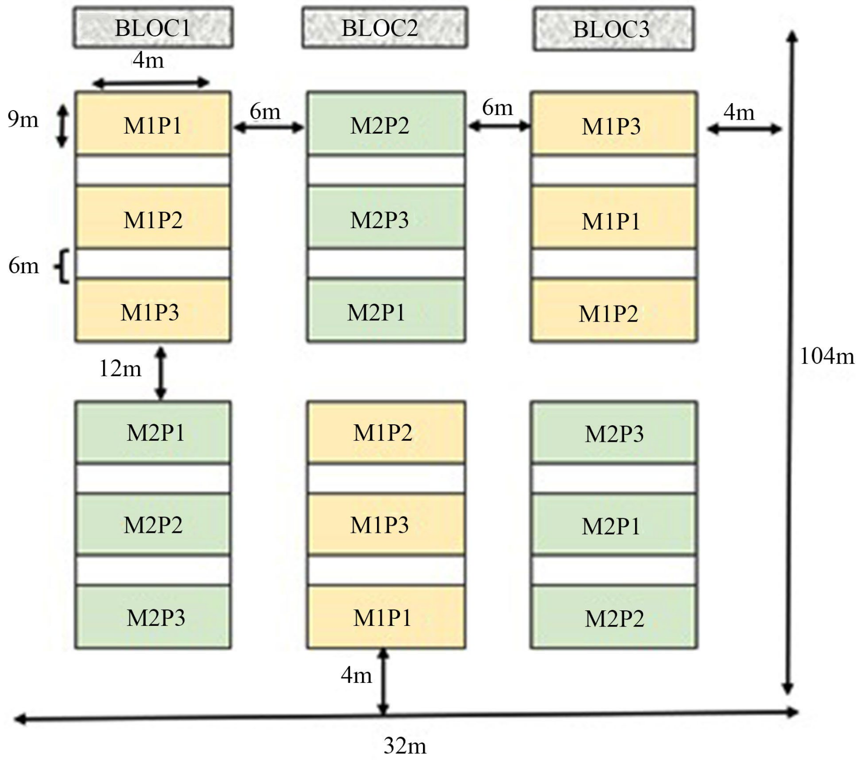



**Figure 5.** Experimental design.

Legend

M1: Observation before the passage of hitched tractors

M2: Observation after the passage of hitched tractors

P1: 75 hp John Deere tractor with FIELDKING 3-disc plough and FIELDKING 20-disc harrow

P2: 120 hp John Deere tractor with FIELDKING 3-disc plough and FIELDKING 24-disc harrow

P3: 215 hp John Deere tractor with FIELDKING 3-disc plough and FIELDKING 32-disc harrow.

**2) Soil sampling**

Before any tillage, we used a 5 cm diameter auger to take 6 soil samples (Baseline) at a depth of 30 cm in the plots where the three tractor levels should pass, *i.e.* before the A agricultural season of the 2020/2021 campaign.

The second batch of 9 composite samples, at the same location, was taken after the harvest of the 2021/2022 season A, *i.e.* after two agricultural seasons or two tractor passes.

The 200 g composite samples were weighed using a Q-CONNECT precision balance, dried in the open air and then brought to the soil laboratories of INERA M'vuazi and Kongo University (UK) in Mbanza Ngungu for particle size analysis, $NH_4^+$, $NO_3^-$, $Ca^{2+}$, exchangeable K ($K^+$), assimilable P ($P_2O_5$) assays, Organic matter and pH-H20. The sampling campaigns took place on July 21, 2020 and March 11, 2022.

The soil profile at varying depths (10, 30, 50, 70 and 90 cm) was dug using a spade and tape measure to study certain soil characteristics before any tillage. This could facilitate the interpretation of certain changes in soil properties after crop years.

**3) Laboratory Sample Analysis**

To evaluate the effect of mechanization and cultivation practices on soil fertility, several variables were analyzed. These include:

**a) Chemical parameters**

These parameters notably include: pH; levels of available phosphorus ($P_2O_5$), ammoniacal nitrogen ( $NH_4^+$ ), and nitrate nitrogen ( $NO_3^-$ ); as well as levels of calcium ($Ca^{2+}$) and exchangeable potassium ($K^+$). These parameters were selected due to their crucial role in plant nutrition and soil structural stability [14]-[20].

The samples for chemical analysis were first air-dried, then crushed and sieved using 2 mm particle size mesh sieves. The various chemical variables considered were pH-water, the content of the soil in assimilable phosphorus ($P_2O_5$), ammoniacal nitrogen ( $NH_4^+$ ) and nitrate nitrogen ( $NO_3^-$ ), calcium ($Ca^{2+}$), exchangeable potassium ($K^+$) determined at the soil laboratory of INERA M'vuazi and the soil laboratory of Kongo University in Mbanza Ngungu (for $NH_4^+$ and $NO_3^-$ ).

Measurements were performed using standardized protocols: pH was determined via the pH-$H_2O$ method (1:2.5 soil/water ratio) recommended by FAO [21]; available phosphorus via the Bray II method initially designated by Bray and Kurtz [22] (1945) recommended by FAO [23]; nitrate nitrogen via the cadmium reduction method; ammoniacal nitrogen via the Nesslerization method; calcium via EDTA complexometric titration; and exchangeable potassium via the CAL test using a flame photometer.

**b) Physical parameters**

Agricultural intensification is a practice that puts more and more strain on the soil in terms of its physical properties [24]. Thus, the study of certain physical parameters of the soil seems very important to us insofar as they can indicate the modifications brought about by agricultural motorization with machines of different power levels in the texture and structure of the soil. The analyses carried out are based on certain physical parameters of the soil, in particular the particle size, the structural stability by the beating index and the rate of organic matter with regard to the clay content of the Nkwadi soils. Regarding soil physical parameters, observations focused on particle-size distribution, structural stability (via the crusting index), and the organic matter-to-clay ratio of the Nkwadi soils; the following methods were used:

① **Particle size**

In this research, we used the particle size sieving method for sands and the siphoning method (Stokes' law) with Robinson's pipette for silts and clay for particle size. The limits chosen are those proposed by Chalumeau cited by Farine and Gerber [25] and the Louispolaire particle size triangle 2022 used for soil classification.

② **Structural stability with the batting index**

The control of structural stability makes it possible to avoid soil compaction in agricultural motorization by reducing the pressure exerted on the ground by the machines (by an increase in the contact surface: wider tires, etc.) and the number of passes combined with tillage tools [26]. If the stresses applied exceed the load-bearing capacity of the soil, the passage of a machine will cause a decrease in the volume of voids in relation to the volume of soil (total porosity) and increase the resistance to soil penetration until an equilibrium is established between the deformation of the soil and the stress exerted, an equilibrium that can be established after one or more passes of the machine [10]. And the calculation of the soil Crusting Susceptibility Index (CSI) allows you to better assess the risks.

The calculation of the Crusting Susceptibility Index (CSI) was done with the formula of Rémy and Marin-Laflèche [27], which makes it possible to approximate the *a priori* sensitivity of a soil to this phenomenon.

$$\text{CSI} = \frac{(1.5 * \%\text{Fine Silt}) + (0.75 * \text{Coarse Silt})}{(\%\text{Clay} + 10 * \%\text{Organic matter})} - \text{C} \quad (1)$$

If pH < 7, C = 0;

If pH > 7, C = pH − 7.

The calculation results make it possible to classify the soil according to its risk level as follows:

| Index Value (CSI) | Crusting Risk/Slaking Risk | Soil Condition |
|---|---|---|
| Below 1.4 | Very low | Stable soil. Soil aggregates resist rainfall well. |
| Between 1.4 and 1.8 | Moderate/Tolerable | Moderate risk. A crust can form during heavy rains |
| Above 1.8 | High to very high | Highly sensitive soil. A hard crust forms very quickly |

③ **The rate of organic matter in relation to the level of clay**

It is accepted that an OM/clay ratio of 17% is a minimum requirement for a sufficiently structured soil [28] because the organic matter associated with clay elements (clay-humic complex) participates in the structural stability of soil aggregates as well as in the diversity of activities of microorganisms and macrofauna [29].

The calculation is done by dividing the percentage of organic matter by that of clay.

**c) The biological variable (organic matter)**

Having regard to the roles played by organic matter, including in modifying the physical, chemical and biological properties of soils by creating a more favorable environment for plant growth and in contributing to the improvement of soil cation exchange capacity by providing a source of nutrients for plants [30] [31]. Analysis of soil organic matter content is usually used to determine the level of soil richness [32]. Two processes exist for the determination of the soil Organic Carbon (SOC) content: the titration method and the colorimetric method. For our research, we used the titration method.

#### 2.2.3. Statistical Analyses

Analyses of variance (ANOVA) were performed to compare treatment means and identify significant differences between tractor power levels. Where significant differences were observed, multiple comparisons were conducted using the Tukey HSD test.

Results are expressed as means accompanied by their standard deviations, and significance levels were set at $p < 0.05$. Statistical analyses were performed using R software (version 4.5.2), with packages suitable for the analysis of agronomic data.

## 3. Results

### 3.1. Soil Chemical Parameters

#### 3.1.1. The pH-Water

Close examination of Figure 6 reveals that soil pH remains generally stable between the two observation points (before and after the tractor pass), with values ranging from 5.00 to 5.61. Before the pass, the pH is slightly higher at the 215 hp level (5.61) compared to the 75 hp (5.26) and 120 hp (5.08) levels. After the pass, a decrease is observed at 215 hp (5.27), whereas the variations at 75 hp (5.25 vs. 5.26) and 120 hp (5.00 vs. 5.08) remain very slight. The general trend of these results shows changes in nutrient and acidity levels as a function of tractor power levels and soil depth.

Figure 6 shows that the soil was heterogeneous, the pH of this soil has decreased according to the passage of tractors. The most pronounced decrease was observed in the ground below 215 hp (−34 units) followed by the one under 120 hp (−0.08 units) while under 75 hp, the decrease remained very small (−0.01 units) after the second pass. It fell into the range of 5.00 - 5.37 after the second pass of the tractors.

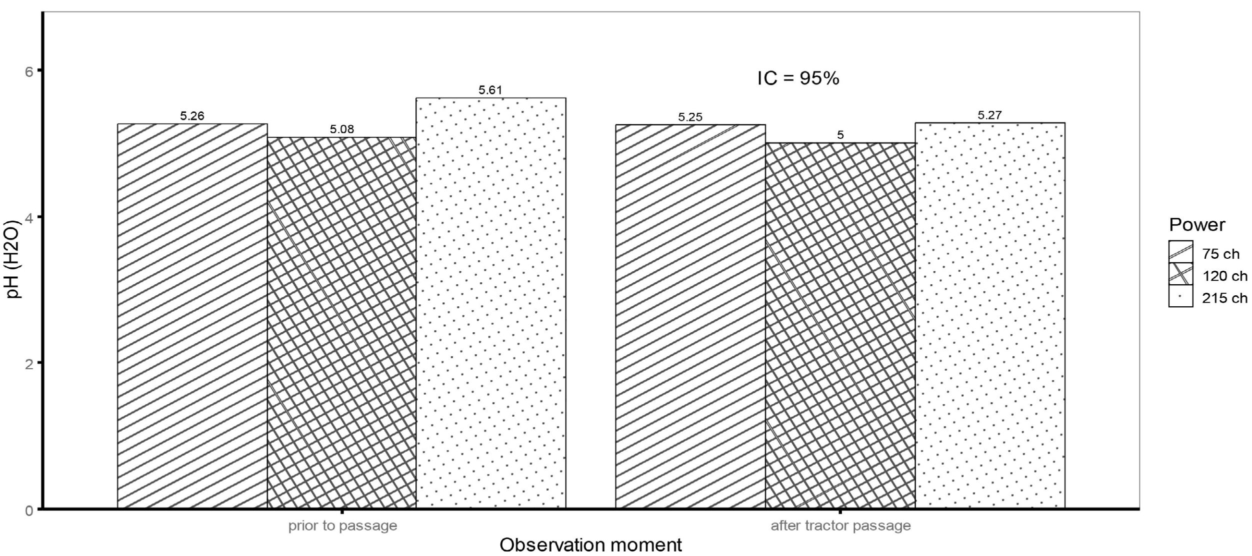



Figure 6. Interaction effect between tractor power and the time of soil pH observation.

### 3.1.2. Available Phosphorus

Figure 7 shows that levels of available phosphorus are higher before the tractor passes, with values ranging from 11.16 ppm (75 hp) to 13.28 ppm (215 hp). After the pass, a distinct decrease is observed across all power levels, particularly at 75 hp (from 11.16 to 3.92 ppm) and 215 hp (from 13.28 to 5.26 ppm). At 120 hp, the drop is less pronounced but still significant (from 11.88 to 9.27 ppm).

These results indicate that the tractor's passage is associated with a reduction in available soil phosphorus, with the magnitude of the change varying according to power output. The decrease is greatest at the extreme power levels (75 hp and 215 hp), whereas it is more moderate at 120 hp. Confidence intervals (95% CI) confirm that these differences are statistically significant. Thus, available phosphorus shows a general downward trend following the tractor's passage, reflecting a measurable change in the availability of this nutrient in the soil.

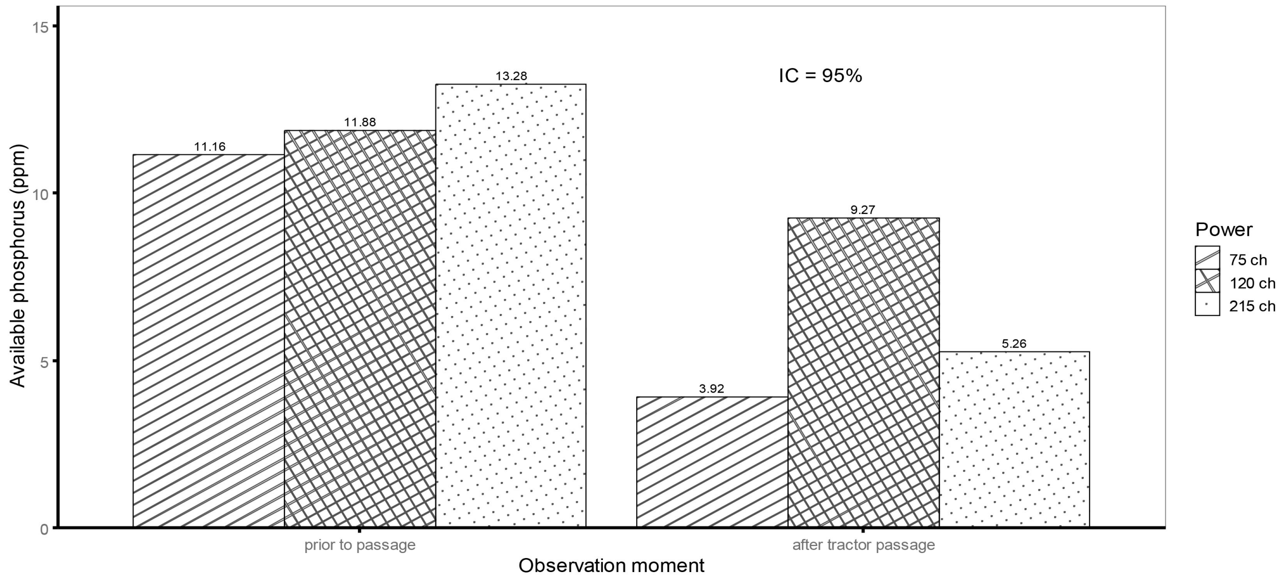



Figure 7. Interaction effect between tractor power and time of observation on available soil phosphorus.

### 3.1.3. Exchangeable Potassium

The results in Figure 8 show that exchangeable potassium levels are generally low but vary depending on power output and timing. Before the tractor pass, values range from 0.02 cmol(+)/kg (215 hp) to 0.10 cmol(+)/kg (75 hp). After the pass, an increase is observed: potassium levels remain unchanged at 75 hp (0.10 cmol(+)/kg) but rise significantly at 120 hp (from 0.04 to 0.12 cmol(+)/kg) and at 215 hp (from 0.02 to 0.07 cmol(+)/kg).

These data highlight an improvement in exchangeable potassium availability following the pass, which is particularly pronounced at 120 hp. The effect is more moderate at 215 hp and negligible at 75 hp. Confidence intervals (95% CI) confirm the statistical validity of the observed differences. The exchangeable potassium shows a general upward trend following the tractor pass, with the magnitude of the change varying according to the power applied.

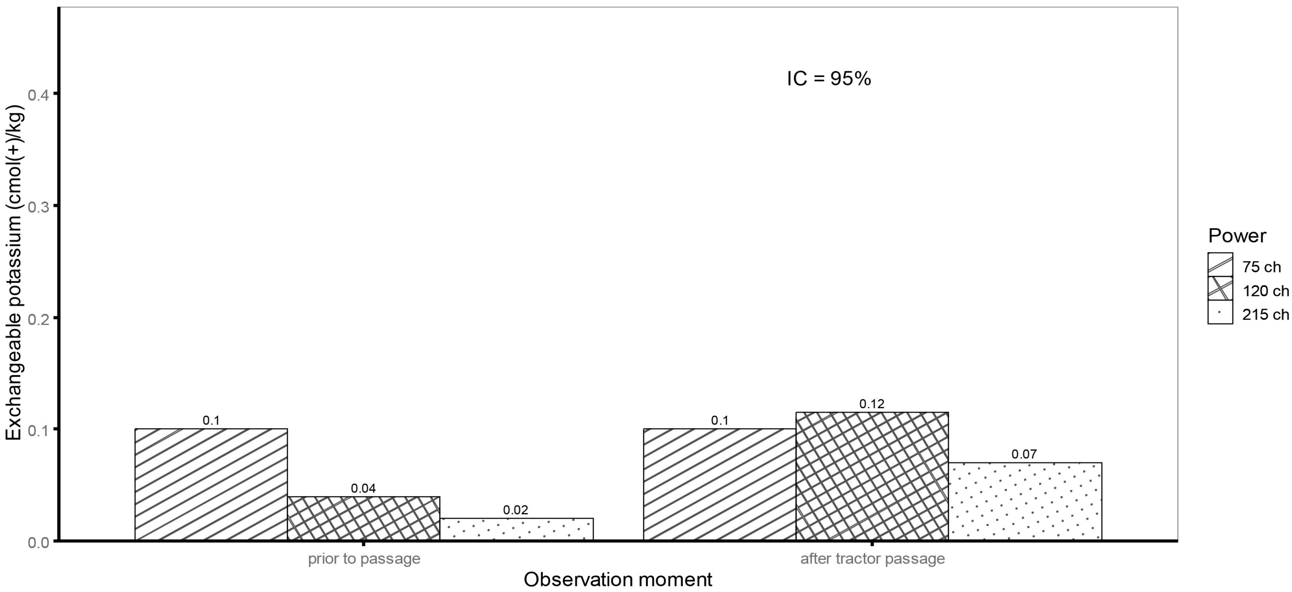



**Figure 8.** Interaction effect between tractor power and the time of observation of exchangeable potassium in the soil.

### 3.1.4. Calcium

The results presented in **Figure 9** show that calcium levels are relatively high prior to the tractor's passage, with values ranging from 3.77 cmol(+)/kg at 215 hp to 6.84 cmol(+)/kg at 75 hp. Following the passage, a decrease is observed across all power levels. At 75 hp, calcium levels drop from 6.84 to 4.34 cmol(+)/kg; at 120 hp, from 5.13 to 4.34 cmol(+)/kg; and at 215 hp, from 3.77 to 3.46 cmol(+)/kg.

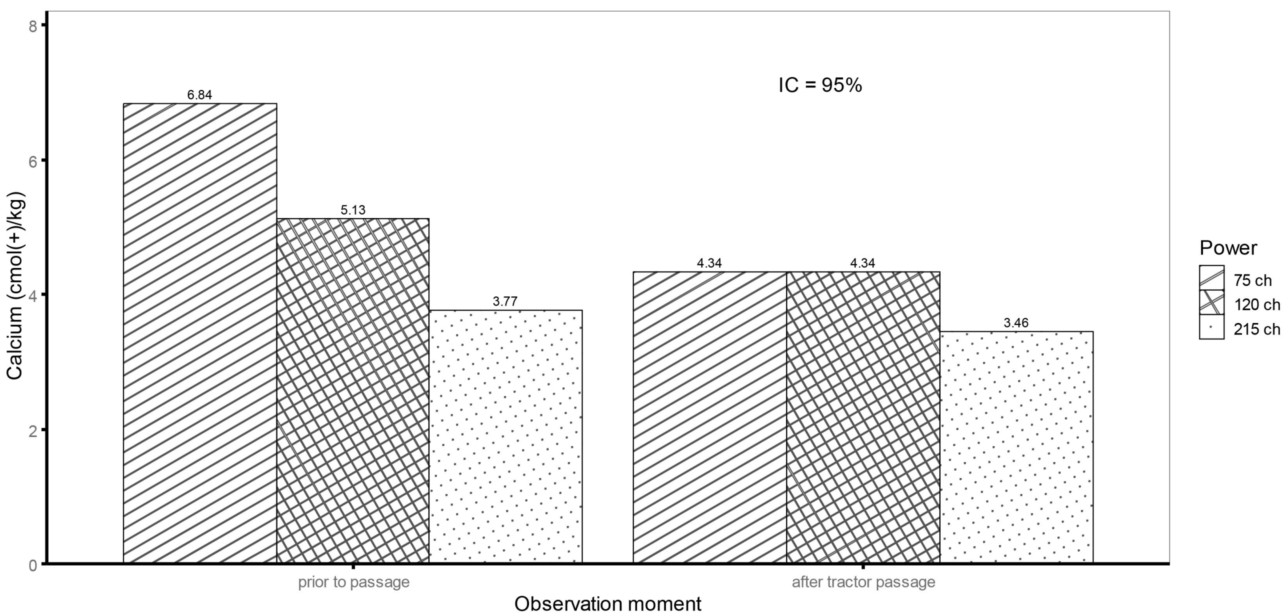



**Figure 9.** Interaction effect between tractor power and the timing of soil calcium observation.

These data highlight a general downward trend in exchangeable calcium after the tractor's passage, regardless of the power level used. The reduction is most pronounced at 75 hp, while remaining moderate at 120 hp and slight at 215 hp. Confidence intervals (95% CI) confirm the statistical validity of these differences. It appears that the exchangeable calcium consistently decreases after the passage, with the magnitude of the change varying according to power level, reflecting a measurable alteration in the soil availability of this cation.

#### 3.1.5. The Nitrate $NO_3^-$

The nitrate concentrations shown in Figure 10 indicate that, prior to the tractor's pass, levels ranged from 78 ppm (215 hp) to 93.65 ppm (75 hp), with an intermediate value of 81.5 ppm at 120 hp. After the pass, a sharp drop was recorded at 75 hp (from 93.65 to 62.5 ppm), whereas at 120 hp the change was minimal (from 81.5 to 79.65 ppm). At 215 hp, the value remained virtually stable (78 to 78.65 ppm).

These results highlight a marked decrease in nitrate levels at low power, near-stability at high power, and a slight reduction at intermediate power. Confidence intervals (95% CI) confirm the statistical reliability of the observed differences.

Thus, nitrate levels show contrasting trends depending on power output: a sharp drop at 75 hp, stability at 215 hp, and limited variation at 120 hp.

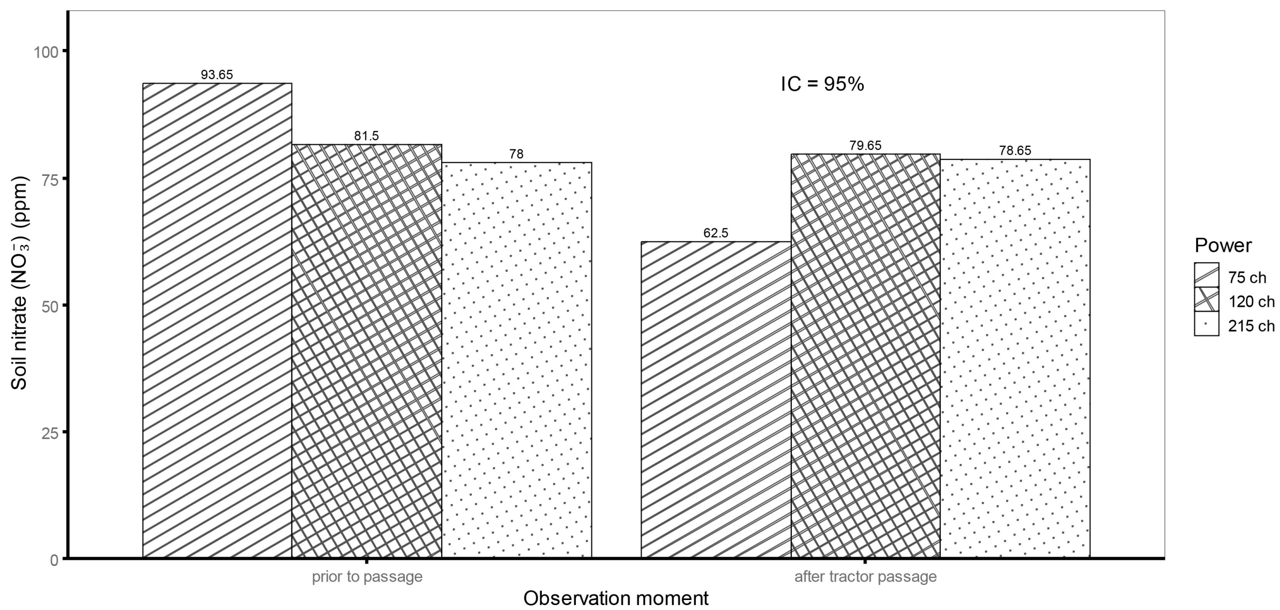



Figure 10. Interaction effect between tractor power and the timing of soil nitrate observation.

#### 3.1.6. The Ammonium $NH_4^+$

Figure 11 shows that ammonium concentrations prior to the tractor pass ranged from 39.88 ppm (120 hp) to 64.25 ppm (75 hp), with an intermediate value of 45 ppm at 215 hp. Following the pass, a decrease was observed across all power levels. At 75 hp, the drop was pronounced, falling from 64.25 to 29.5 ppm. At 120 hp, the reduction was more moderate (from 39.88 to 36 ppm), while at 215 hp, the value decreased from 45 to 35 ppm.

These results highlight a general trend of decreasing ammonium levels following the tractor pass, with the magnitude of the change varying according to power output. The reduction was most marked at 75 hp, more limited at 120 hp, and intermediate at 215 hp. Confidence intervals (95% CI) confirm the statistical validity of the observed differences.

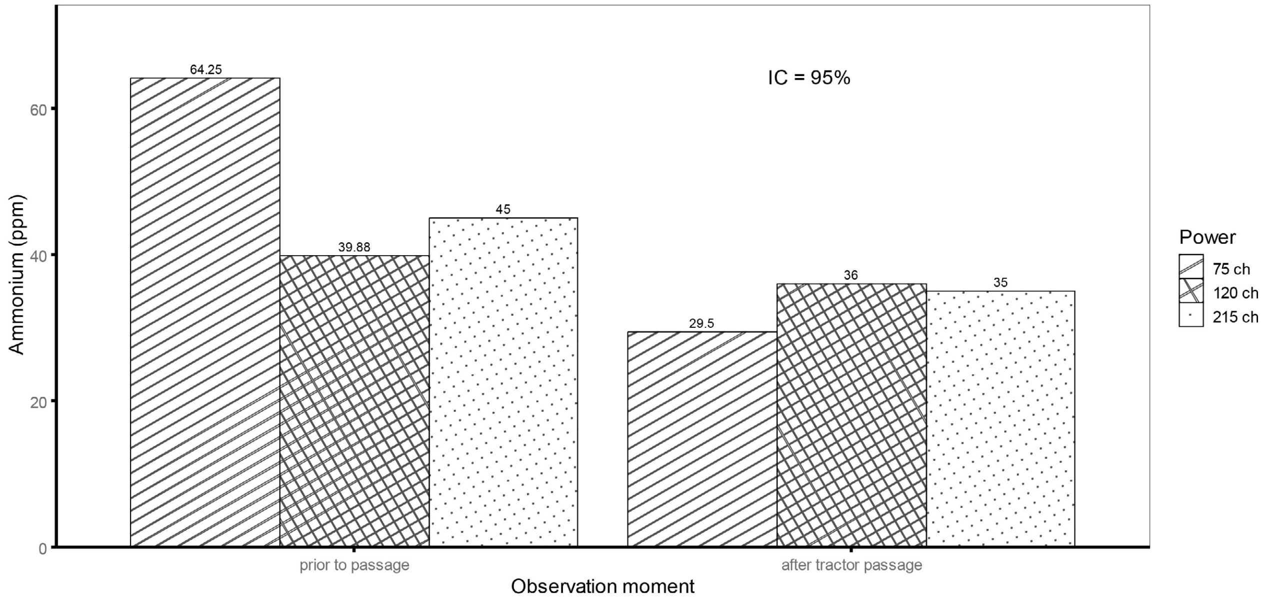



**Figure 11.** Interaction effect between tractor power and the time of ammonium observation in the soil.

### 3.1.7. The Ratio $NO_3^- / NH_4^+$

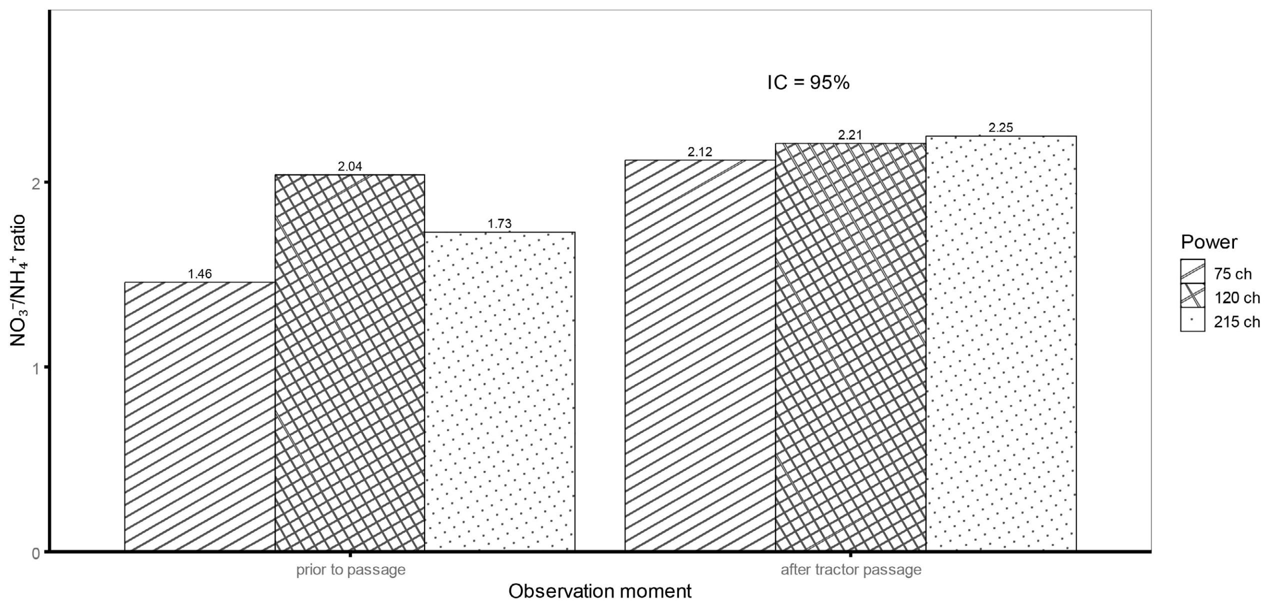



**Figure 12.** Interaction effect between tractor power and the time of observation of the soil $NO_3^- / NH_4^+$ ratio.

The ratio values shown in **Figure 12** indicate that, prior to the tractor's passage, the ratio ranges from 1.46 (75 hp) to 2.04 (120 hp), with an intermediate value of 1.73 at 215 hp. Following the passage, an increase is observed across all power levels. At 75 hp, the ratio rises from 1.46 to 2.12; at 120 hp, from 2.04 to 2.21; and at 215 hp, from 1.73 to 2.25.

These results demonstrate a consistent trend: the $NO_3^- / NH_4^+$ ratio rises systematically after the tractor passes, regardless of the power level used. The increase is most pronounced at 75 hp and more moderate at 120 hp and 215 hp. Confidence intervals (95% CI) confirm the statistical reliability of the observed differences. In summary, the passage of the tractor is associated with an increase in the $NO_3^- / NH_4^+$ ratio, reflecting a measurable shift in the balance between the two mineral forms of nitrogen.

## 3.2. Physical Parameters

### 3.2.1. Particle Size

Soil texture results are presented in **Table 1**. It shows that there was a decrease in sand in the soil after the two 215 hp runs, with the recorded increase in clay and silt. A decrease in clay per tale was observed under passage of 120 and 75 hp. Apart from fine and coarse sand, the content of which increased relatively below 75 hp, the other variables saw their content decrease significantly. This explains the change of the soil from the_clay-sandy loam of sandy loam textural class below 120 hp and 75 hp, while the soil that has undergone the transition from 215 hp to the initial sandy loam to clay.

**Table 1.** Effects of tractor power variation on detailed soil texture at 30 cm depth before the first and second motorization cycles at the Nkwadi site.

| Moment | Tractor power | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 75 horsepower (hp) | | | 120 horsepower (hp) | | | 215 horsepower (hp) | | |
| | 0 - 2 | 2 - 50 | 50 - 2000 | 0 - 2 | 2 - 50 | 50 - 2000 | 0 - 2 | 2 - 50 | 50 - 2000 |
| | Clay | Silt | Sand | Clay | Silt | Sand | Clay | Silt | Sand |
| Befor to passage | 15.1 ± 1.20ax | 30.4 ± 1.46aw | 53.5 ± 3.33bx | 23.1 ± 1.43aw | 25.3 ± 3.49bx | 49.5 ± 6.22ay | 16.8 ± 0.62bx | 23.0 ± 1.44by | 60.0 ± 2.50aw |
| After to passage | 11.6 ± 1.36by | 21.1 ± 1.03by | 72.5 ± 5.32 aw | 18.0 ± 2.51bx | 32.2 ± 2.29ax | 48.7 ± 3.99bx | 24.8 ± 3.17aw | 52.6 ± 5.75aw | 24.4 ± 1.41by |
| CV | 9.83 | 4.85 | 6.78 | 10.1 | 10.45 | 10.39 | 8.26 | 8.57 | 4.98 |
| p-Value | 0.021 | 0.021 | 0.03 | 0.042 | 0.02 | 0.05 | 0.03 | 0.01 | 0.02 |

Means followed by the same letter do not differ significantly at the 5% threshold according to Tukey HSD. The first series of letters a, b, c, d is used for comparison in columns; while the second series w, x, y is used for the line comparison.

Analysis of particle-size fractions reveals significant differences between the traction power levels and the times of observation. At 75 horsepower, the soil composition prior to the pass is 15.1% clay, 30.4% silt, and 53.5% sand. After the pass, clay and silt contents decrease to 11.6% and 21.1% respectively, while sand content rises sharply to 72.5%. P-values < 0.05 confirm the significance of these variations.

At 120 horsepower, the initial distribution is 23.1% clay, 25.3% silt, and 49.5% sand. After the pass, clay drops to 18.0%, silt rises to 32.2%, and sand remains close to its initial value (48.7%). The observed differences are statistically significant (P-value < 0.05).

At 215 horsepower, the soil composition prior to the pass is 16.8% clay, 23.0% silt, and 60.0% sand. After the pass, the clay content rises to 24.8% and silt to 52.6%, while sand drops to 24.4%. P-values < 0.05 confirm the statistical significance of these changes.

The coefficients of variation (CV) remain moderate, indicating good measurement consistency. Overall, the results demonstrate that tractor power directly influences soil particle-size distribution:

- At low power (75 hp), the pass promotes a predominance of sand at the expense of fines.
- At intermediate power (120 hp), the effect manifests as a redistribution between clay and silt, with sand content remaining relatively stable.
- At high power (215 hp), the phenomenon is reversed, showing a marked increase in fine fractions and a reduction in sand.

**Table 2.** Summary of the effects of tractor power variation on soil textural synthesis at 30 cm depth before the first and second motorization cycles at the Nkwadi site.

| Tractor power level | Time | Particle size µm (%) | | | Texture according to the particle size triangle |
|---|---|---|---|---|---|
| | | 0 - 2 | 2 - 50 | 50 - 2000 | |
| | | Clay | Silt | Sand | |
| 215 hp | Prior to passage | 18.15 | 22.42 | 59.43 | Sandy loam |
| | After to passage | 25.10 | 51.72 | 23.18 | Clayey loam |
| 120 hp | Prior to passage | 22.40 | 24.69 | 52.91 | Clayey-sandy loam |
| | After to passage | 17.80 | 33.09 | 49.11 | Sandy loam |
| 75 hp | Prior to passage | 14.80 | 28.79 | 56.41 | Clayey-sandy loam |
| | After to passage | 11.70 | 20.92 | 67.38 | Sandy loam |

While reading the results presented at Table 1 and Table 2, it appears that medium and coarse sands decrease with depth, while clay, fine and coarse silt, increase with depth. Deep ploughing using 215 hp enriched the soil with clay and silt from deep to change these textural classes.

#### 3.2.2. Structural Stability by the Soil Crusting Susceptibility Index (CSI)

Analysing the soil CSI (Table 3) under the passage of different tractor powers on the ground, the soils under 215 and 120 hp went from soil with lower tendency to surface crusting to soil with higher tendency to surface crusting, unlike the ground under 75 hp which had higher tendency to surface crusting to soil with lower tendency to surface crusting.

The values of the surface soil CSI are presented at **Table 3** and show that, prior to the tractor's passage, they are 1.1 for the 120 hp tractor, 1.2 for the 215 hp tractor, and 2.2 for the 75 hp tractor. Following the passage, an increase is observed for the 120 hp and 215 hp tractors, with the CSI rising to 1.6 and 1.7, respectively. In contrast, for the 75 hp tractor, the CSI decreases markedly, dropping from 2.2 to 1.1.

**Table 3.** Evolution of the soil Crusting Susceptibility Index (CSI) under tractor power variation at a depth of 30 cm before the first and after the second mechanization cycles at the Nkwadi site.

| Tractor power | Moment | Soil particle size distribution (µm en %) | | | SOM (%) | CSI |
|---|---|---|---|---|---|---|
| | | LF | LG | A | | |
| 215 hp | Before | 18.15 | 16.54 | 5.88 | 0.765 | **1.2** |
| | After | 25.10 | 30.70 | 21.02 | 1.085 | **1.7** |
| 120 hp | Before | 22.40 | 17.74 | 6.95 | 0.870 | **1.1** |
| | After | 17.80 | 27.10 | 5.99 | 2.355 | **1.6** |
| 75 hp | Before | 14.80 | 23.96 | 4.82 | 0.480 | **2.2** |
| | After | 11.70 | 18.40 | 2.52 | 1.570 | **1.1** |

These results highlight contrasting trends in the surface crusting index depending on tractor power. It rises after the passage of intermediate- and high-power tractors, whereas it drops significantly at low power.

### 3.3. Biologicals Properties (Soil Organic Matter)

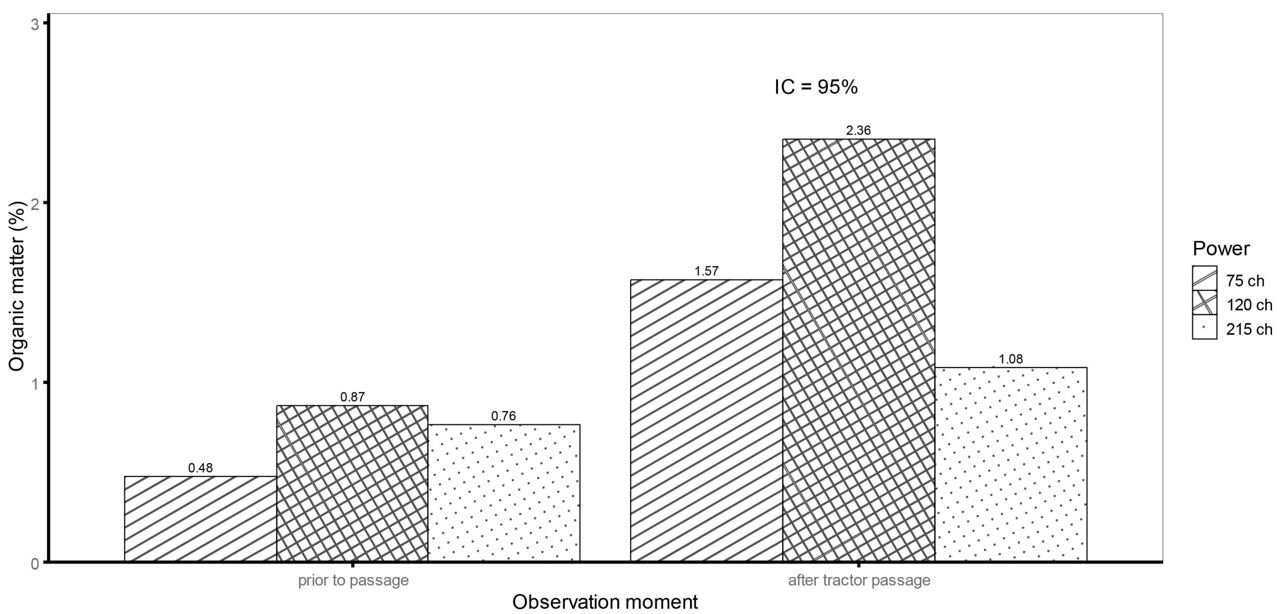



**Figure 13.** Interaction effect between tractor power and the time of observation of soil organic matter content.

Soil Organic Matter (SOC) content levels are shown in **Figure 13**. They indicate that, prior to the tractor's passage, levels are relatively low—ranging from 0.48% (75 hp) to 0.87% (120 hp), with an intermediate value of 0.76% at 215 hp. Following the passage, an increase is observed across all power ratings. At 75 hp, organic matter content rises from 0.48% to 1.57%; at 120 hp, from 0.87% to 2.36%; and at 215 hp, from 0.76% to 1.08%.

These results highlight a clear increase in Soil Organic Carbon (SOC) content following the tractor's passage, which is particularly pronounced at 120 hp, where the value nearly triples. The increase is also notable at 75 hp, whereas it remains more limited at 215 hp. Confidence intervals (95% CI) confirm the statistical validity of the observed differences.

### 3.4. The Rate of SOC in Relation with the Level of Clay

The SOM/Clay ratio (Soil Organic Matter to Clay ration) is presented at **Table 4**. This ratio indicates the stability of the soil structure and its vulnerability to degradation. It assesses whether the soil has enough organic matter to bind the clay particles together. If this ratio is above 17%, the soil is stable. It mean's that, the structure resists damage from rain and compaction well. Therefore, if this value is between 10% and 17%, the soil is moderately stable. There is a risk of degradation if poorly managed. The value of ration below 10% indicate that the soil is unstable. The risk of structure breakdown is very high.

**Table 4.** Effects of the variation in tractor power on the ratio of organic matter to soil clay at a depth of 30 cm before the first and after the second motorization cycles at the Nkwadi site.

| Tractor Power Level | Moment | O.M% | Clay % | O.M/clay ratio in % |
|---|---|---|---|---|
| 215 hp | Before passage | 0.765 | 18.150 | 4.215 |
| | After passage | 1.085 | 25.100 | 4.323 |
| 120 hp | Before passage | 0.870 | 22.400 | 3.884 |
| | After passage | 2.355 | 17.800 | 13.230 |
| 75 hp | Before passage | 0.480 | 14.800 | 3.243 |
| | After passage | 1.570 | 11.700 | 13.419 |

**Table 4** reveals that the soils subjected to all tractor power ratings were initially unstable with very high risk of degradation (SOM/clay ratio of less than 10%). However, after the passage of the tractor, the soils under the 75 hp and 120 hp power shifted from unstable to moderately stable, with the ratio falling within the 10% to 17% range.

## 4. Discussion

In general, through this series of experiments that made up the present research, several results related to the objectives pursued were recorded.

Thus, the results presented in this study demonstrate that the soils of Nkwadi are very heterogeneous in terms of chemical properties and are acidic. The pH analysed before the tractors pass varies from 5.08 - 5.61 under all treatments. In the second season, the pH fell to the range of 5.0 - 5.37. This led to a decrease in phosphorus and calcium levels. The increase in acidity is more marked with the 215 and 120 hp tractors. This aspect of things is justified with ploughing under powerful tractors since the acidity in these soils increases with the depth of the profile.

The Soil Organic Matter (SOM) content of these soils ranged from 0.40% - 0.87% before the tractors passed through to slightly increased to 1.085% - 2.355% after the second tractor pass for tillage. These are very insignificant values to support optimal maize production. The increase in SOM at the second pass is due to the burial of residues from the first season corn plants. However, the SOM content has been increased under the effect of all the power of the tractors; This would be due to the burial of corn debris after harvest, a trend that is more noticeable under 75 hp than under 120 hp. The increase in this rate below these two levels would be due to the fact that the debris of the corn plants is buried a little more superficially than below 215 hp. A similar trend was found in Switzerland, Germany, France and the Netherlands by Krauss *et al.* [33]. They found the reduced SOC by tillage compared to deep tillage who increased SOC stocks in the surface layer (0 - 10/15 cm) by 20.8%.

The very superficial burial of Soil Organic Matter below 75 hp significantly reduced the $NO_3^-$ and $NH_4^+$ contents compared to 120 and 215 hp and the $NO_3^-$ / $NH_4^+$ ratio is greater than 1. $NH_4^+$ decreased with the power level. The fact that nitrogen in both forms is more available in the surface layer near the roots would also justify its high assimilation below 75 hp. This justifies a rate of increase in efficiency of around 38% in the second season compared to the first under the 75 hp tractor.

Potassium tended to increase below 215 and 120 hp. It is stable at the 75 hp level. This would be due to the addition by fertilization, the mineralization of organic matter as well as its resurfacing by deep ploughing. The effects of the variation in tractor power on the ground are more apparent on a few physical properties of the soil. Apart from compaction [34], the different movements of machines and tools in the soil have had an impact on the particle size.

Soils that were initially sandy silt and clayey-sandy silt have significantly changed the classes in the classification of soils according to the particle size triangle under all power levels. Under the 215 hp tractor there is a noticeable increase in the level of clay and silt. The content of the sand has decreased under the same power. This tendency is due to the very high ploughing depth bringing the clay from the lower horizons to the surface. Under the 120 hp tractor there is a decrease in the clay and sand content.

Under the 75 hp tractor there is a decrease in the level of clay and silt with an increase in the level of sand. The soil remained sandy loam with a little more sand than under the 120 hp. By averaging all the particle size contents, it appears that these soils were generally sandy silt before the passage of the machines and they became silty after the second passage of the machines, types of soils having a very low capacity to retain fertilizing elements because the silt lacks this capacity.

This aspect was investigated by Destain [11], who found that increasing tractor power leads to higher total weight and wheel loads, thereby intensifying soil compaction and negatively affecting the physical fertility of both cultivated and deep soil layers. Shani and Musa [35] also found that soil compaction increases with higher tractor power and a greater number of machine passes, based on tests using 40, 60, 80, and 100 kW tractors over 1, 3, and 5 passes. The average textural analyses of the soil before the passage of tractor presented at **Figure 14** and **Figure 15** confirm this conclusion.

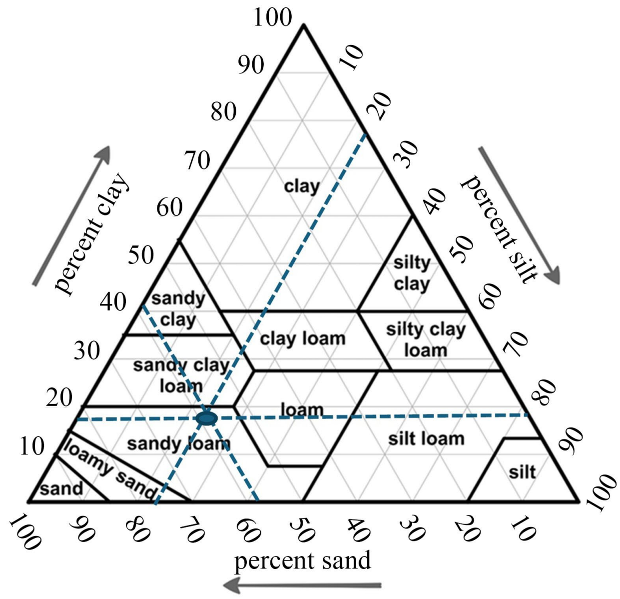



**Figure 14.** Average textural analysis of the soil at a depth of 30 cm before the machines pass through.

Also following the soil profile, it appears that the A horizon with the clayey-sandy silt texture is 25 cm thick. From 30 cm onwards, there is a significant increase in the level of clay and silt with a very significant decrease in sand. The acidity also increases with depth. This situation shows that light ploughing will have to be considered in this soil.

The ratio of Soil Organic Matter to clay was very low before the tractors passed, *i.e.* 4.215%, 3.884% and 3.243% respectively under 215, 120 and 75 hp. After the second pass, it turned out that the 215 hp tractor kept the soil at a very low level that was not tolerable according to Boivin *et al.* [28]. On the other hand, under the 120 hp and 75 hp tractors, the ratio increased by 13.230% and 12.419% respectively.

Given that it is accepted that an SOM/clay ratio of 17% is a minimum requirement for sufficiently structured soil and for land with a ratio close to 12%, we should even think about abandoning ploughing [28] and think about sustainable agricultural mechanization through the principles of conservation agriculture with adequate equipment. For tillage and seeding/planting/transplanting operations, solutions such as zero tillage with rotary drills, strip ploughing exercises, ploughing machines, raised bed planters, ridgers, precision seeders and planters [36] should be considered.

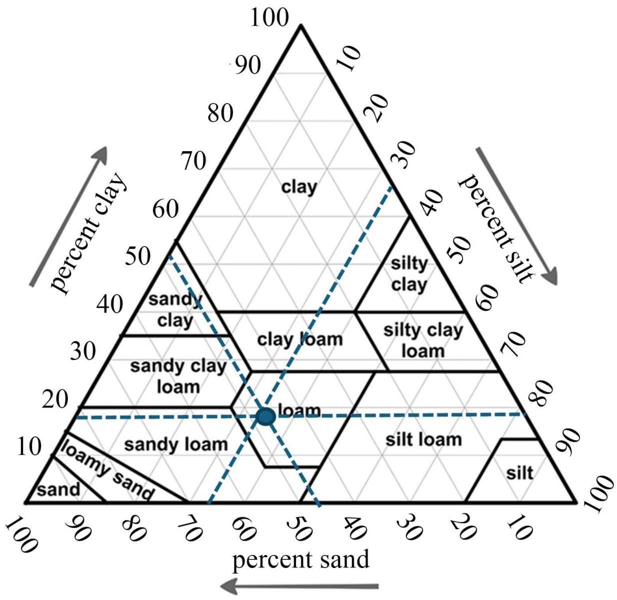



**Figure 15.** Average textural analysis of the soil at a depth of 30 cm after machine passage.

The increase in silt content with low levels of organic matter is the basis for the increase in the beating index. Under the 215 hp and 120 hp tractors, the ground is brought back from non-flapping to fairly swinging ground. In the field, this aspect of things has increased the erodibility of the soil and the formation of crusts of beating, which significantly decreases permeability. Puddles of water began to form in the field. The 75 hp tractor, on the other hand, brought the soil, which was very beating, back to the non-beating ground. Organic matter inputs will not only play a large role in acidity and nutrient availability, but also a role in reducing beating and maintaining structural stability.

The increase of soil Crusting Susceptibility Index (CSI) under the 215 and 120 hp tractors would be due in part to their weight (11,800 kg and 4640 kg respectively) and to the ploughing depth under these two tractors. The protection or even improvement of structural stability by the 75 hp tractor weighing 2425 kg would also be due to these two factors. However, the management of cropping systems determines a succession of disturbances in the surface condition over time, by fragmentation under the effect of tillage, by compaction by agricultural machinery and by the phenomenon of beating [37].

## 5. Conclusions

This study on the effects of tractor power variation on soil properties under maize in the DRC, the case of the Agricultural Voluntary Program in Nkwadi/Kasai Oriental Province, had set itself the main objective of comparing the effects on the physical, chemical and biological properties of the soil under the passage of three power levels of JOHN DEERE tractors (75 hp, 120 hp and 215 hp) in order to identify and popularize the level that causes less harmful effects on the soil for the sustainability of the crop.

After analysis of the chemical, physical and biological parameters in the soil samples taken before the tractors passed through the test site under different tractor power levels in order to understand the changes in the soil properties made by the tractors during the 2020/2021 and 2021/2022 crop years in their A seasons, several results were obtained.

The results showed that the intensive motorization of agriculture has effects by following the power of the tractor used in modifying the physical, chemical and biological properties of the soil. 75 hp tractors affect soil properties less negatively compared to 120 hp tractors. The 215 hp tractors have been shown to have more pronounced effects in soil degradation and should no longer be used in the Nkwadi area.

To preserve the properties of the soil, the 75 hp tractor would be best suited for mechanizing ploughing, the 120 hp tractor for preparing the seedbed and sowing. The 215 hp tractor is not listed on this site.

The advantage of combining the 120 and 75 hp tractors is that ploughing, harrowing, seedbed preparation and seeding are shallow with acceptable weights on the ground.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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