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# Trade-off between agronomical and energetical performances during barley sowing varying adjustable parameters in a tractor-tire-tool system

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## Abstract

Soil compaction on seedbed, resulted from the traffic of a tractor-tire-tool system, alters soil structure and harmfully impacts crop production. Soil conservation during sowing operations and the optimization of energy consumption of tractor-tire-tool system, form the focus of the global agriculture policies and farmers under the energetical and the agroecological transitions. The present study aims to find a trade-off between the agronomical and the energetical performances, during a sowing operation of spring barley (*Hordeum vulgare*), varying adjustable parameters (controlled factors) in tractor-tire-tool system (i.e. tractor speed, axle load distribution, inflation pressure and soil working depth). The adjustable parameters have been chosen as to be adjustable by a regular tractor operator. The study was carried out on a silty loam soil (with an average soil gravimetric water content of 23.4%) located in Northern-France. The used tractor-tire-tool system consisted of a Four-Wheel Drive tractor (140 HP of power) equipped with 480/70 R28 front tires and 580/70 R38 rear tires, and hitched to an air seeder. Agronomical performance is evaluated via the conservation of soil physical properties, and via

the success of the sowing operation. The energetical performance is evaluated via the optimization of energy consumption. The conservation of soil physical properties was assessed via soil bulk density (BD) and air permeability ($k_a$). The success of the sowing operation was assessed via barley seedling, counting the emerged plants at one to two leaves stage, and crop yield. Energy consumption was assessed via the consumption of fuel per hectare. BD and $k_a$ were negatively correlated ($\rho$=-0.56 and p-value<0.001), but $k_a$ was significantly more influenced by the controlled factors and their combinations showing higher sensitivity of pore continuity to the structural disturbance than pore space. Crop seedling and yield were slightly influenced by the variation of the controlled factors and their combinations. All these agronomical indicators depended significantly on the combination between the four factors showed as single treatment. Fuel consumption decreased significantly with the equal load distribution and increased with tractor speed and soil working depth solely. Nonetheless, it showed higher dependence on the combinations between the factors. As a conclusion, soil physical properties could be conserved, better barley seedling and yield could be obtained, and energy consumption could be optimized by equally distributing the axle load, accelerating tractor at 14 km/h, working the soil at 10 cm of depth and inflating tires at 140 or 80 kPa of inflation pressure.

**Keywords:** seedbed soil conservation, crop seedling and yield, fuel consumption, performance optimization, tractor-tire-tool system, adjustable parameters.

# 1 Introduction

A successful agricultural operation is the one that prevents soil damage and energy waste and that allows a sustainable consumption agronomical production (Botta et al., 2007; Naujokienė et al., 2022). For sowing operations, it is essential to have a suitable seedbed for the germination of grains and to obtain the needed crop yield (Barnhisel and Hower, 1997; John et al., 2011).

The agriculture machinery and its connected tools increased in weight and size to meet the massive requirement of agricultural operations, from sowing to the harvesting of different crops (Keller and Or, 2022). The barley sowing occurs usually in mildly wet conditions of soil, which has the potential to increase soil damage and energy waste (Asinyetogha et al., 2019; Reintam et al., 2009). The traffic of a tractor-tire-tool system upon the soil in such wet soil conditions, applies a mechanical stress to the soil and results in serious soil degradation by compaction which stands behind the degradation of 23% of arable lands (Bai et al., 2008; Hillel, 2003). The well aerated soil structure undergoes a deformation when the mechanical stress exceeds its bearing capacity, which is a compression of the biopores, shearing of pores' continuity and change of pores' size distribution (Keller et al., 2022). This deformation is translated directly by the increase of soil penetration resistance, bulk density and shear strength (Alblas et al., 1994; Forster et al., 2018; Raper, 2005). The compaction results in a reduction of mineralization of organic matters, resource availability for plants, soil permeability, germination ability of grains, and root development and penetrability (Forster et al., 2020, 2018; Kuncoro et al., 2014). Topsoil compaction influences soil hydric states leading to reduce tillage performance and the effectiveness of fertilizers amendment, then indirectly it leads to a loss in crop yield and cultivatable areas, then creates a significant cost for farmers and society (Batey, 2009; Håkansson and Medvedev, 1995; Keller et al., 2022).

The interaction between topsoil and tire causes a stochastic tire deflection and soil deformation, which wastes up to 55% of the tractor available energy (Janulevičius and Damanauskas, 2015; Pranav and Pandey, 2008). The achievable energy optimization is obtained when all the energy from fuel combustion are used in the drawbar work of tractor without soil damage (Grisso et al., 2004). In fact, manufacturers of machinery and tires worked to develop new technologies to improve the vibration process and stress distribution in the soil, and reduce tire defection (Kising and Göhlich, 1989; Schjønning et al., 2012). Even though new tires could carry heavier

load with lower inflation pressure, tire innovation and development could not overcome the heavy impact of machinery traffic in agricultural operations (Comparetti et al., 2019; ten Damme et al., 2019). Therefore, practices focusing on the interaction between soil and the tractor-tire-tool system could play a significant role to improve soil-tractor-tire-tool interaction and contribute to mitigate soil compaction and energy waste. The previous studies show that the operator can improve this interaction by some adjustable parameters on its tractor-tire-tool system, where some settings are reviewed, such as the adjustment of tractor speed, tires and ballast, as well as soil tillage methods and working depth (Farias et al., 2019; Janulevičius and Damanauskas, 2015; Spagnolo et al., 2012; Tayel et al., 2015). Most of studies focused on tire adjustment as stress transmitter, when the primary focus is to widen the soil-tire contact area which affects the rolling resistance, which in turn has high impact on fuel consumption (Taghavifar and Mardani, 2012). There is some available methods that provide wider contact area between soil and tire (Raper, 2005). Wider contact area can be obtained using dual tires, but it leads to impact a wider surface, then better results can be obtained lowering the inflation pressure of single tires (Raper, 2005; Schwanghart, 1991). One of the effective methods to widen this contact area is the use of rubber tracks instead of tires, which results in a lower compression but can lead to a higher shear of soil (Blunden et al., 1994; Lamandé et al., 2018). Low-corrected inflation pressure can reduce the compaction severity, increase traction efficiency and decrease fuel consumption (Antille et al., 2013; Battiato and Diserens, 2013; D L Antille et al., 2008; Douglas et al., 1992; Schwanghart, 1991; Udompetaikul et al., 2011). However, an over-inflation of tires can result in a ballooning effect, reducing energy waste by the reduction of tire deflection (Taghavifar et al., 2014). Ground pressure is the principal element controlling the severity of topsoil compaction (Raper, 2005). During tractor-pull operations, like sowing, an appropriate adjustment of tire load and pressure is essential to improve tractor traction through the diminution of tire slippage and thereby reduce soil

compaction and energy waste (Davies et al., 1973; Janulevičius and Damanauskas, 2015). This improvement is usually performed by configuration of load distribution of ballast between rear and front tires (Janulevičius and Damanauskas, 2015; Mamkagh, 2018; Pranav and Pandey, 2008). Wheels are used to be loaded by 55-65% of total axle load in static conditions, and an overloading ballast increases rolling resistance and soil compaction which, also, waste the energy (Damanauskas et al., 2015; Janulevičius and Damanauskas, 2015; Pranav and Pandey, 2008). Soil compaction occurs under a process of vibration of the mechanical pressure. The increase of tractor speed decreases the hold-time of this process and take up more power at lower slip, and therefore may provoke a lesser compaction to the soil (Al Aridhee et al., 2020; Davies et al., 1973). On the other hand, consumption of fuel increases with the increase of speed leading to use higher energy for the motion of tractor and decreasing the traction efficiency (Adewoyin and Ajav, 2013; Taghavifar et al., 2014). The optimization of an agricultural operation take into account the duration to perform the operation. Thus, an optimal operation is the one does not waste time also. Accordingly, it should find a compromise between saving time and fuel to a better energetical performance depending on the soil conditions. For instance, an increase of traffic speed could achieve the operation in a reasonable duration and result in an acceptable compaction within a conventional system, when the soil has lower bulk density, but at the same time it could result higher energy waste (Stafford and de Carvalho Mattos, 1981). Except of the no-till system, the farmers work their soils to prepare the seedbed for the sowing. Therefore, to reduce soil degradation and energy waste, the operator can play on the tillage or soil working depth. Soil tillage or working before sowing softens the compacted soil by decompression and cracking of compacted blocs (Parkhomenko et al., 2019; Zimdahl, 2018). Primary tillage is one of the effective practices to prepare the seedbed increasing structural macro-porosity and breaking up compacted soil, but a significant soil compaction could be generated following a secondary tillage over a freshly tilled soil (Botta et al., 2009; Zimdahl,

2018). However, it is one of the highest energy consuming between the agricultural operations (Badalíková, 2010; Moitzi et al., 2013). The effect of tillage, and its different methods and practices, is vastly arguable, but it depends always on soil and climatic conditions (Badalíková, 2010; Bogunovic et al., 2018). For example, an increase of tillage depth can positively affect crop yield but negatively affect soil structure, as well as it requires higher energy supply (Arvidsson et al., 2013). Even though, the conventional tillage using mouldboard ploughing reduces soil bulk density and results in a higher crop yield, it can increase compaction and erosion risk and decrease soil bioactivity (Arvidsson et al., 2013; Badalíková, 2010; Bogunovic et al., 2018).

To the best of our knowledge, the combination between all the adjustable settings to reduce soil compaction and optimize energy consumption is not documented. These settings are usually setup together, as single combination, but the previous researches focus on the closest settings only, such as tire inflation pressure and ballasting or tire inflation pressure and tractor speed etc. Energetic and agronomic performance are rarely treated as a single target of a successful agricultural operation. The objective of the present study is to examine the possibility of conciliating the optimization of energetic performance, via the reduction of fuel consumption, and the optimization of agronomic performance, via the conservation of soil physical properties on seedbed and a best crop production. The aim of this study is to find the best combinations consisted of adjustable parameters (i.e. tire inflation pressure, tractor speed, axle load distribution and soil working depth) to present the trade-off between the energetical and agronomical performances.

# 2 Materials and methods

## 2.1 Study site and experimental design

The study was conducted on an agriculture parcel of 1.5 ha of flat surface, located in Milly-sur-Thérain, Northern-France (49°29'48.6"N 2°01'10.3"E). The climate is sub-oceanic with average of annual precipitation of 749 mm and average annual temperature of 10.8 °C (Climate-Data.org). The soil is a Luvisol (IUSS Working Group WRB, 2015) of silty loam texture, with an average of clay content of 167 g/Kg, an average of organic matter content of 17.5 g/Kg, an average of cation exchange capacity (CEC) of 8.93 cmol+/Kg and an average of pH (in distilled water) of 7.9. The parcel is used for cereal cultivation: before the barley (*Hordeum vulgare*), the parcel was cultivated in wheat (*Triticum turgidum L. var. durum*). The two cereal crops were separated by Brassicaceae cover crop of white mustard (*Sinapis alba*). The parcel was stubbled then soil was tilled up to 30 cm and shallow tilled up to 5 cm just before sowing.

The used tractor-tire-tool system consisted of a Four-Wheel Drive tractor of 140 HP (Massey-Ferguson 6714 S) equipped by Michelin Multibib 480/70 R28 and 580/70 R38 tires (front and rear tires respectively), and hitched to a towed mini-till air-seeder fitted with a disc harrow concave scalloped discs (Kuhn Espro 3000). The adjustable parameters chosen as controlled factor were: tractor speed (three levels: 10, 12 and 14 Km/h), inflation pressure (three levels: 80, 100 and 140 kPa equivalent to 0.8, 1 and 1.4 bar), soil working depth (two levels: 5 and 10 cm) and the static axle load distribution (two levels: 60%/40% and 50%/50% on rear and front axles respectively). The total load of the whole system within unequal axle load distribution was 9.3 Mg and within the equal one was 9.28 Mg.

The combination between all controlled factors established an experimental design consisting of 36 treatments enumerated from T01 to T36 (see table AII-I in Appendix II). Each treatment was used to sow one strip of 60 m of length and 3 m of width. As shown in figure 1, Treatment

strips were randomized in three blocks horizontally. A buffer zone of 20 m of width was settled between the blocks and served as setting adjustment zone (adjustment of parameters' level). Each parallel treatment strips were spaced about 20 cm apart to prevent any possible sowing overlap. Three additional lines of 3 m of width were also settled between treatment strips: the first one is non-sowed line serving as control soil and the others served as traffic path of the sprayer (later intervention in the cultivation process) to protect the treatment strips from any additional traffic after sowing (c.f. figure 1). Sowing took place late February and soil was near field capacity during sowing (average soil gravimetric water content = 23.4% and average matric potential = -14.9 kPa).

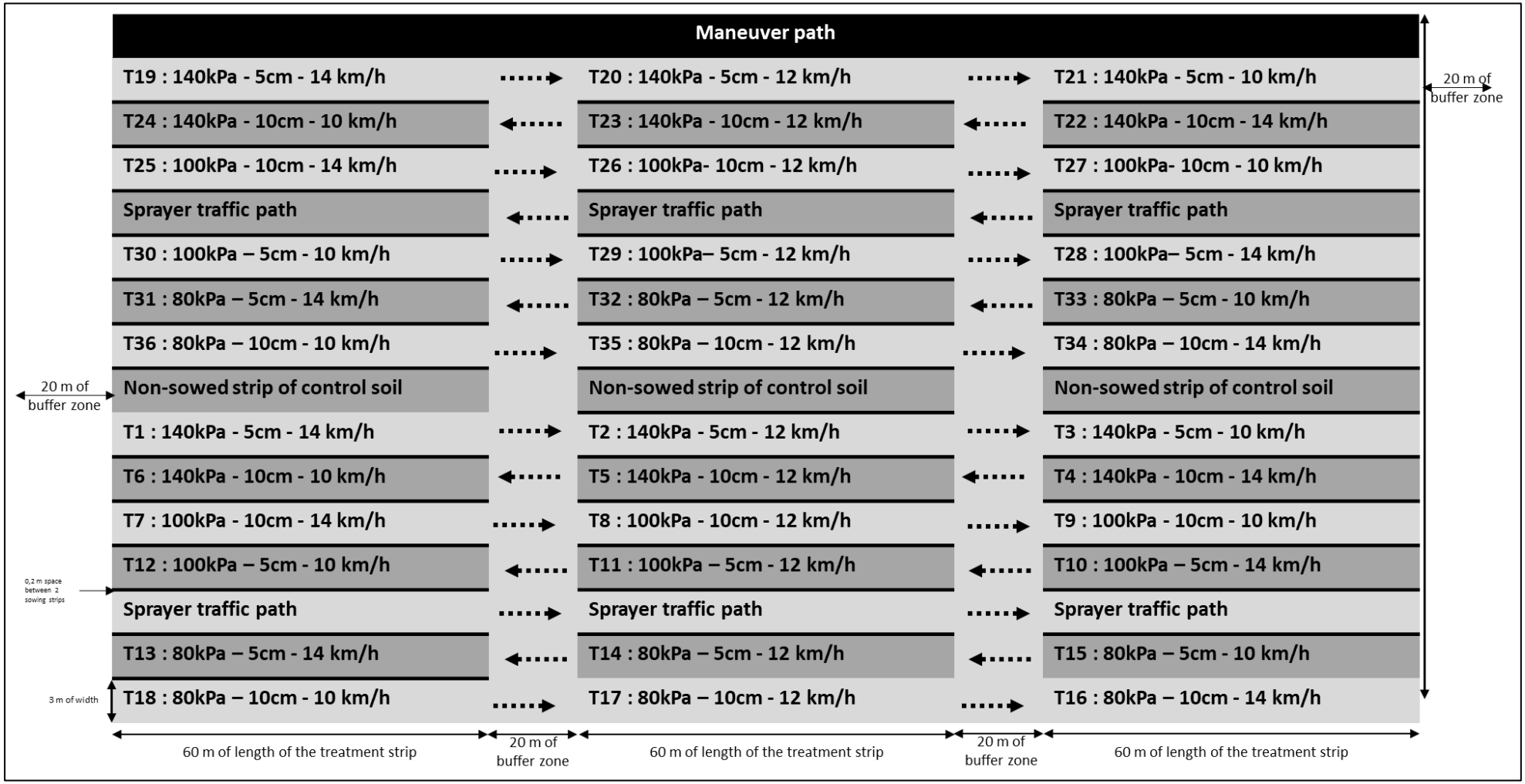


*Figure 1: Schema of the experimental design showing the treatment strips enumerated from T01 to T36 and their distribution on field. Each treatment is defined in the schema starting by axel load distribution (%), inflation pressure (kPa), soil working depth (cm), and tractor speed (km/h). The dashed arrows indicate the direction of sowing.*

## 2.2 Energetic data acquisition

Energy consumption was characterized by the specific fuel consumption per worked hectare. Absolute fuel consumption was provided by the volumetric differential flow meter Aquametro Contoil DFM8D installed in the supply and return lines of tractor's engine. Tractor pull was determined using a dynamometric frame, equipped with two three-axial force transducers SIXAXES FX2.3 (0.8 to 1.5 mV $V^{-1}$). A part of data such as an engine's RPM (Rotation Per Minute), tractor real speed and Global Position System (GPS) data were provided through CAN (controller area network) bus network (CAN 2.0A, 500 kb s-1). Data were recorded every 10 ms with a universal acquisition unit (SIRIUSi 8xSTG+, DEWESoft) on the same time scale. All necessary computing and conversions were made through the post-processing software (Devesoft X) provided by DEWESoft. The straightforward during trails was controlled by an autosteering option of Massey Ferguson Auto-Guide 3000 coupled with an RTK receiver (Trimble AG-382) installed in the tractor cab and used position protocol J1939 with a precision of 2.5 cm. In each treatment, mechanical data recording was started once the target value of the ground speed is reached and motor regime was stabilized. In average, motor regime stabilized after about 20 m from the beginning of the sowing on a treatment strip.

*Figure 2: Energetical data acquisition setup. a. general view of the tractor-seeder assembly. b. volumetric differential flow meter, c. dynamometric frame, d. three-axial force transducer, e. GPS-RTK receiver, f. universal acquisition unit.*

## 2.3 Soil properties and crop data acquisition

Sampling was conducted on the zone where the motor regime is stabilized during sowing. To insure a uniform sampling, the sampling was performed following the direction of sowing and on the traffic trail of the right tires. Two sampling transects were selected, the first one at 30 m of length, and the second one at 45 m. On each transect, three repetitions, spaced 1 m apart, were sampled (i.e. six sampling repetition per treatment). Soil was sampled between 3-7 cm of depth (on the seedbed) using a metallic cylinder of 100 $cm^3$ of volume (inner diameter 5 cm, height 5.1 cm). Soil sampling took place the next day after the sowing and soil was near field capacity (same conditions of soil during the operation). The sampled cylinders were used to measure air permeability ($k_a$ in $\mu m^2$) using the method of Iversen et al. (2001) with a pressure gradient of 5 hPa. Then, soil samples were oven-dried at 105 °C for 48 hours to determine bulk density (BD in $g/cm^3$) using core method (ISO 11272). Barley emergence was assessed counting the emerged barley plants at one to two leaves' stage on a linear meter for two successive sowing arrays. Barley harvest was carried out late July and three repetitions were sampled on a 5 m of length and 3 m of width of each treatment, then barley grains were weighted and yield crop was calculated.

## 2.4 Statistical analyses

The relations between the controlled factors (i.e. tractor speed, inflation pressure, soil working depth and axle load distribution) as explanatory variables and the normally distributed response variables (i.e. BD, count of emerged plant, crop yield and fuel consumption) were examined applying ordinary least square regression (OLS). The relations between the controlled factors as explanatory variables and the non-normally distributed response variable (i.e. $k_a$) were examined applying generalized linear model regression (GLM) using Poisson family. The acquisition of tractor speed simultaneously with the energetic data acquisition offers the use of

the values of tractor speed as continuous explanatory factor to analyze the energetic response variables, in which these values are close or equal to the three levels of tractor speed in a stabilized motor regime. The interaction between the explanatory variables was considered in the examination of the regressions. Then, the treatment was applied as explanatory variable of the different response studied variables to examine its effect as single body factor. Analysis of variance (ANOVA) was applied on the regression models to test the effect of the explanatory variables and their interactions (in case of interaction) on the response variables. Multiple mean comparison using post-hoc Duncan test following ANOVA analysis of variance was performed to compare between the means of the different response variables with respect to the treatment. Furthermore, means of BD per treatment was compared to the bulk density threshold for soil compaction of 1.4 g/cm$^3$ (USDA Natural Resources Conservation Service) to assess whether the treatment induced soil damage or not. Mean count of emerged barley was compared to the count should be obtained with the germination rate of the sowed variety (51 plants/m) to assess the effect of treatment on the success of the germination and seedling. Mean crop yield per treatment was compared to the 2021 average crop yield of spring barley in Northern France (Hauts-de-France state), which is equal to 6.32 t/ha (Arvalis, 2021), to assess the effect of treatment on the success of the operation. A principle component analysis (PCA) was performed to reveal the correlation between the agronomical performance indicators. Fuel consumption means were also compared referring to the median of the fuel consumption, and the treatments show significantly equal or lower consumption than this median are considered as showing optimal consumption. To better explain the variation of fuel consumption as energetic response variable, tractor pull (expressed in KN) was analyzed in the same way to discuss the effect of controlled factors on energy consumption and traction efficiency. Then a Granger-Causality test was performed to test the possible forecasting of fuel consumption by tractor pull.

All statistical analyses were performed using R software environment (R. Core Development Team, 2020).

# 3 Results

## 3.1 Effect of controlled factors on soil properties

The regression of BD as function of the controlled factors shows that BD increased significantly with the combination of the unequal axle load distribution, tractor speed and soil working depth (see table AI-I in appendix I). $k_a$ increased significantly with: i) soil working depth, ii) inflation pressure, iii) the combination of unequal axle load distribution, tractor speed and soil working depth, iv) the combination of unequal axle load distribution, tractor speed and inflation pressure, v) the combination of unequal axle load distribution, soil working depth and inflation pressure, vi) and the combination of tractor speed, soil working depth and inflation pressure. $k_a$ decreased significantly with: i) the combination of unequal axle load distribution and soil working depth, ii) the combination of tractor speed and soil working depth, iii) the combination of unequal axle load distribution and inflation pressure, iv) the combination of soil working depth and inflation pressure, and v) the combination of the four factors together (see table AI-II in appendix I). Noteworthy, the coefficient of determination ($R^2$) for the regression models of BD and $k_a$ in function to the controlled factors were 0.06 and 0.25 respectively. On the other hand, when the combination of the four factors together (treatment) was used as single factor, then $R^2$ increased to be 0.49 and 0.55 for BD and $k_a$ respectively with a p-value < 0.001.

## 3.2 Effect of controlled factors on the emergence of barley and crop yield

The count of emerged plant decreased significantly with the unequal axle load distribution, the inflation pressure, and the combination of unequal axle load distribution, soil working depth and inflation pressure (table AI-III, appendix I). Likewise, crop yield decreased significantly

with the combination of unequal load distribution, soil working depth and inflation pressure (table AI-IV, appendix I). Noteworthy, $R^2$ for the regression models of the count of emerged plant and the crop yield as function of the controlled factors were 0.46 and 0.19 respectively. On the other hand, when the combination of the four factors together (treatment) was used as single factor, then $R^2$ increased to 0.57 and 0.49 for the count of emerged plant and the crop yield respectively with a p-value < 0.001 and p-value = 0.008 respectively.

## 3.3 Effect of controlled factors on fuel consumption

Fuel consumption increased significantly with: i) unequal axle load distribution, ii) soil working depth, iii) tractor speed, iv) the combination of soil working depth and tractor speed, v) the combination of unequal axle load distribution, tractor speed and soil working depth, vi) the combination of unequal axle load distribution, tractor speed and inflation pressure, vii) the combination of unequal axle load distribution, soil working depth and inflation pressure, and viii) the combination of tractor speed, soil working depth and inflation pressure. Fuel consumption decreased significantly with the combination of unequal axle load distribution and inflation pressure, and ii) the combination of tractor speed and inflation pressure (table AI-V in appendix AI). Noteworthy, $R^2$ of the regression model for fuel consumption as function of the controlled factors was 0.50 and it increased to 0.56 when the combination of the four factors together (treatment) was used as single factor. Considering the non-significant effect of inflation pressure solely on fuel consumption, Figure 3 shows the fuel consumption as function of the continuous tractor speed and categorized with respect to soil working depth and axle load distribution. Irrespectively to the axle load distribution, fuel consumption was significantly higher with the highest soil working depth, but the difference became non-significant when tractor accelerate between 13 and 14 km/h (figure 3). Likewise, fuel consumption was higher with the unequal axle load distribution (figure 3). Figure 3 shows that fuel consumption was significantly equal using unequal axle load distribution combined to the 5 cm of soil working

depth or the equal axle load distribution combined to the 10 cm of soil working depth, independently from the speed of tractor. On the other hand, it shows that the combination between the equal axle load distribution and the 5 cm of soil working depth demonstrated the lowest fuel consumption. A slight decrease of fuel consumption with the continuous tractor speed was also found (figure 3).

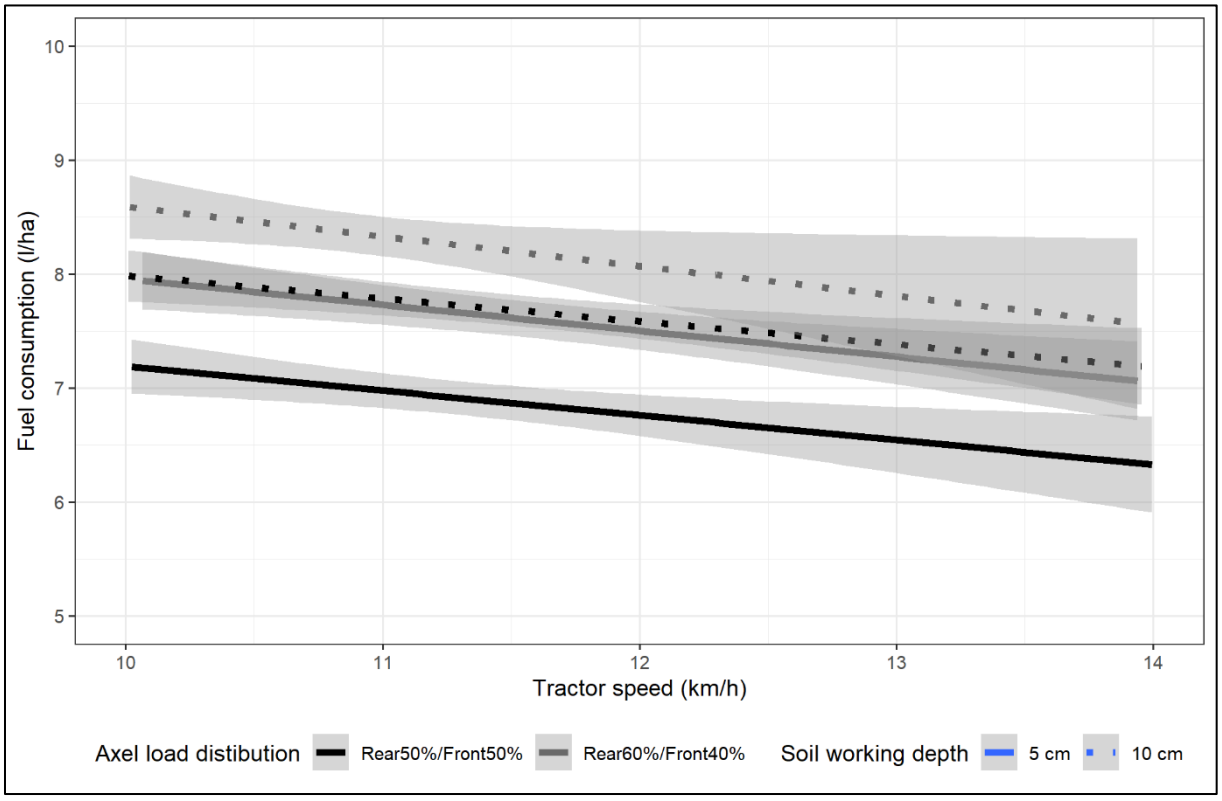


*Figure 3: Variation of fuel consumption in function to the continuous tractor speed and categorized with respect to soil working depth (line type) and axel load distribution (line color).*

## 3.4 Trade-off between fuel consumption, soil conservation and barley production

Table 1 shows the means of the different studied indicators and the results of their comparison. Six treatments (T05, T12, T26, T27, T29 and T32) show an average of $k_a$ significantly lower than the average $k_a$ of the control soil (9.46 µm²). There was no treatment showing an average BD significantly higher than the control soil (1.39 g/cm$^3$), but 10 treatments (T12, T13, T19, T26, T27, T29, T31, T32, T33, T36) showed an average BD higher than the threshold of compaction for a silty loam soil (1.4 g/cm$^3$). A total of 19 treatments (T01, T02, T07, T13, T17,

T18, T20, T21, T24, T25, T27, T28, T29, T30, T31, T32, T33, T35, T36) showed an average count of emerged plant lower than the average of emerged plants expected at the germination rate of the used variety of barley (51 emerged plant/m). For the reason of an operational problem, we could not have the count of emerged plant for T19, T22, T23 and T34. A total of 11 treatments (T02, T05, T06, T07, T08, T17, T24, T25, T30, T31 and T34) showed an average crop yield lower than the average of barley yield in Northern France in 2021 (6.32 t/ha). For the reason of an operational problem, the yield of T19, T22 and T23 are missed.

*Table 1: Mean of the studied indicators (i.e. air permeability, bulk density, count of emerged plant, crop yield, fuel consumption and traction power) and their groups resulted from post-hoc Duncan mean comparison analyses following one-way analysis of variance (ANOVA). Means that are not in same group of letters are significantly different at a level of p-value ≤ 0.05. NA means No Available and corresponds to the missed data. (See Table AII-1 in Appendix II for the details of the treatments).*

| Treatment | *ka* (µm²) | BD (g/cm$^3$) | Count of emerged plant | Crop yield (t/ha) | Fuel consumption (l/ha) | Tractor pull (KN) |
|---|---|---|---|---|---|---|
| Control | 9.46 klmnop | 1.39 abcdef | NA | NA | NA | NA |
| T01 | 7.74 nopqr | 1.26 gh | 50.83 abcdef | 6.378 abcdef | 5.88 s | 12.69 ij |
| T02 | 12.36 jkl | 1.37 bcdef | 49.83 abcdefg | 5.964 cdef | 7.15 lmno | 12.69 ij |
| T03 | 5.12 klmnop | 1.32 efg | 53.5 abc | 6.747 abcdef | 7.46 hi | 11.56 klm |
| T04 | 7.95 mnopqr | 1.37 bcdef | 54 ab | 6.782 abcdef | 7.05 pqr | 14.19 fgh |
| T05 | 5.72 rst | 1.39 abcdef | 56.5 a | 6.133 bcdef | NA | NA |
| T06 | 8.27 pqrs | 1.33 cdefg | 52.83 abcde | 6.169 bcdef | 7.62 ijkl | 13.59 ghi |
| T07 | 15.88 hi | 1.36 cdef | 46.5 bcdefgh | 6.262 abcdef | 7.43 o | 14.31 efgh |
| T08 | 21.11 f | 1.25 gh | 52.83 abcde | 6.129 bcdef | 7.75 klmno | 15.15 bcde |
| T09 | 13.71 ijk | 1.31 efg | 54 ab | 7.729 a | 8.16 cde | 14.14 fgh |
| T10 | 8.93 klmno | 1.38 abcdef | 52.67 abcde | 7.049 abcd | 6.23 rs | 11.56 klm |
| T11 | 24.13 e | 1.21 h | 55 a | 6.373 abcdef | 7.09 jklmn | 11.19 mno |
| T12 | 7.15 qrs | 1.41 abcdef | 53.5 abc | 6.644 abcdef | 7.03 op | 11.44 lmn |
| T13 | 8.93 lmnopq | 1.41 abcdef | 50.33 abcdefg | 6.076 bcdef | 5.7 rs | 12.18 jkl |
| T14 | 40.89 a | 1.3 fg | 52 abcde | 7.609 ab | 6.28 pqr | 10.47 o |
| T15 | 12.84 klmn | 1.37 bcdef | 51 abcde | 6.911 abcdef | 6.59 qr | 10.58 no |
| T16 | 8.71 nopqr | 1.35 cdefg | 53.33 abcd | 6.72 abcdef | 7.59 jklmn | 13.36 hi |
| T17 | 7.75 klmno | 1.37 bcdef | 49.67 abcdefg | 6.036 cdef | 7.89 a | 14.24 efgh |
| T18 | 12.35 klmno | 1.38 abcdef | 46.67 bcdefgh | 6.533 abcdef | 7.61 mno | 14.23 efgh |
| T19 | 37.49 b | 1.41 abcde | NA | NA | 6.99 hij | 12.39 jk |
| T20 | 20.46 fg | 1.33 defg | 49.33 abcdefg | 6.56 abcdef | 7.38 jklmn | 12.79 ij |
| T21 | 3.85 t | 1.36 cdef | 50.33 abcdefg | 6.711 abcdef | 6.86 pq | 12.36 jk |
| T22 | 10.35 jkl | 1.39 abcdef | NA | NA | 7.03 no | 14.45 defg |
| T23 | 9.03 opqr | 1.36 cdef | NA | NA | 8.52 hij | 14.84 cdef |
| T24 | 17.05 gh | 1.36 bcdef | 40 hij | 5.431 ef | 8.85 def | 14.84 cdef |
| T25 | 11.64 klm | 1.38 abcdef | 40 hij | 5.409 f | 8.14 gh | 15.78 b |
| T26 | 7.4 qrs | 1.4 abcdef | 48.67 abcdefg | 7.391 abc | 8.52 fg | 15.31 bcd |
| T27 | 7.63 qrs | 1.48 a | 44.83 efghi | 7.204 abc | 8.87 bc | 14.15 fgh |
| T28 | 17 hij | 1.34 cdefg | 46 bcdefgh | 7.413 abc | 7.71 gh | 12.66 ij |
| T29 | 4.08 st | 1.44 abc | 36 j | 7.347 abc | 7.75 ijk | 13.41 hi |
| T30 | 15.78 d | 1.17 h | 37.67 ij | 6.218 abcdef | 7.89 ijklm | 11.41 lmn |
| T31 | 9.65 mnopqr | 1.41 abcde | 45.5 cdefghi | 5.667 def | 7.36 ijk | 13 ij |
| T32 | 7.21 qrs | 1.4 abcdef | 37.83 ij | 6.573 abcdef | 6.69 op | 12.82 ij |
| T33 | 9.58 mnopqr | 1.43 abcd | 40.83 hij | 6.373 abcdef | 8.58 bcd | 12.8 ij |
| T34 | 10.64 klmnop | 1.39 abcdef | NA | 5.569 def | 6.09 rs | 10.43 o |
| T35 | 32.26 c | 1.32 efg | 39 hij | 7.436 abc | 8.43 b | 16.93 a |
| T36 | 36.39 b | 1.47 ab | 42.83 ghij | 6.942 abcde | 8.71 efg | 15.54 bc |

Nine treatments (T09, T17, T24, T26, T27, T28, T33, T35 and T36) show an average fuel consumption significantly higher than the median of the global consumption (7.46 l/ha). For a reason of a technical problem during the registration of energetical data, the consumption of

T05 was missed. All the remaining treatments could be considered as performant for the specific studied indicator. The common performant treatments between all the indicators are considered as the expected trade-off between the soil conservation, barley production and fuel consumption. Seven treatments (T03, T04, T10, T11, T14, T15, and T16) showed this trade-off (see table AII-I in appendix II for the details of treatment combinations).

# 4 Discussion

## 4.1 Influence of adjustable parameters on the agronomical performance

The agronomical performance is evaluated with regard to the conservation of soil physical properties and the success of the sowing operation. BD and $k_a$ were negatively correlated ($\rho$=-0.56 and p-value<0.001) but they did not show similar response. The impact of the controlled factors and their combinations was higher on $k_a$ than BD. Indeed, air permeability is reported to be highly sensitive to macroporosity and pore continuity, and the change in pore continuity exceed the change in pore volume (Chen et al., 2014; Dörner and Horn, 2009). The present results agree with Tuli et al. (2005) showing the greatest effect of structural disturbance on air permeability. The increase of $k_a$ with the increase soil working depth indicates that a deeper soil cultivation work can improve soil porosity and their continuity. Contrarily to what was expected, the increase of inflation pressure did not lead to neither decrease $k_a$ via the decrease of soil-tire contact area, nor showing significant increase of BD. This could be attributed to probable beneficial effect of soil compaction after deep tillage of the soil, under which aggregate stability, as determinant factor of soil permeability, can be degraded (Cavalieri et al., 2009; Tuli et al., 2005). Both, BD and $k_a$ were influenced by the combinations of the controlled factors, and the augmentation of $R^2$ when the treatment was applied as single body factor may explain that the four adjustable parameters interact between them and act to explain the variation in the soil properties. This support our hypothesis that to reduce soil compaction on

seedbed, a tractor-tire-tool system should be adjusted as an entire system rather to treat each parameter in solo. For instance, the reduction of soil structural deformation via adjustments on inflation pressure is well documented (see as example: Douglas et al., 1992; Keller, 2005; Raper, 2005; Schjønning et al., 2008; Schwanghart, 1991), but rarely the distribution of axle load between rear and front axles was reported in the considered researches. Our findings show that the distribution of axle load between rear and front axle is an important factor to reduce soil deformation, though its effect appears when it is coupled with adjustments of other factors. As an example, the increase of BD with the combination of unequal axle load distribution, tractor speed and soil working depth, can be explained by the combined effect of the higher load on the rear axle and the deeper soil work on the traction which may increase slip and increase soil compaction (Janulevičius and Damanauskas, 2015). This result is consistent with Çarman (1994) who found that tire load has higher effect than tractor forward velocity on soil cone index, shear strength and bulk density. The increase of $k_a$ with the previous combination may be justified by an increase of soil microporosity (Dickerson, 1976) increasing air diffusion. Even though, the increase of inflation pressure showed a positive effect on $k_a$, it decreased when inflation pressure joined the combination mentioned above. This suggests that the obtained improvement of pore continuity and connectivity can be disadvantaged by the decrease of soil-tire contact area and related closer to the inflation pressure than the other factors.

The controlled factors affected the crop yield and seedling of barley. Their effect appeared clearly when they were analyzed as a single factor (i.e. treatment) by the increase of $R^2$ of the regression models for the count of emerged plant and crop yield. The two models showed that about 50% of the variation of crop yield and emergence of barley is explained by the treatment as a single factor. However, there was no one evident effect of the controlled factors and their combinations on these two indicators. The principle component analysis (PCA) showed a positive correlation between crop yield and air permeability, as well as a negative correlation

between emergence of barley and bulk density (figure 4). Consequently, the compression of soil porosity impedes barley seedling, but the increase of air permeability benefits the growth of barley leading to a greater yield. Thus, the impact of the controlled factors on soil physical properties leads to influence indirectly plant seedling and crop yield.

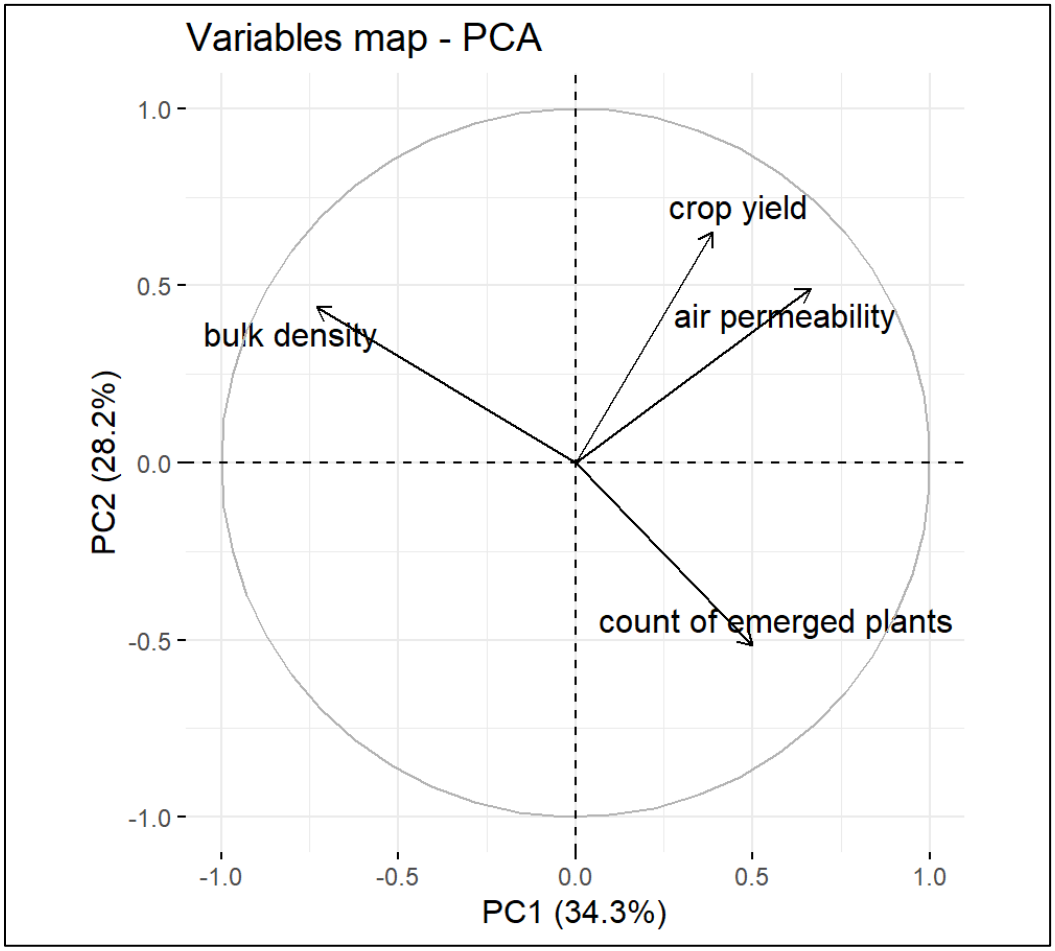


*Figure 4: Principal Component Analysis on the agronomic performance indicators*

A fully sufficient agronomical performance could be obtained without introducing damage on soil physical properties disturbing soil aeration to obtain a favorable seedling and crop yield (Tang et al., 2011). The treatments identified as agronomically performing are the ones showing higher $k_a$, lowest BD, higher crop yield and higher count of emergence plant. The fully agronomical performing treatments are T03, T04, T09, T10, T11, T14, T15, T16 (see table AII-I in appendix II for the details of the treatment combinations). We remark that the agronomically performing treatments belong to the equal distributed axle load. This result probably

demonstrates better distribution of stress on the soil when the load is equally distributed between rear and front axle, leading to a lesser disturbance of soil structure, and therefore, improving agronomical production.

## 4.2 Influence of adjustable parameters on the energetical performance

Our findings show the decrease of fuel consumption when the axle load was equally distributed. They are consistent with previous studies showing the increase of fuel consumption with the increase of tillage depth (named as soil working depth in the present study) and tractor speed (Mamkagh, 2018). Even though, there was no significant effect of inflation pressure solely on fuel consumption. Inflation pressure has the power to significantly decrease fuel consumption when it is combined to tractor speed or unequal axle load distribution. In contrast, when soil working depth is added to these two combinations, fuel consumption increases significantly. The slight decrease of fuel consumption with the increase of tractor speed, shown in figure 3, is induced by the effect of the combination of tractor speed, soil working depth and axle load distribution. This combination showed a significant effect on decreasing fuel consumption when soil working depth decreases and the axle load is equally distributed. Thus, an evident higher effect of the working depth and axle load distribution compared to tractor speed on fuel consumption is found. To better explain the variation of fuel consumption, tractor pull was also examined through the same data analyses performed for fuel consumption. Regarding the variation of tractor pull in function of the continuous speed of tractor and categorized with respect to the soil working depth and axle load distribution, we observed almost a similar relationship compared to fuel consumption, but inversely related to the tractor speed (see figure AI-1 in appendix I). Fuel consumption and total tractor pull were correlated ($\rho = 0.47$, p-value $< 0.001$), and these two variables depend on the variation of the controlled factors and their combinations. Otherwise, the factors and their combinations that influenced significantly fuel consumption showed significant influences on tractor pull. Running a Granger-Causality test to

investigate whether tractor pull is useful for forecasting fuel consumption or not, we found that tractor pull significantly Granger-causes fuel consumption (F-value = 32.1, p-value < 0.001). For instance, the lower tractor pull was found with the combination showed the lower fuel consumption (see figure 3 and figure AI-1 in appendix I).

Similarly to what we found studying the agronomical performance for the tractor-tire-tool system, the augmentation of $R^2$ when we applied the treatment as single body factor may explain that the four adjustable parameters interact between them and act as a combination to explain the variation of the energetical performance. The energetical performance must compromise between efficient tractor pull (i.e. higher tractor pull) and the lower fuel consumption. Means of tractor pull were compared using Duncan post-hoc test following ANOVA analysis of variance, then they were compared referring to the median of tractor pull (13 KN). When a tractor pull is significantly equal or higher than this median, the tractor power of the treatment is considered efficient. Several treatments showed an efficient tractor pull and lower fuel consumption, including the treatments showed high fuel consumption. The energetically performant treatments are those showed optimal fuel consumption and efficient tractor pull. Consequently, a total of 17 treatments (T01, T02, T04, T06, T07, T08, T16, T17, T18, T20, T22, T23, T25, T29, T31, T32, T33) are considered as energetically performant.

## 4.3 Trade-off between the agronomical performance and the energetical performance

Even though, the agronomical performance and the energetical performance could not be correlated, the adjustable parameters on a tractor-tire-tool system influence them both. The studied adjustable parameters on a tractor-tire-tool system (i.e. tractor speed, inflation pressure, ale load distribution and soil working depth), shown as treatment, to affect, both, the energetical and the agronomical performances. Thus, the adjustment on a tractor-tire-tool system should

consider all these four factors as a combination to optimize the performance energetically and agronomically. A trade-off between the optimization of these performances could be obtained considering the common treatments as energetically and agronomically performant in the present paper. This trade-off can be obtained with T04 and T16, so applying an equal axle load distribution, 10 cm of soil working depth, and accelerating tractor speed at 14 km/h combined to 80 kPa or 140 kPa of inflation pressure.

# 5 Conclusion

The present paper presents the first study showing the combined effect of adjustable parameters, in a tractor-tire-tool system, on soil conservation, agronomical production, and energy optimization. Our study showed that the combination between tractor speed, axle load distribution, soil working depth and inflation pressure could be adjusted in a simple way by the operator to optimize the energetical and agronomical performances. We found that pore continuity is more sensitive than pore space to the variation of the adjustable parameters in tractor-tire-tool system. Fuel consumption depends on the variation of the adjustable parameters and their combinations. The agronomical performance, revealed by barley successful seedling, barley yield, and the conservation of physical soil properties on seedbed, as well as the energetical performance, revealed by the optimization of fuel consumption, depend on the combination of the studied adjustable parameters shown as treatment. Equally distributing the axle load on the rear and the front axle may lead to better agronomical and energetical performances. The trade-off between an agronomical performance and an energetical performance, for a tractor-tire-tool system carrying out a sowing operation of spring barley on a silty loam Luvisol with an average of gravimetric water content of 23.4% , can be obtained, equally distributing the axle load distribution, working the soil at 10 cm of depth, and accelerating tractor speed at 14 km/h combined to 80 kPa or 140 kPa of inflation pressure. We

state that the present work shows the results of an experiment conducted on one site with specific soil conditions and over one season of an agricultural year. Therefore, as perspectives, complementary studies will take place over other season (some of them are conducted) and on other conditions, which they will support the finding presented in this manuscript.

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# 7 Conflict of interest

The authors declare no conflict of interest.

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672

# Appendix I

Table AI-I: Descriptive of the regression model of soil bulk density as response variable to the controlled factors as explanatory variables and their combinations and the descriptive statistics of its analysis of variance (ANOVA). Significance is required at level of p-value ≤0.05

| | Regression model | | One-way ANOVA | |
|---|---|---|---|---|
| Factor | coefficient estimate | t value | F value | p-value |
| Intercept | -2420.1585 | -1.104 | | |
| axle load distribution | 47.56 | 1.2 | 0.4341 | 0.51088 |
| tractor speed | 194.6304 | 1.076 | 1.1436 | 0.28642 |
| soil working depth | 259.5075 | 0.945 | 1.0241 | 0.31299 |
| inflation pressure | 1362.7166 | 0.687 | 0.1555 | 0.69385 |
| axle load distribution*tractor speed | -3.7847 | -1.156 | 0.6287 | 0.42895 |
| axle load distribution*soil working depth | -4.9872 | -1.001 | 0.0363 | 0.84906 |
| tractor speed*soil working depth | -19.4962 | -0.862 | 1.2033 | 0.27423 |
| axle load distribution*inflation pressure | -26.6938 | -0.744 | 0.6164 | 0.43348 |
| tractor speed*inflation pressure | -105.3601 | -0.642 | 0.7889 | 0.37571 |
| soil working depth*inflation pressure | -131.7564 | -0.532 | 0.046 | 0.83038 |
| axle load distribution*tractor speed*soil working depth | 0.3747 | 0.912 | 3.9665 | 0.04802 |
| axle load distribution*tractor speed*inflation pressure | 2.0643 | 0.695 | 0.6699 | 0.41422 |
| axle load distribution*soil working depth*inflation pressure | 2.5349 | 0.564 | 0.4857 | 0.48683 |
| tractor speed*inflation pressure*soil working depth | 9.1423 | 0.447 | 0.0908 | 0.7635 |
| axle load distribution*tractor speed*soil working depth*inflation pressure | -0.1769 | -0.447 | 0.2271 | 0.63429 |

Table AI-II: Descriptive of the regression model of air permeability (*ka)* as response variable to the controlled factors as explanatory variables and their combinations and the descriptive statistics of its analysis of variance (ANOVA). Significance is required at level of p-value ≤0.05.

| | Regression model | | One-way ANOVA | |
|---|---|---|---|---|
| Factor | coefficient estimate | z value | F value | p-value |
| Intercept | -71.127679 | -2.976 | | |
| axle load distribution | 1.469154 | 3.386 | 3.3941 | 0.06 |
| tractor speed | 8.058658 | 1.095 | 0.0591 | 0.8 |
| soil working depth | 6.322077 | 2.042 | 6.9021 | 0.008 |
| inflation pressure | 84.263647 | 3.778 | 9.0476 | 0.003 |
| axle load distribution*tractor speed | -0.158306 | -4.428 | 0.0015 | 0.97 |
| axle load distribution*soil working depth | -0.120532 | -2.158 | 8.3178 | 0.003 |
| tractor speed*soil working depth | -0.721726 | -2.842 | 14.6787 | 0.0001 |
| axle load distribution*inflation pressure | -1.668115 | -4.135 | 38.1062 | < 0.001 |
| tractor speed*inflation pressure | -8.616875 | -4.717 | 54.8486 | < 0.001 |
| soil working depth*inflation pressure | -8.083682 | -2.784 | 29.5376 | < 0.001 |
| axle load distribution*tractor speed*soil working depth | 0.013822 | 3.014 | 13.6397 | < 0.001 |
| axle load distribution*tractor speed*inflation pressure | 0.169227 | 5.129 | 23.782 | < 0.001 |
| axle load distribution*soil working depth*inflation pressure | 0.154501 | 2.955 | 31.2684 | < 0.001 |
| tractor speed*inflation pressure*soil working depth | 0.828213 | 3.488 | 6.1723 | 0.01 |
| axle load distribution*tractor speed*soil working depth*inflation pressure | -0.015923 | -3.724 | 13.9243 | < 0.001 |

Table AI-III: Descriptive of the regression model of the count of emerged plant as response variable to the controlled factors as explanatory variables and their combinations and the descriptive statistics of its analysis of variance (ANOVA). Significance is required at level of p-value ≤0.05.

| | Regression model | | One-way ANOVA | |
|---|---|---|---|---|
| Factor | coefficient estimate | t value | F value | p-value |
| Intercept | 1096.29412 | 2.289 | | |
| axle load distribution | -20.66779 | -2.373 | 1198.8177 | < 0.001 |
| tractor speed | -67.23739 | -1.69 | 0.0021 | 0.96 |
| soil working depth | -783.98693 | -1.804 | 7.9275 | 0.005 |
| inflation pressure | -126.67311 | -2.03 | 0.5992 | 0.44 |
| axle load distribution*tractor speed | 1.34237 | 1.853 | 0.2026 | 0.65 |
| axle load distribution*soil working depth | 15.64402 | 1.982 | 0.4774 | 0.49 |
| tractor speed*soil working depth | 49.94223 | 1.386 | 1.9705 | 0.16 |
| axle load distribution*inflation pressure | 2.46372 | 2.158 | 0.176 | 0.66 |
| tractor speed*inflation pressure | 8.53557 | 1.635 | 0.6332 | 0.43 |
| soil working depth*inflation pressure | 100.26564 | 1.785 | 0.8358 | 0.36 |
| axle load distribution*tractor speed*soil working depth | -1.01015 | -1.542 | 0.1815 | 0.67 |
| axle load distribution*tractor speed*inflation pressure | -0.16788 | -1.753 | 2.3595 | 0.12 |
| axle load distribution*soil working depth*inflation pressure | -1.95777 | -1.911 | 11.7516 | < 0.001 |
| tractor speed*inflation pressure*soil working depth | -6.39916 | -1.366 | 1.404 | 0.24 |
| axle load distribution*tractor speed*soil working depth*inflation pressure | 0.12673 | 1.48 | 2.1907 | 0.14 |

Table AI-IV: Descriptive of the regression model of crop yield as response variable to the controlled factors as explanatory variables and their combinations and the descriptive statistics of its analysis of variance (ANOVA). Significance is required at level of p-value ≤0.05.

| | Regression model | | One-way ANOVA | |
|---|---|---|---|---|
| Factor | coefficient estimate | t value | F value | p-value |
| Intercept | 298.56431 | 0.275 | | |
| axle load distribution | -4.48587 | -0.222 | 0.0127 | 0.91 |
| tractor speed | 5.50072 | 0.059 | 1.9101 | 0.17 |
| soil working depth | -68.03469 | -0.74 | 0.6039 | 0.44 |
| inflation pressure | 101.85032 | 0.096 | 2.1096 | 0.15 |
| axle load distribution*tractor speed | -0.09509 | -0.054 | 0.2229 | 0.64 |
| axle load distribution*soil working depth | 1.44673 | 0.541 | 0.003 | 0.96 |
| tractor speed*soil working depth | 2.59027 | 0.207 | 1.0844 | 0.30 |
| axle load distribution*inflation pressure | -1.98357 | -0.1 | 0.0176 | 0.89 |
| tractor speed*inflation pressure | -33.18263 | -0.359 | 3.2114 | 0.07 |
| soil working depth*inflation pressure | 23.39295 | 0.166 | 0.7032 | 0.40 |
| axle load distribution*tractor speed*soil working depth | -0.06162 | -0.262 | 1.9576 | 0.17 |
| axle load distribution*tractor speed*inflation pressure | 0.63508 | 0.718 | 1.8725 | 0.17 |
| axle load distribution*soil working depth*inflation pressure | -0.55876 | -0.21 | 5.4257 | 0.02 |
| tractor speed*inflation pressure*soil working depth | 1.13126 | 0.09 | 0.2011 | 0.65 |
| axle load distribution*tractor speed*soil working depth*inflation pressure | -0.01301 | -0.054 | 0.003 | 0.96 |

Table AI-V: Descriptive of the regression model of fuel consumption as response variable to the controlled factors as explanatory variables and their combinations and the descriptive statistics of its analysis of variance (ANOVA). Significance is required at level of p-value ≤0.05.

| | Regression model | | One-way ANOVA | |
|---|---|---|---|---|
| Factor | coefficient estimate | t value | F value | p-value |
| Intercept | -78.4 | 44.69 | | |
| axle load distribution | 1.669 | 0.7983 | 104.1911 | < 0.001 |
| tractor speed | 4.319 | 3.902 | 158.4399 | < 0.001 |
| soil working depth | 2.941 | 6.368 | 104.857 | < 0.001 |
| inflation pressure | 91.64 | 43.49 | 1.6555 | 0.198885 |
| axle load distribution*tractor speed | -91.45 | 0.06965 | 0.7545 | 0.385527 |
| axle load distribution*soil working depth | -0.06271 | 0.1124 | 1.7052 | 0.192282 |
| tractor speed*soil working depth | -0.05395 | 0.5676 | 6.7989 | 0.009428 |
| axle load distribution*inflation pressure | -1.774 | 0.7658 | 19.8829 | < 0.001 |
| tractor speed*inflation pressure | -5.52 | 3.834 | 4.2082 | 0.040813 |
| soil working depth*inflation pressure | -4.75 | 6.517 | 2.4127 | 0.121065 |
| axle load distribution*tractor speed*soil working depth | 0.000265 | 0.01002 | 15.7643 | < 0.001 |
| axle load distribution*tractor speed*inflation pressure | 0.11 | 0.06772 | 5.7153 | 0.017233 |
| axle load distribution*soil working depth*inflation pressure | 0.102 | 0.1143 | 22.386 | < 0.001 |
| tractor speed*inflation pressure*soil working depth | 0.148 | 0.5868 | 3.9397 | 0.047773 |
| axle load distribution*tractor speed*soil working depth*inflation pressure | 0.00428 | 0.01029 | 0.1733 | 0.67739 |

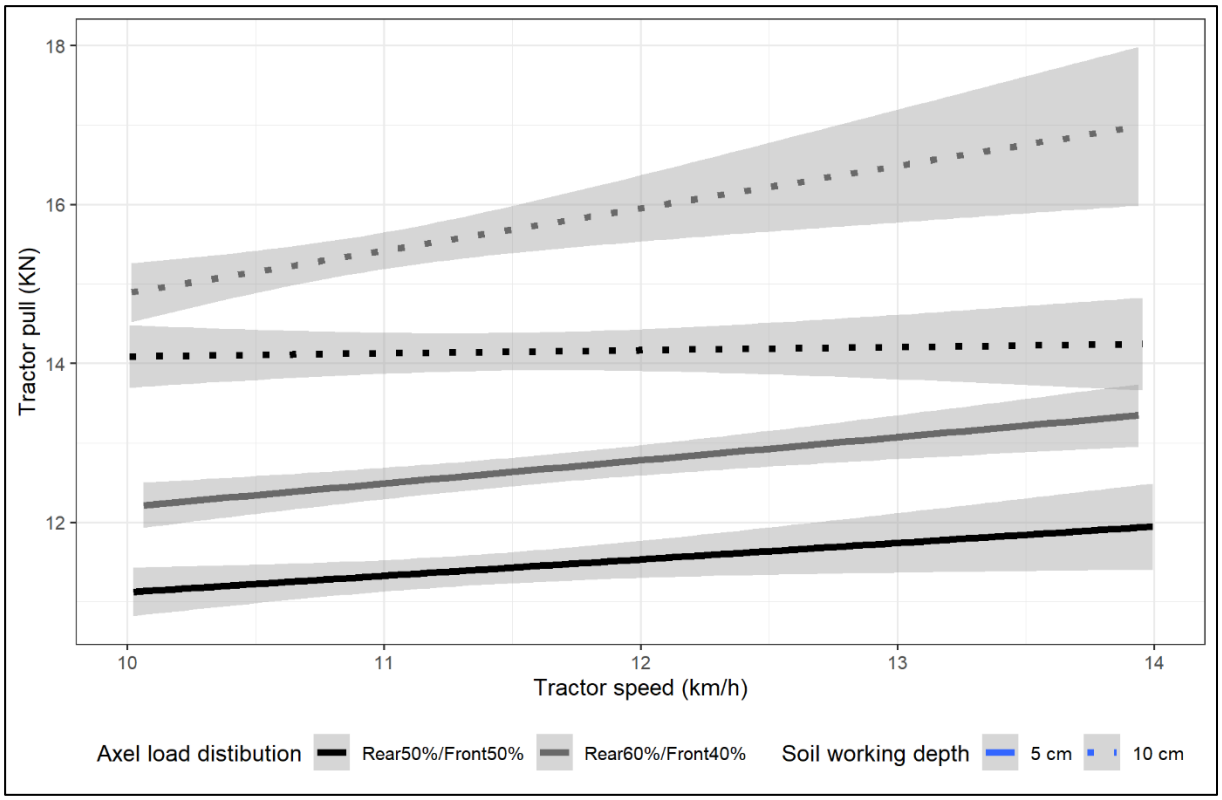


Figure AI-I: Variation of tractor pull (KN) in function to the continuous tractor speed and categorized with respect to soil working depth (line type) and axle load distribution (line color).

# Appendix II

| Treatment | Axel load distribution (rear axle/front axle) | Tractor speed (km/h) | Inflation pressure (kPa) | Soil working depth (cm) |
|---|---|---|---|---|
| **T01** | 50%/50% | 14 | 140 | 5 |
| **T02** | 50%/50% | 12 | 140 | 5 |
| **T03** | 50%/50% | 10 | 140 | 5 |
| **T04** | 50%/50% | 14 | 140 | 10 |
| **T05** | 50%/50% | 12 | 140 | 10 |
| **T06** | 50%/50% | 10 | 140 | 10 |
| **T07** | 50%/50% | 14 | 100 | 10 |
| **T08** | 50%/50% | 12 | 100 | 10 |
| **T09** | 50%/50% | 10 | 100 | 10 |
| **T10** | 50%/50% | 14 | 100 | 5 |
| **T11** | 50%/50% | 12 | 100 | 5 |
| **T12** | 50%/50% | 10 | 100 | 5 |
| **T13** | 50%/50% | 14 | 80 | 5 |
| **T14** | 50%/50% | 12 | 80 | 5 |
| **T15** | 50%/50% | 10 | 80 | 5 |
| **T16** | 50%/50% | 14 | 80 | 10 |
| **T17** | 50%/50% | 12 | 80 | 10 |
| **T18** | 50%/50% | 10 | 80 | 10 |
| **T19** | 60%/40% | 14 | 140 | 5 |
| **T20** | 60%/40% | 12 | 140 | 5 |
| **T21** | 60%/40% | 10 | 140 | 5 |
| **T22** | 60%/40% | 14 | 140 | 10 |
| **T23** | 60%/40% | 12 | 140 | 10 |
| **T24** | 60%/40% | 10 | 140 | 10 |
| **T25** | 60%/40% | 14 | 100 | 10 |
| **T26** | 60%/40% | 12 | 100 | 10 |
| **T27** | 60%/40% | 10 | 100 | 10 |
| **T28** | 60%/40% | 14 | 100 | 5 |
| **T29** | 60%/40% | 12 | 100 | 5 |
| **T30** | 60%/40% | 10 | 100 | 5 |
| **T31** | 60%/40% | 14 | 80 | 5 |
| **T32** | 60%/40% | 12 | 80 | 5 |
| **T33** | 60%/40% | 10 | 80 | 5 |
| **T34** | 60%/40% | 14 | 80 | 10 |
| **T35** | 60%/40% | 12 | 80 | 10 |
| **T36** | 60%/40% | 10 | 80 | 10 |

Table AII-I: the configuration of the combinations between the adjustable parameters (controlled factors).