Czech University of Life Sciences in Prague

Faculty of Engineering

ANALYSIS OF TELEMATICS SYSTEMS IN AGRICULTURE

BY

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UNDER SUPERVISION

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A Thesis

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DIPLOMA THESIS ASSIGNMENT

Mohamed Ahmed Khaled Abd El-Wahab

Thesis title

Analysis of telematic systems in agriculture

Objectives of thesis

Analysis of telematic systems on the market from the viewpoint of hardware and software design and of information efficiency, demonstrated by employment analysis of chosen farm machinery.

Methodology

Methods of current state analysis. Methods of telematic system comparison according to selected criteria. Methods of statistical data analysis.

Outline of the structure

1. Introduction
2. Literature search (telematics; precision agriculture, characteristics of farm machinery employment – time structure, workrate etc.)
3. Objectives and methodology
4. Results and discussion (overview of telematic systems on the market; comparison of characteristics, employment analysis of chosen farm machinery)
5. Conclusions

The proposed extent of the thesis
cca 55 pages

Keywords
telematics, telematic system, farm machinery, GPS, workrate analysis

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Recommended information sources

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LANDERS, A.: Resource Management. Farming Press, 2002, 160 pp. ISBN 9780852365403.

SRINIVASAN, A. Handbook of Precision Agriculture: Principles and Applications. Food Products Press, 2006. 683 pp. ISBN 978-1560229551.

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STATUTORY DECLARATION:

I hereby certify that I have elaborated my thesis independently, only with the expert guidance of my supervisor doc. Ing. Petr Šařec, Ph.D.

I further declare that all data and information I have used in my thesis are stated in the reference.

In Prague ………… ....……...…………………………

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ABSTRACT:

The improving of the agricultural machinery efficiency is the simplest way to optimize the costs of the agricultural operations and maximize the profitability. In the other case the good management may reduce the environmental impact. The employment of the up-to date technologies achieves those goals by collecting the information and by using it for improving the machines productivity. Precision agriculture facilitates the ways to improving the productivity, reducing the demands of the chemicals and fertilizers and reducing the breakdown risks, monitoring and mapping systems is a part of precision agriculture which can be used to predict the farm demands to the chemicals and fertilizers. The using of machine performance data is one of the most important steps to the good management of the machine it cause to reduce the operating costs. Telematics system is the simplest way to collect data from the machines and distribute it to the places of the managers by using a combination of the sensors, positioning system, telecommunication technologies and a way of processing these data. Within this study, data has been collected from John Deere telematics system site and used it side by side with the data records from the farm which are collected manually by the farm manager. The study compared the performance and utilization data between four types of tillage tools.

Keywords: Precision agriculture; Telematics systems; Tractor performance; machinery management; Tillage systems; tillage power requirements.

ČESKÝ ABSTRAKT:

Zlepšování parametrů nasazení zemědělských strojů je nejjednodušší způsob, jak optimalizovat náklady v zemědělských provozech a maximalizovat ziskovost. Dále může dobré vedení snížit dopady na životní prostředí. Využití moderních technologií umožňuje dosáhnout těchto cílů tím, že jsou automaticky sbírány informace a používány pro zlepšování produktivity stroje. Precizní zemědělství usnadňuje způsoby, jak zvýšit produktivitu, snížit spotřebu chemikálií a hnojiv, snížit riziko prostojů. Monitorování a mapování systémů je součástí precizního zemědělství, které může být použito k předpovědi potřeby chemických látek a hnojiv. Použití údajů o výkonnosti mechanizace je jedním z nejdůležitějších kroků k řádnému řízení jejího nasazení a k snižování operativních nákladů. Telematický systém je nejjednodušší způsob, jak sbírat data o nasazení mechanizace a šířit vedoucím pracovníkům pomocí kombinace snímačů, navigačního systému, telekomunikačních technologií a softwaru určenému ke zpracování těchto údajů. V rámci této práce byla sbírána data z telematického systému firmy John Deere a použita bok po boku se záznamy ze zemědělského, která jsou vedeny pověřeným mechanizátorem. Studie porovnávala výkonnost a využití dat mezi čtyřmi typy strojů pro zpracování půdy.

Klíčová slova: precizní zemědělství; telematické systémy; výkonnost; management mechanizace; systémy zpracování půdy; tahové požadavky.

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1. INTRODUCTION

Agricultural engineering is a branch of engineering which is interested in the environmental sciences. From many years the main points of agricultural engineering researchers are how to reduce the cost of the different agricultural productions and how to increase the system efficiency, good management can achieve these goals.

The most of agricultural field operations are accomplished by using the combination of Tractor and implement. The quality of work and the output of a tractor-implement combination relies heavily upon the skill and concentration of the operator (Scarlett, 2001). Best farm management can achieve the manager targets (reducing the cost as much as possible and increasing the profit) and the environmental target (reducing the chemical and fertilizer remaining amount in the environment and plant and reducing the greenhouse gases emissions.

The effectiveness of the mechanization policy is determined by the management skill in matching the work output of the power and machinery complement to the time available at an acceptable level of fixed and operating costs (Witney, 1988). The choosing of the size for tractor-implement combination has complicated procedures. The fall using of the total tractor power is so comfort for reducing the costs, so that the manager should choose the suitable implement which can utilize the most of the tractor power during its function, as well the tractor implement combination must be not so large to effect on the soil properties. In the other case the tractor power should be enough to the draught requirements to the farm which is evaluated by the power demand for the primary tillage operation.

The recording system for the machine performance parameter is very important for the farm machinery management. It can increase the productivity, improve safety, and reduce costs for many agricultural operations (Stentz et al., 2002). As well the recording of the machine data such as working time, working speed, exact place, and the other machine behavior can be evaluate the operator and the machine efficiency if its behavior is going well or it needs to replace.

Telematics system is the simplest way for recording the data and the simplest way to access it. The system is present a lot of information about machine behavior, productivity and place. The reality of the obtaining data from the system is so high and it depends on the sensors calibration, so it gives the manager the real data without human error to make a true decision for his farm machinery.

This work is studying the tractor-tillage tools combination using the telematics system data to analyze the system performance.

2. LITERATURE SEARCH

2.1 Precision Agriculture and Telematics System:

Precision agriculture and telematics system is the simplest way to make a decision. In the following overview for these terms.

2.1.1 Precision agriculture:

The collecting real-time data on weather, soil and air quality, crop maturity, equipment, labor costs and availability, predictive analytics can be used to make the perfect decisions regard to planting, fertilizing and harvesting crops, this decision can be used to maximize food production, minimize environmental impact and reduce cost (IBM Research). The precision farming encourages the adoption of variable-rate application of nutrients and pesticides and promotes the use of Global Positioning System (GPS)-enabled precision agricultural technology and equipment (NRCS). Decision should be start from the moment of choosing the suitable seed in the given location according to the weather and location conditions, after this the decision will be around the fertilization and maintain the crops which is depending upon the weather data, then the decision will be around the harvesting and transporting to the distribution centers by using the weather and traffic data it can be reduced the losses of the crop because of the time and the temperature (IBM Research).

The information age brings the ability of integration between the technological advances into precision agriculture (Whelan et al., 1997). Precision agriculture is designed to reorganize the total system of agriculture towards a low-input, high-efficiency, sustainable agriculture (Shibusawa, 1998). The approach of the system is mainly benefits from the emergence and convergence of several technologies, including the GPS, geographic information system (GIS), miniaturized computer components, automatic control, in-field and remote sensing, mobile computing, advanced information processing, and telecommunications (Gibbons, 2000). success of precision agriculture technologies will have to be measured by economic and environmental gains (Zhang et al., 2002).

2.1.1.1 Spatial and temporal variability:

(Zhang et al., 2002) expressed 6 groups of variabilities which effect on the agricultural production, these groups is:

1. yield variability.
2. field topography variability.
3. soil variability including (fertility, physical properties, texture, mechanical strength, moisture content, EC, chemical properties-pH, organic matter, salinity, CEC, water holding capacity, hydraulic conductivity and soil depth).
4. Crop variability.
5. Variability of anomalous factors: such as weed infection, insect infection, nematode infection, disease infection, wind damage, and hay damage.
6. Management variability: including (Tillage practice, crop hybrid, crop seeding rate, crop rotation, fertilizer application, pesticide application, and irrigation pattern).

The yield variability is the most important one which is affected by the rest of them. The most variability-rate technology for chemical applications have been developed on nitrogen- fertilizer applications. The intensive precipitation monitoring across fields is important to assisting decision making for fertilizer applications (O'Neal et al., 2000).

2.1.1.2 Managing variability:

The variability can be managed by two approaches: map-based approach and sensor-based approach, using GPS, remote sensing, yield monitoring and soil sampling, this approach requires the some procedures such as grid sampling a field, performing laboratory analyzes of soil samples, generating a site-specific map and using this map to control a variable-rate applicator, positioning system is required for this approach (Zhang et al., 2002). The sensor-based approach measures the desired properties, such as soil and plant properties, using real-time sensors in an 'on-the-go' type and controls variable-rate applicator based on the measurements. For the sensor-based approach, a positioning device is often not necessary (Zhang et al., 2002). Most of the researchers in precision-agriculture field are studying are map-based systems, by the integration between the databases and GPS to make integrating maps derived from remote sensing, soil sampling, yield monitoring, and various sensors (Zhang et al., 2002).

2.1.1.2 Management zone:

A management zone is defined as a portion of a field that expresses a homogeneous combination of yield-limiting factors for which a single rate of a specific crop input is appropriate (Doerge, 1998).

2.1.1.3 Impact of precision agriculture:

There are two main sources of the impact, the first one is the profit to the producer and the second one is the environmental benifit (Zhang et al., 2002).

2.1.1.3.1 profitability:

Precision agriculture technology help the farmer to maximize the benefit of each operation by minimize the losses and maximize the advantages for each operation. These technologies provide farmers with opportunities of changing the distribution and timing of fertilizers and other agrochemicals based on spatial and temporal variability in a field (Zhang et al., 2002).

2.1.1.3.2 Environment:

The reduce usage of chemicals in the farms is an environmental target. Precision agriculture provides the means of precise and targeted application, recording of all field treatments at the meter scale, tracking from operation to operation, and transfer of recorded information with the harvested products (Zhang et al., 2002), the precision agriculture prcedures help the farmers to reduce the demans to the chemicals.

The availability of topographic data for fields implemented with PA technologies, the interaction between tillage and soil/water erosion can be examined and, thus, reduction in erosion can be achieved (Schumacher et al., 2000).

2.1.2 Telematics system:

Telematics (TELEcommunication and inforMATICS) techniques cover fields ranging from high-tech computing to communications and remote interactions between people, processes or equipment (Arnback,1987). (Heacox, 2008) defined telematics as the transmitting of data via wireless communication links. Telematics use sophisticated sensors to send on the information about tractor, forager or combine’s performance back to the farm office (Cousins, 2008). It is achieving the remotely connect owners and managers to their equipment, providing alerts and machine information including location, utilization, performance, and maintenance data to manage where and how equipment is being used (JD-Link).

The systems use cellular modems with embedded low-end GPS receivers to relay machine information via the Internet to a central server computer and any authorized person can access real-time location and current operations information with a smartphone or compute (Tractorlife).

2.1.2.1 System component:

Figure (2.1) present the main components of the system, (Santa et al., 2012) described the system and journey of the data from the vehicle to the monitoring center as written in the following. The main component is On-Board Unit (OBU). OBU is the most intelligent component in the system. It receives the information from the on-board sensors. The information about the location can be collect from the GPS based navigation system, and odometer is cassed means of an OBD (On-Board Diagnostics) interface. These information which is collected by OBU can be sent to the Distributed collection Logic, these data accessed by means GPRS (General Packet Radio Service) or UMTS (Universal Mobile Telecommunications System-3G), in case of the device is out of GPRS/UMTS coverage the system hold all of the data till the availability of send all of these data. All of the data which collect from several collection points can be distributed in the internet and they share a synchronized database which stores the data for each operating time. Then the monitoring center accesses this data to present it to the operators and users. All the procedures carried out at the core infrastructure including the data filteration processing. The next stage is to present more informations about the design and operation details for the most important parts and describing the developed prototype. Figure (2.2) shows the data flow chart.

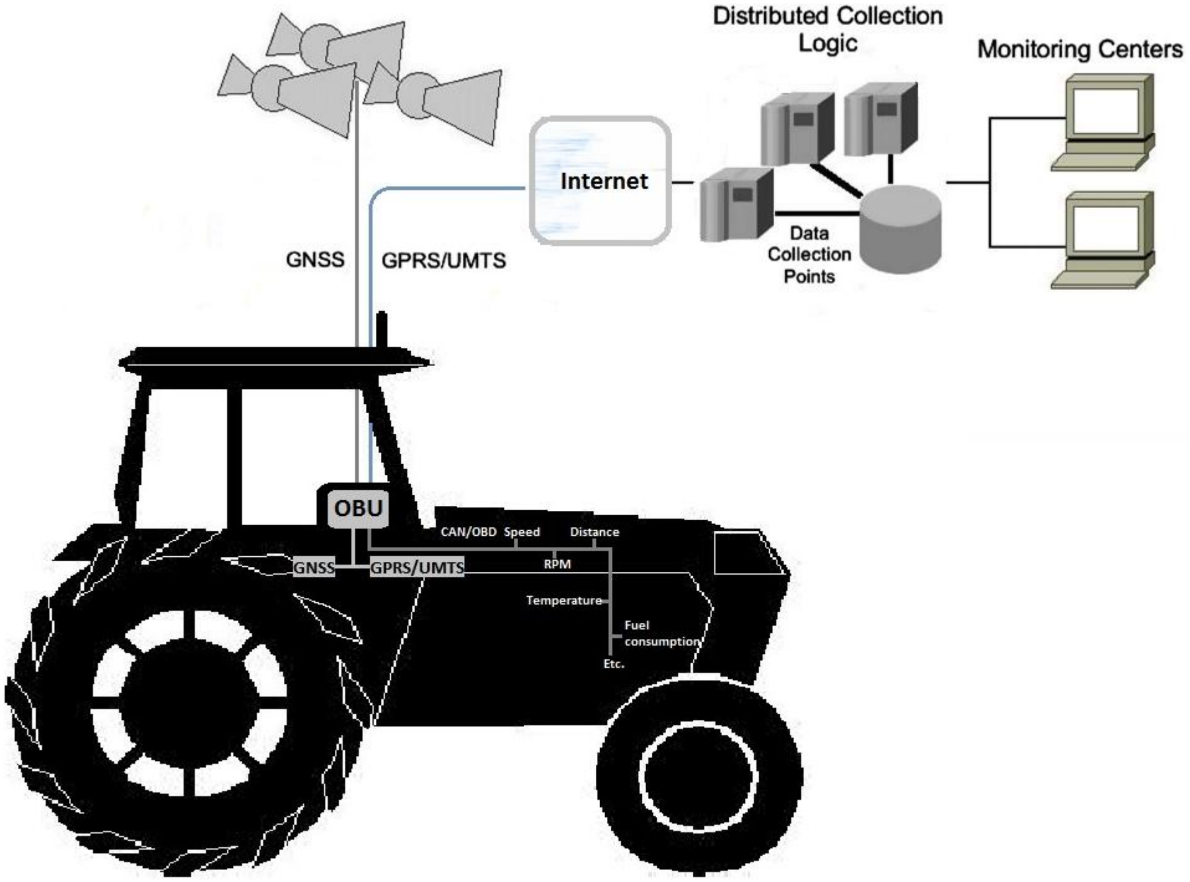


Figure (2.1): Telematics system components (Santa et al., 2012), edited by author.

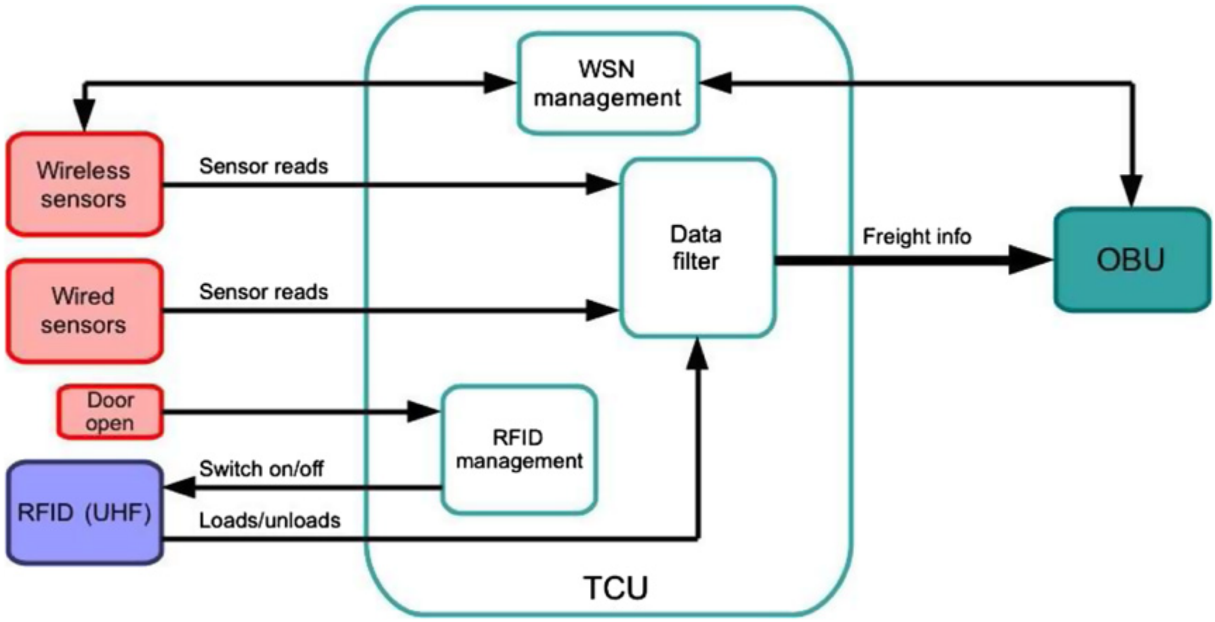


Figure (2.2): Data flow chart [first processing stage] (Santa et al., 2012).
RFID is Radio Frequency IDentification; WSN is the Wireless Sensor Network

2.1.2.1.1 Navigation system:

The vehicle comprises a recent ambit where new Information and Communication Technologies (ICTs) have been applied in the recent years (Giannopoulos, 2004). Many commercial products and adhoc solutions have been developed for improving fleet management in logistics companies. These systems are mainly based on two technologies: GPS and GSM (Global System for Mobile Communications) (Santa et al., 2012). The navigation and cellular communication technologies are considering as only solution for terrestrial vehicles as based in the research of (Sadoun and Al-Bayari, 2007). A hypbrid navigation system has been designed to provide location information even under periods of Global Navigation Satellite System (GNSS) signal obstruction. This navigation system integrates information from the GPS receiver, odometer, and intrial sensors (gyroscope and accelerometer), by means of an Extended Kalman Filter (Santa et al., 2012)

2.1.2.2 Examples of the telematics from different companies:

There are different companies introduce the telematics serveces in agricultural field. Those companies have a different styles. In the following subsections overview for this companies.

2.1.2.2.1 John Deere Telematics (JD-Link):

JD-Link is a tools to facilitate the equipment management by the telematics system. JD-Link telematics designed to remotely connect owners and managers to their equipment, provided alerts and machine information such as the location, performance, maintenance date, and how the implement is utilizing. JDLink select provides everything that Express does, plus advanced geofencing. This product will also support sensor installation to monitor custom information such as: fuel consumption, loss of engine oil pressure, engine over temperature, and air filter restrictions.

JD-Link gives the customers information about what percentage of their machine hours are spent idling instead of working. It also provides critical system temperatures and/or pressures for machine-specific applications including hydraulics, transmissions, and coolant. Ultimate also provides low fuel level warnings, dashboard alerts, idle time and low-load, medium-load and high-load work levels giving equipment managers better visibility to machine problems. Both dashboard alerts and low fuel level warnings can be accessed on the internet or sent directly to a customer’s cell phone, pager, or e-mail address.

JD-Link uses a communications modem/controller, GPS and cellular antennas, and harnesses installed in a machine to send machine data to the JD-Link data server. This machine data can be obtain through the website.

2.1.2.2.2 CLAAS Telematics:

Claas company used telematics system with the combine harvester to compare the performance of the combine under all conditions every day(CLAAS). User can obtain the data from the internet. A report with operating time analysis with other important characteristics of the equipment are sent via e-mail each day to facilitate the analysis of the machine performance and to give an information about how efficiency the combine. As well it gives the manager the working tracks information for helping him to achieve the obtimum logistics transportation. The system helps the users to facilitates systematic fleet management and avoids unprofitable idle time.

Claas telematics can give the user the important data which is helped the user to obtimize his requirements and maximize his profit this data can be shown by access the (claas telematics) using demo user name and password includes.

1. Work hour analysis:
    - Total time [Duration] Total time [Percentage]
    - Other time [Duration]Other time [Percentage]
    - Engine Off [Duration]
    - Engine Off [Percentage]
    - Process time with PTO shafts on [Duration]
    - Process time with PTO shafts on [Percentage]
    - Process time with front PTO shaft on [Duration]
    - Process time with front PTO shaft on [Percentage]
    - Process time with rear PTO shaft on [Duration]
    - Process time with rear PTO shaft on [Percentage]
    - Process time [Duration]
    - Process time [Percentage]
    - Transport time [Duration]
    - Transport time [Percentage]
    - Idle [Duration]

- Idle [Percentage]

2. Actual Value map:
    - Engine load.
    - Fuel consumption.
3. Harvest report.
4. Performance analysis (Charts)
5. Counter status.
6. Alarm messages.
7. Maintenance messages including machine status, GPS longitude and latitude, working hour and service counter
8. Operating status including the last measurements, parameter, working hours, alarm and maintenance messages, and status and diesel tank level.
9. Tracking and mapping including the remote tracking, track in Google earth, online tracking.

The data collected is sent to the telematics web server at regular intervals via the cellphone network. This enables you or an authorized service partner to access and evaluate the relevant information via the internet.

2.1.2.2.3 Topcon Tierra:

Tierra intrduce remote asset management, tracking, monitoring, reporting and telemetry solutions, that help the manager to improve the performance of his work (Topcon Tierra).

The company offers tools to facilitate the central management for all assets from one website.

<u>The benefits of the company is:</u>

- Save on fuel costs and reduce emissions by monitoring and managing excessive idling.
- Maximize equipment deployment and utilization.
- Minimize losses due to theft or unauthorized equipment use.
- Respond to maintenance issues only when there is a need.
- Optimize productivity and reduce job costs.

2.1.2.2.4 AGCO:

Introduce a telematics system to get real time access to the information about the machine to help the manager to improve the performance, productivity and profitability (AGCO).

The service is provides through wireless modem and computer access for many different important information about the machine. That kind of data is:

1. The state of motor.
2. Vehicle position.
3. Machine utilization time rtc.,

All of these data are sent through wireless modem or GSM and its working by using any device can be connected with the internet. The system send the alerts to the phone or email including the variety of situations.

<u>The benefits of the system is:</u>

- Access to near real-time access to valuable information about machines.
- Increased machine productivity and operator.
- Availability of critical information on the state of the machine, helping to achieve maximum uptime.
- Minimize downtime through rapid information service personnel.
- E-mail alerts or warnings via SMS when unusual activity Machines.
- Simple planning and management of vehicle maintenance.
- Fully automatic recording and transmission of data.

2.1.2.2.4 Wyle:

Is industry producer telemetry data processing equipment (Wyle). The systems and applications which introduce by Wyle is:

1. Systems:
    a. RF Receivers.
    b. Data recorders and reproducers.
    c. System integration.

    d. Real time display software.
    e. Data mining software.
    f. Best source selection.
2. Applications
    a. Flight Test Ground Stations.
    b. Satellite Control Networks.
    c. Flight Line Checkout Systems.
    d. Rocket Launch Control Systems.
    e. Software Test and Integration Labs (STIL).
    f. Airborne Recorders.
    g. Mobile Ground Station Systems.
    h. Hot Mic Audio Distribution.

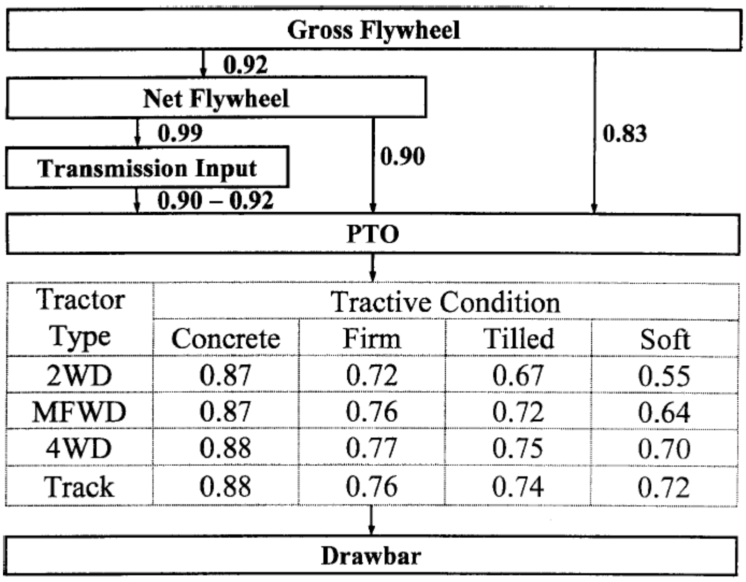
2.2 Tractor and Tractive Performance:

Tractor power used in two ways by transmitting the engine power through driving wheels as traction to provide the drawbar power requirement to pull implement, and through the power take-off shaft, as well through the hydraulic system; to provide mobile support for attached machine. Tractive is essential for heavy draught operations, such as ploughing, and this drawbar power is an indicator for the total tractor power requirement on the arable farm (Witney, 1988).

2.2.1 Tractor performance:

Drawbar performance of tractors depends primarily on engine power, weight distribution on drive wheels, type of hitch, and soil surface. Maximum tractive efficiency, TE, is optimized by compromising drive wheel slip, s, and motion resistance, MR (ASABE D497, 2011). Figure (2.3) shows the typical power relationships for the tractors with the required operating speed in the load status. The methodology for predicting tractor performance based on drawbar performance for 4WD tractors (Zoz, 1987). (Zoz, 1970) presented a graphical method for predicting tractor field performance. The method was useful for predicting drawbar pull, drawbar power, travel speed, and travel reduction of 2WD tractors under various soil conditions. (Kumar and Pandey, 2009) developed a visual basic program for predicting haulage and field performance of 2WD tractors.

(Wismer and Luth, 1972) presented equations for the tractive performance of tires on agricultural (cohesive–frictional) soils. These equations described tractive characteristics of both towed and driven tires and these were used later by many researchers to develop tractive performance models for tractors. (Clark, 1985) proposed generalized forms of the Wismer and Luth model for a wider range of actual field conditions. (Brixius, 1987) presented equations to predict the tractive performance of bias-ply tires operating on agricultural soils as revisions of equations introduced by (Wismer and Luth, 1972).



Tractor Type	Tractive Condition			
	Concrete	Firm	Tilled	Soft
2WD	0.87	0.72	0.67	0.55
MFWD	0.87	0.76	0.72	0.64
4WD	0.88	0.77	0.75	0.70
Track	0.88	0.76	0.74	0.72

Figure (2.3): Power relationships for agricultural tractors. Power at a given location in the drive train can be used to estimate power at another location. For example, PTO power can be estimated from net flywheel power by multiplying the net flywheel power by 0.90. If drawbar power is desired, choose the tractor type and tractive condition to determine the ratio. To estimate the drawbar power for a four-wheel drive tractor with 224 kW of net flywheel power operating on firm soil, multiply 224 by 0.90 and 0.77 to arrive at 155.23 kW. (ASABE D497, 2011)

2.2.1.1 Motion resistance or rolling resistance (MR):

Motion resistance is the difference between gross traction and net traction; accounts for all energy losses of a traction device not attributed to travel reduction (ASABE S295, 2011). In figure (2.4) the forces and resistances which is affecting on the wheel.

$$MR = GT - NT = W\left(\frac{1}{B_n} + 0.04 + \frac{0.5s}{\sqrt{B_n}}\right) \qquad (1)$$

Where:

$$B_n = \left(\frac{Cl \cdot b \cdot d}{W}\right)\left(\frac{1+5\frac{\delta}{h}}{1+3\frac{b}{d}}\right) \qquad (2)$$

Where:

MR: is the motion resistance, N;

GT: is the gross traction, N;

NT: is the net traction, N;

W: is the dynamic wheel load in force units normal to the soil surface, kN;

B_n: is a dimensionless ratio;

s: is the slip, decimal;

Cl: is the cone index for the soil, kPa;

b: is the unloaded tire section width, m;

d: is the unloaded overall tire diameter, m;

h: is the tire section height, m; and

δ: is the tire deflection, m.

Motion resistance ratio [ρ] is the ratio of the motion resistance to the dynamic wheel load it can be calculated from equation (3)

$$\rho = \frac{MR}{W} = \frac{1}{B_n} + 0.04 + \frac{0.5s}{\sqrt{B_n}} \tag{3}$$

The slope of the land can be effect on the motion resistance ratio. The effective motion resistance ratio (ρ_e) can be calculated by equation (4) (ASABE D497, 2011).

$$\rho_e = \rho \cos \alpha \pm \sin \alpha \tag{3}$$

Where:

α: is the slope. The minus sign is to be used for motion down slopes.

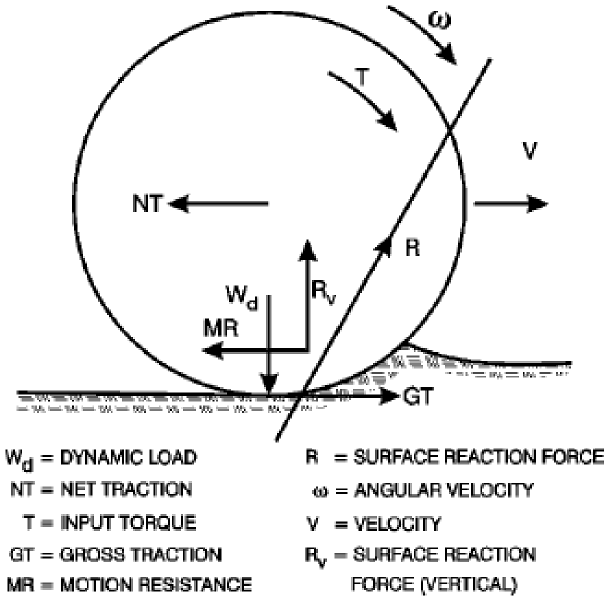


Figure (2.4) Basic velocities and forces on a wheel, including resultant soil reaction force (ASABE D497, 2011).

Table (2.1) shows the Values of CI and B_n for agricultural drive tires ($W/bd \cong 30\ \mathrm{kN \cdot m^{-2}}$) on typical soil surfaces. These values are applicable to soils that are not highly compactible (ASABE D497, 2011).

Table (2,1) values of Cl and B_n in the different kinds of agricultural soil

Soil	Cl (kPa)	B_n
Hard	1800	80
Firm	1200	55
Tilled	900	40
Soft, Sand	450	20

Source (ASABE D497, 2011)

2.2.1.2 Net traction (NT):

Net truction is the force parallel to the direction of travel, developed by the traction device and transferred to the vehicle (ASABE S296, 2011). Equation (5) expressed by (ASA-BE D497, 2011) to calculate the net traction.

$$NT = W\left(0.88(1 - e^{-0.1B_n})(1 - e^{-7.5s}) - \frac{1}{B_n} - \frac{0.5s}{\sqrt{B_n}}\right) \quad (5)$$

Where:

e: are the natural logarithms.

2.2.1.3 Gross traction (GT):

Gross truction is the sum of net traction and motion resistance. Gross traction can be calculated from the energy balance: [GT=NT* (1-travel reduction)/TE] (ASABE S296, 2011). Equation (6) estimated by (ASABE D497, 2011) to calculate the gross traction.

$$GT = W(0.88(1 - e^{-0.1B_n})(1 - e^{-7.5s}) + 0.04) \quad (6)$$

2.2.1.4 Tractive efficiency (E_t):

Tractive efficiency is the ratio between output to input power for a traction device (ASABE S296, 2011). Equation (7) presented in (ASABE D497, 2011) to calculate the tractive efficiency.

$$E_t = (1 - s)\frac{NT}{GT} \quad (7)$$

2.2.1.5 Engine load (E_L):

Engine load is determined by the extent of torque utilization (Rakopoulos and Giakoumis, 2009; Uxanov et al., 2009; Janulevičius et al., 2010).

$$E_L = \frac{M_m}{M_{max}} \quad (8)$$

Where:

E_L: is the engine load factor, decimal;

M_m: is the engine torque for the operating mode, Nm; and

M_{max}: is the engine maximum torque, Nm.

2.2.1.6 Draft and power requirement:

Draft data are the requirement of the force in the horizontal direction of travel. The draft force is a function of (soil and crop resistance). and the motion resistance is included into the draft requirement with one exception: during manure injection operation, motion resistance motion resistance of spreader transport wheels must be added to get the total implement draft (ASABE D497, 2011). Equation (9) shows the calculation of draft according to its components

$$D = R_{sc} + MR \tag{9}$$

Where:

D: is implement draft, N;

R_{sc}: is the soil and crop resistance, N; and

MR: is total implement motion resistance, N.

Soil and crop resistance is the contact resistance between soil or crop and the working components of the implement and it has a parallel direction to the travel direction (ASABE EP496, 2011)

2.2.1.6.1 Draft and power requirement model for the drawbar shaft:

Draft requirement can be prediction by using ASABE model for predicting the power requirement for the different implements. Equation (10) shows the ASABE draft model. This model can be using to calculate the power requirements for many seeding implements and minor tillage tools operated at shallow depth is primarily function of width of the implement and the speed at which it is pulled. For tillage tools operated at deeper depths, draft also depends upon soil texture, depth, and geometry of the tool.

$$D = F_i[A + B(S) + C(S)^2]WT \tag{10}$$

Where:

F: is a dimensionless soil texture adjustment parameter, in Appendix A;

i: is a factor related to the soil texture, 1 for fine, 2 for medium and 3 for coarse textured soils;

$A, B \text{ and } C$: are machine-specific parameters, in Appendix A;

S: is field speed, km.h^{-1};

W: is machine width, m or number of bodies or tools, in Appendix A

T: is the depth of the tillage operation, cm for major tools, 1(dimensionless) for minor tillage tools and seeding implements.

(Sahu, 2005) developed a model the draft requirements for different tillage implements on agricultural soil and prevailing operating conditions. Equation (11) shows this model.

$$\frac{D_p}{D_r^s} = \left(\frac{W_p}{W_r}\right)^a \left(\frac{\rho_w}{\rho_{ws}}\right)^b \left(\frac{CI}{CI_s}\right)^c \tag{11}$$

Where:

D_p: is the draft of prototype/model implement in any soil condition, N;

D_r^s: is the draft of reference tillage tool in reference soil condition, N;

W_p: is the prototype/model implement width, cm, for moldboard plow and disk harrow and number of tine for cultivator;

W_r: is the reference tillage tool width, 10 and 9 cm for moldboard plow and disk, respectively and 1 for cultivator tine;

ρ_w: is the wet bulk density of soil, g.cm^{-3};

ρ_{ws}: is the wet bulk density of reference soil condition, 1.28 g.cm^{-3};

CI: is the cone index of soil, kPa;

CI_s: is the cone index of reference soil condition, 472 kPa; and

a, b and c: are soil- and implement-specific coefficients.

Draft power is calculated from equation (12) as its express in (ASABE EP496, 2011)

$$P_{db} = \frac{D \cdot S}{3.6} \tag{12}$$

Where:

P_{db}: is drawbar power required for the implement, kW;

2.2.1.6.2 Draft and power requirement model for the PTO shaft:

Power requirement from Power takeoff (PTO) shaft is important to estimate the power consumption for the rotary tools as shown in Appendix B. (ASABE EP496, 2011) expressed equation (13) to determine the power requirements from the PTO shaft.

$$P_{pto} = a + bw + cF \tag{13}$$

Where:

P_{pto}: is power-takeoff power required for the implement, kW;

w: is the implement working width, m;

F: is the material feed rate, t.h^{-1} wet basis; and

$a, b \text{ and } c$: are machine-specific parameters, Appendix B;

2.2.1.6.3 Hydraulic power requirements:

Hydraulic power is the fluid power requirements from the tractor hydraulic system. It can be calculated from equation (14) as expressed in (ASABE EP496, 2011).

$$P_{hyd} = \frac{pF}{1000} \tag{14}$$

Where:

P_{hyd}: is hydraulic power required for the implement, kW;

F: is the fluid flow, L.s^{-1}; and

p: is the fluid pressure, kPa;

2.2.1.6.4 Electric power requirements:

Some implements need the electric power and it can be calculated from the equation (15) as expressed in (ASABE EP496, 2011).

$$P_{el} = \frac{IE}{1000} \tag{15}$$

Where:

P_{el}: is the electric power required for the implement, kW;

I: is the electric current, A; and

E: is the electric potential, V.

2.2.1.6.5 Total power requirements:

The total power requirements for the operating implements are the sum of the previous power components.it can be computed as expressed in (ASABE EP496, 2011).

$$P_T = \frac{P_{db}}{E_m E_t} + P_{pto} + P_{hyd} + P_{el} \quad (16)$$

Where:

P_T: is the total power required for the implement, kW;

E_t: is the tractive efficiency, decimal;

E_m: is the mechanical efficiency of the transmission and power train. This coefficient is typically 0.96 for tractors with gear transmissions.

2.2.1.7 Tractor fuel consumption:

Fuel consumption is an important factor which effecting on the operating cost. The fuel consumption can be computed according to the kind of power which use by the implement. Fuel consumption can be found by multiplying specific fuel consumption volume by current power delivery. (ASABE EP496, 2011) presented equations to calculate the fuel consumption.

$$Q_{avg} = 0.305 \times P_{pto} \quad (17)$$

Where:

Q_{avg}: is the average gasoline consumption, $L.h^{-1}$.

$$Q_i = Q_s \times P_T \quad (18)$$

Where:

Q_i: is the estimated fuel consumption for a particular operation, L.h^{-1};

Q_s: is the specific fuel consumption for the given tractor, L.kW^{-1}h^{-1}.

2.2.1.7.1 Specific fuel consumption:

Specific fuel consumption is the ratio between the fuel consumption the total tractor power. (ASABE D497, 2011) presented some equations for calculate the specific fuel consumption depending upon the kind of engine fuel.

Specific fuel consumption for typical spark ignition tractor and combine engines operating above 20% load and at full throttle.

For gasoline

$$Q_s = \left(0.282 + \frac{0.159}{X}\right) \tag{19}$$

$$\left(Q_s = \left[0.052 + \frac{0.0328}{X}\right]\right) \tag{20}$$

Where:

X: is the fraction of equivalent PTO power available.

$$X = \left(\frac{P_{pto}}{P_{rated}}\right) \tag{21}$$

Where:

P_{rated}: is the rated PTO power available, kW.

For LPG (liquid petroleum gas)

$$Q_s = \left(0.632 + \frac{0.139}{X}\right) \tag{22}$$

$$\left(Q_s = \left[0.129 + \frac{0.0263}{X}\right]\right) \tag{23}$$

For diesel

$$Q_s = \left(0.22 + \frac{0.096}{X}\right) PTM \tag{24}$$

$$\left(Q_s = \left[0.0434 + \frac{0.019}{X}\right] PTM\right) \tag{25}$$

Where: PTM is the partial throttle multiplier given in equation (26).

$$PTM = 1 - (N - 1) \cdot (0.45\,X - 0.877) \tag{26}$$

Where: N: is the ratio of partial throttle engine speed to full throttle engine speed at operating load. N is given by equation (27)

$$N = \left(\frac{n_{PT}}{n_{FT}}\right) \tag{27}$$

Where:

n_{PT}: is the partial throttle engine speed, rpm; and

n_{FT}: is the full throttle engine speed, rpm.

2.2.2 Tractor-implement matching:

The matching and performance of tractor implement system are depending upon some factors such as tractor, tire and implement specifications, soil conditions, etc. are inherent to tractor-implement system and cannot be altered or controlled. And there are another factors effect on the performance of the tractor implement system such as hitching type (mounted, semi mounted and trailed), operating conditions (depth and speed of operation), types of field operation (primary or secondary), etc. these factors can be adjusted for achieving the maximum performance. Both of these factors which are controllable and uncontrollable cover a wide variety of alternatives on which decisions have to be based such as which implement and of what size is to be attached to the tractor (Sahu and Raheman, 2008).

The correct matching of tractor and implement should decrease the power losses, increase efficiency of the operation, reduce the operating costs and optimize utilization of fixed costs (Taylor et al., 1991). The matching process is something that farmers often do sub consciously (Gould et al., 1999). Many researchers are involved developing decision support system (DSS)/ computer programs/models for the tractor-implement selection (Gee-Clough et al., 1978; Ozkan et al., 1984; Upadhyaya et al., 1984; Brixius, 1987; Zoz, 1987; Colvin et al., 1989; Evans et al., 1989; Grisso et al., 1992, 1996; Al-Hamed et al., 1994; Harrigan and Rotz, 1994; Gould et al., 1999; Al-Hamed and Al-Janobi, 2001; ASAE, 2011; Sahu and Raheman, 2008; Mehta et al., 2011). Different interactive computer models, templates, and software/programs have been developed to estimate the draft requirement of implement, tractive performance parameters (slip, net traction, gross traction, motion resistance, etc.), fuel consumption, turning time and field capacity of tractor-implement combination system during operations in different soil and operating conditions. These studies are soil and site-specific and their validity needs to be checked in other soils and locations (Sahu and Raheman, 2008). A few other researchers mentioned the general characteristics for matching of tractor and implement depending upon the power availability and power required by considering the soil factor, unit draft, field efficiency, tractive efficiency and transmission efficiency (Downs et al., 1990; Downs and Hansen, 1998; Gould et al., 1999; Powell, 2001).

2.2.2.1 Overall efficiency of tractor-implement system:

(Sahu and Raheman, 2008) defined the overall efficiency (O_{eff}) of a tractor-implement system (which takes into account the field efficiency of implement as well as the efficiency in converting fuel power to drawbar power) for carrying out tillage operation can be predicted using the following expression:

$$O_{eff} = \frac{C_a}{C_{at}} \times \frac{DBE}{FLE} \times 100 \quad (28)$$

Where:

C_a: is the actual field capacity, $ha.h^{-1}$;

C_{at}: is the theoretical field capacity, $ha.h^{-1}$;

DBE: is the Drawbar energy, kJ; and

FLE: is the fuel energy, kJ.

2.3 Machinery Management:

The machinery management is the study of the selection, operation and replacement of farm machines (Witeney, 1988). The using of the optimum machinery management can be achieving the maximum profit and minimum cost. There are many problems in the machinery management such as how to choose the suitable tractor and machinery combinations and optimum utilization may require area adjustments which are unacceptable for some causes. Inadequate machine capacity may incur yield penalties from untimely operations, whereas over capacity may introduce the risk of greater soil damage due to additional weight of the large equipment (Witeney, 1988). The efficient machinery management is depending on the accurate performance data of the machine.

Most of the models are based on some kind of optimization technique, e.g. linear programming, where available workdays are included as a probability (Hughes and Holtman, 1976; Nilsson, 1976; Edwards and Boehlje, 1980; Pfeiffer and Peterson, 1980; Whitson et al., 1981; Witney and Eradat, 1982; Oving, 1989; Siemens et al. 1990; Jannot and Nicoletti, 1992; Jannot and Cairol, 1994; Etyang et al., 1998; Siemens, 1998; Ekman, 2000). (Misener and McLeod, 1987) developed a machinery model on computer program which facilitates the collecting and summarizing of operational data related to farm machinery use. (Gajendra and Madan, 1980) developed a computer programs to handle the lengthy iteration computations for selecting the least cost, power and machine combinations for farms up to 20 ha growing maize and wheat in the Ludhiana district of Punjab, India.

2.3.1 Machine performance:

The efficient machinery management requires accurate performance data on the capability of individual machines in order to meet project work schedules and from balance mechanization systems by matching the performance of separate items of equipment (Witeney, 1988). Each piece of machinery must perform reliably under a variety of field conditions or it is a poor investment regardless of its cost (IOWA PM-952, 2009). The skills of operator, weather and soil conditions are the effective parameters on the machine performance (IOWA PM-952, 2009).

2.3.1.1 Field capacity:

The field capacity defined in Standard S495 as the rate of land or crop processed in a given time (ASABE, 2011). It is using to evaluate the machine performance it should be determining by the accomplished operation and the quality of output. Field capacity is an important factor to assess the productivity of the machine (Witeney, 1988). Field capacity can be calculating in two ways. Effective and theoretical field capacity, both of them defined in the Standard S495, the effective field capacity is the actual rate of land or crop processed in a given time. and the theoretical field capacity is the Rate of performance obtained if a machine performs its function 100% of the time at a given operating speed using 100% of its theoretical width (ASABE, 2011). Field capacity includes.

- Area capacity;
- Commodity throughput capacity;
- Total throughput capacity.

2.3.1.1.1 Area capacity:

Area capacity uses to define the rate of work for field and it is an indicator for the work achieved during the several kinds of field operations such as tillage, planting, spraying, and harvesting operation.

Theoretical area capacity is the maximum capacity at given operating speed and fully utilizing the operational width of the machine (Witeney, 1988). In the practice there are some losses of time and the overlap which is give effective width 2-5% less than the maximum width, the ration of effective area capacity to theoretical area capacity defined as field efficiency in the Standard S495 (ASABE, 2011). Equation (29) situated in the standard EP496 to calculate area capacity (ASABE, 2011).

$$C_a = \frac{s \cdot w \cdot E_f}{10} \qquad (29)$$

Where:

C_a: is area capacity, $ha \cdot h^{-1}$;

w: is implement working width, m;

s: is field speed, $km \cdot h^{-1}$;

E_f: is field efficiency, decimal;

2.3.1.1.2 Throughput capacity (material capacity):

The throughput capacity defines as the mass of machine productivity per the unit of time, or the number of tonnes per operating time. Throughput capacity determine especially for the harvesting machine. Total throughput capacity is using to indicate the performance in terms of total material flow through a machine, such as combine harvester or potato harvester which separate a saleable product from crop residues or soil contamination (Witeney, 1988).

Throughput capacity is important for digital yield mapping. Digital stored yield maps are an important part of recording basic data for spatially variable field operations (Searcy et al., 1989; Schnug et al., 1990; Stafford et al., 1991; Vansichen and De Baerdemaeker, 1991 Auernhammer, 1992). Yield maps contain a wealth of information and can be an important tool for making informed decisions on paddock management (Robinson and Metternicht, 2005). Yield map can be using to define field sections with equal growing conditions and determine the field operations depending on the variations of the soil properties such as soil moisture, nutrient content and slope (Reitz and Kutzbach, 1996). (Papageorgiou et al., 2010, Papageorgiou et al., 2011) studied fuzzy cognitive maps (FCMs) for managing the cotton yield. (Y.K. Chang et al., 2012) developed automated yield monitoring system (AYMS II) to implement site-specific management practices within the blueberry fields to optimize productivity while minimizing the environmental impact of farming operations.

Equation (30) situated in the standard EP496 to calculate throughput capacity (ASABE, 2011).

$$C_m = C_a \cdot y \tag{30}$$

Where:

C_m: is material capacity, $t \cdot h^{-1}$;

y: is the average yield of the field in, $t.ha^{-1}$;

2.3.1.2 Field efficiency:

Field efficiency expressed in ASABE Standard S495 as the ratio between the productivity of a machine under field conditions and the theoretical maximum productivity (ASABE, 2011). Field efficiency is an indication of carrying out field work is obtained from the proportion of productive time during the operation (Witeney, 1988).

The main effective parameters which effect on the field efficiency is the failure to utilize the theoretical operating width of the machine, time lost because of operator capability, habits and operating policy and field characteristics. Field efficiency is changing from the machine to machine, from operation to another operation and from conditions to another conditions depending on the size and shape of the field, pattern of field operation, crop yield, crop moisture and other conditions (ASABE, 2011). In Appendix C the different field efficiency depend on the kind of operation will be shown.

The following activities expressed on the Standard EP496 (ASABE, 2011) as the majority of time lost in the field:

- Turning and idle travel;
- Material handling, such as (seed, fertilizer, chemicals, water, and harvested material);
- Cleaning clogged equipment; and
- Lubrication, refueling and daily service).

2.3.1.3 Unused machine capacity:

The machine bouts in most of the field operations are overlapped to be sure that the whole filed is covering, this overlaps reduce the effective width by approximately 5% (Witeney, 1988). Standard S495 expressed two terms of machine width, the first one is the effective width which is the width over which the machine actually works. It may be more or less than the measured width of the machine, and the theoretical width which is define as the measured width of the working portion of a machine. For row crop machines, it is the average row width times the number of rows (ASABE, 2011)

2.3.2 Machine operating cost:

The estimation of the machine cost is a very important factor for choosing and using the machine. (Misener and McLeod, 1987) developed a computer model for facilitates the collecting and summarizing of operational data related to farm machinery use including the cost data. There are two main categories of the operating cost.

2.3.2.1 Ownership costs:

It is the fixed costs or overhead costs don't change with the change of the operation status of the machine. Ownership costs include.

2.3.2.1.1 Depreciation:

Depreciation cost defined in the ASABE Standard EP496 as the reduction in value of an asset with use and time (ASABE, 2011). There are several methods to calculate the approximate value of the depreciation cost, there are no method to calculate the actual total depreciation (Burnham and Hoskins, 1940). It may calculate as a price per the unit of area (ha) or the unit of time (h). The simplest way to determine the depreciation cost as written in the ASABE Standard EP496, is subtracting the salvage value from the purchase price and dividing by the anticipated length of time owned (ASABE, 2011). Many publications report have been estimate the remaining values approximately as a percentage value of the price of the machine (ASABE D497, 2011).

2.3.2.1.2 Interest:

Is the change of the money for use it in the machine investment. Simply it is possible to determine by calculating the average of investment over the life of machine, it can be added to the depreciation cost to estimate the whole ownership cost including the time value of money makes use of a Capital Recovery Factor (CRF) to give a series of equal payments over the life of the machine which includes both the cost of depreciation and interest (ASABE D497, 2011).

2.3.2.1.3 Other ownership costs:

Taxes, housing and insurance are a part from ownership costs. It can be calculated as a ratio from the purchase price using the following percentages (ASABE D497, 2011).

- Taxes 1.00;
- Housing 0.75 and
- Insurance 0.25.
- Total 2.00% of purchase price.

2.3.2.1.4 Total ownership costs:

It can be calculating as a percentage from the purchase price and by the multiplication of this percentage and the purchase price it can be obtain the total ownership cost. Equation (31) expressed by ASABE Standard D497 (ASABE, 2011).

$$C_o = 100\left[\frac{1-S_v}{L} + \frac{1+S_v}{2} i + K_2\right] \quad (31)$$

Where:

C_o: is ownership cost percentage. Multiplying this value, expressed in decimal form by the machine purchase price yields the average annual total ownership cost of the machine;

S_v: is salvage value factor of machine at end of machine life (year L), decimal;

L: is the machine life, yr;

i: is the annual interest rate, decimal; and

K_2 is the ownership cost factor for taxes, housing, and insurance; decimal.

2.3.2.2 Operating costs:

The operating costs call variable cost as well. The value of operating costs change with the change in the amount of work. The following parameters are parts from the operating costs.

2.3.2.2.1 Repair and maintenance:

It's a kind of cost which is spending to a machine operation due to wear, part failures, accidents and natural deterioration, this cost have a high variability, the good management can keep the cost as low as possible. The machine size and amount of use are the main parameters which effecting on the value of repair and maintenance (ASABE D497, 2011).

Equation (32) expressed in (ASABE D497, 2011) to calculate the cost of repair and maintenance.

$$C_{rm} = (RF1)P\left[\frac{h}{1000}\right]^{(RF2)} \quad (32)$$

Where:

C_{rm}: is accumulated repair and maintenance cost, $;

RF1 andRF2: are repair and maintenance factors as shown in Appendix C;

P: is machine list price in current dollars. In terms of rapid inflation, the original list price must be multiplied by (1+I)n where I is the average inflation rate and n is the age of the machine; and

h: is accumulated use of machine, h.

Figure (2.5) is shown the change of accumulated repair costs for two-wheel drive tractor with the change of the price.

Figure (2.5): Accumulate repair costs for two-wheel drive tractor (IOWA PM-710, 2009).

2.3.2.2.2 Fuel:

The value of the fuel cost depends on the fuel consumption of the tractor or the self-power generating machine. The terms of the fuel consumption will be express in tractor performance section. Annual average fuel requirements for tractors can be using to calculate overall machinery cost for particular enterprise (ASABE D497, 2011). Fuel cost can be determining by multiply the specific fuel consumption by the engine power and price of the unit of volume for the fuel (IOWA PM-710, 2009).

2.3.2.2.3 Oil:

Engine oil consumption is based on 100-h oil change intervals. The consumption rate of oil ranges from 0.0378 to 0.0946 $L.h^{-1}$ depending upon the volume of the engine's crankcase capacity. If oil filters are changed every second oil change, total engine lubrication cost approaches 15% of total fuel cost. Usually the cost of filters and the cost of oil other than crankcase oil are a part of maintenance cost (ASABE D497, 2011).

2.3.2.2.3 labor:

Labor cost is depending upon the geographic location. For hired operators, a constant hourly rate is appropriate. In no instance should charge be less than a typical, community labor rate (ASABE D497, 2011).

2.3.2.3 Total machine costs:

During the calculation of machine cot and for the tractor cost calculation it must be including the cost of use implements. Costs for implements or attachments depend on tractor power are estimated in the same way as the tractor, except that there are no fuel, lubrication or labor costs involved (IOWA PM-710, 2009). The size of machine is affecting on each type of cost. Figure (2.6) shows the change of the several kind of costs as a result for the change of machine size. A slight increase in machinery size can lower timeliness and labor costs significantly, enough to more than offset the higher fixed costs. However, as machinery size continues to increase, the timeliness cost savings diminish, and eventually total costs begin to rise. One objective of machinery selection, then, is to select machinery in the size range where total machinery costs are lowest (IOWA PM-952, 2009). (Edwards, 2013) developed excel model to calculate the different kind of machine costs.

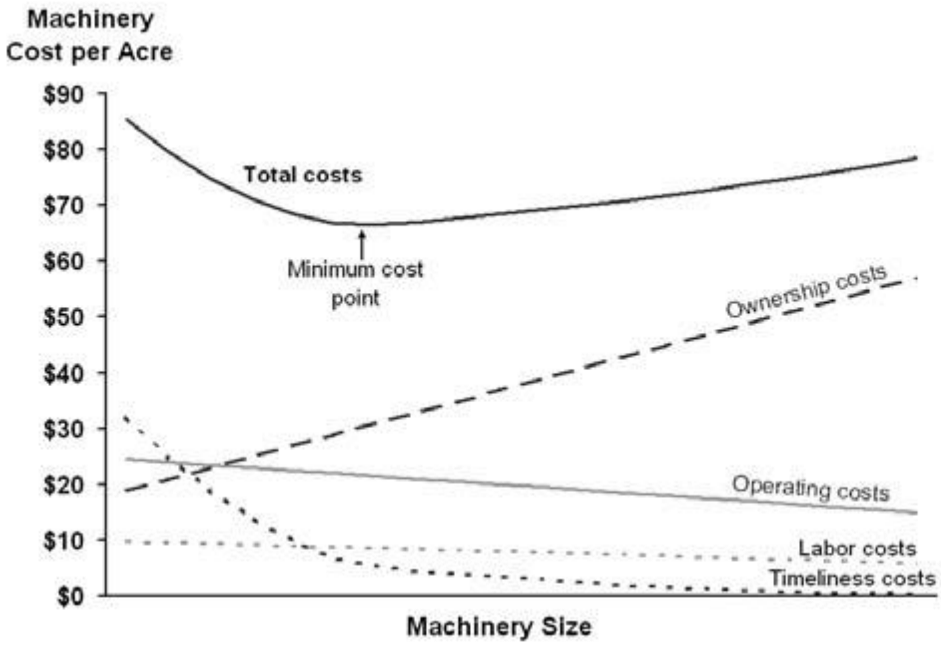


Figure (2.6): Effect of increasing machinery size on machinery costs (IOWA PM-952, 2009).

2.3.3 Machine replacement:

Machines need to replacement for one or more causes of the following as expressed in (ASABE EP496, 2011).

- Suffering from the damage happened by accident when the cost renewal is so great that a new machine is more economical.
- The capacity of machine is not suitable anymore because of the increasing of the production.
- The machine obsolete, when it is either out of production and parts to repair or update it are not available from normal suppliers, or it can be replaced by another machine or method that will produce greater profit (ASABE S495, 2011).
- The machine is not expected to operate reliably. By unanticipated suffering from random part failures.
- The increasing of the repair and maintenance costs with the time. That is making the repair and maintenance costs are not economic. So that some machines has an economic operating age nine years and the recommendation for this machines is to replace it after 9 years.

2.4 Tillage Operation:

Tillage is the mechanical manipulation of soil for any required purpose, but in agriculture the term is usually restricted to the changing of soil conditions for the increasing the crop production (ASABE EP291, 2009). Soil tilth creation presents a continuous challenge for researchers, developers, manufacturers and farmers. Seedbed preparation, optimization of seedbed structure, and sub-soiling of only those areas of the field requiring it, are vital to precision agriculture (Shmulevich et al., 2007).

The best management of the tillage operation leads to reduce energy and fertilization consumption (Shmulevich et al., 2007). Tillage operation is consuming 50% of the total usable energy in the agricultural crop production (Kushwaha and Zhang, 1998).

Many researches in the tillage field was done for developing models for predict the tillage power requirements by studying the soil tillage interaction (e.g., Wismer and Luth, 1972; McKyes and Ali, 1977; Hettaratchi, 1993; Kushwaha and Zhang, 1998; Mouazen and Ramon, 2002; Aluko and Chandler, 2004; Martins and Marques, 2007; Godwin and O'Dogherty, 2007; Karmakar et al., 2007).

(Schroth et al., 1995) found that the ploughing increased the yields independently of tree competition. However, the observed effects of the tillage methods on soil conditions indicate a trade-off between short-term yield improvements and medium-term degradation of soil fertility by level ploughing compared to traditional hoe-ridging.

2.4.1 General concepts of cultivation machinery:

2.4.1.1 Primary cultivation machinery:

The main function of the primary cultivation is to break the soil surface to prepare a suitable condition for crop establishment. Primary cultivation can be achieve many of tillage operation targets such as soil loosening, surface drainage, soil inversion and crop residue incorporation. The equipment which is able to do this primary cultivation is classified as conventional tillage tools such as subsoiler, mole plough and moldboard plough (Scarlrtt, 2001).

2.4.1.2 Secondary cultivation machinery:

Secondary cultivation is carried out to prepare suitable seedbed for successfuly establishment of crop and successfuly crop growing. Secondary tillage treatments inclouded two components, namely aggregate size reduction and seedbed firming, the severity of these actions must tailored to suitable particular soil type, soil moisure content, copping regime and climate, and also there are some important factors for timeliness of crop establishment, combined with the desire to reduce the inputs such as fuel and labour requirements to achieve the target (low cost and high output operation) (Scarlett, 2001).

2.4.2 Tillage systems:

ASABE Standard (ASABE EP291, 2009) introduces some definitions for the tillage systems as given in the following.

- **Conventional tillage:**

The conventional tillage is the traditional method for the seedbed preparation for a given crop and grown it a given geographical area.

- **Minimum tillage:**

Minimum tillage is the minimum soil manipulation necessary for crop production or for meeting tillage requirements under existing soil conditions.

- **Optimum tillage:**

Optimum tillage is an idealized system which permits a maximized net return for a given crop under given conditions.

- **Intensive tillage:**

Any tillage system which is keeping less than 15% residue on the soil surface after planting or keep less than 560 $kg.ha^{-1}$ of small grain residue equivalent on the soil surface during the critical period of erosion.

- **Reduced tillage:**

Reducing tillage is any tillage system which is keeping 15-30% residue on the soil surface after planting or keeping 560-1100 $kg.ha^{-1}$ of small grain residue equivalent on the soil surface during the critical period of erosion, or it is a system which reducing the intensive energy consumption compared with the conventional tillage system.

- **Conservation tillage:**

Conservation tillage is any tillage system which is keeping a residue cover on the soil surface with minimum percentage 30% after planting to reduce the erosion by water or by wind, it is keeping at least 1100 $kg.ha^{-1}$ of flat small grain residue equivalent on the soil surface during the critical point of erosion.

- **No till:**

No till system is the system where the grown of the crops is happened in the narrow tilled strips in previously untilled soil. The tillage is limited to the required placement for seeding and/or fertilizing to remove the residue from the row of the seed and to more than one third width. Plant residue is keeping the soil surface against erosion year-round.

- **Strip tillage:**

Strip tillage is a system makes narrow tilled strips in previous untilled soil to let the crop grown in this strips. Seedbed preparation, planting, and fertilizer placement are only the places which need tilled strips no more than one third of row width for keeping the plant residue to maintain the soil surface year-round.

- **Direct seed:**

Direct seed is a system which let the crops growing in tilled strips in previously untilled soil. Fertilizer and/or seed are only the places which need tilled strips no more than these strips for keeping the plant residue to maintain the soil surface year-round. Fertilizer and/or plant may be in one pass and may be in two passes.

- **Mulch tillage**

Mulch tillage is a full width tillage system where the whole of the field surface is manipulated prior to and/or during planting. Tillage is accomplished in such way that plant residue is kept on soil surface year-round.

- **Ridge tillage:**

Ridge tillage is a system where crops are grown on pre-formed ridges separated by furrows protected by crop residue. Soil is left undisturbed from harvest to planting. After planting, ridges are rebuilt by cultivation. Planting and fertilizer placement disturb less than one third of row width.

- **Reservoir tillage:**

Reservoir tillage is a system which a big number of small reservoirs have a suitable form to keep the rain or sprinkler applied water.

2.4.3 The effect of tillage systems on soil erosion:

Soil erosion is associated with about 85% of land degradation in the world, causing up to 17% reduction in crop productivity (Oldeman et al., 1990).

Under conventional tillage system which applied by moldboard plow soil erosion is increasing (Alvarez et al., 1995), soil nutrients are loss (Bernardos et al., 2001) and soil organic carbon as well (Alvarez, 2001; Hevia et al., 2003; Quiroga et al., 1996). Conventional tillage system is one of the soil degradation reasons notwithstanding the conventional tillage increases the crops yield (SAGPyA, 2008). Limited tillage systems combined with fertilization, and no-till, introduced as a management practices in 1990and were adopted at an exponential rate by farmers since them (AACREA, 2008; Fertilizar, 2008; SAGPyA, 2008). In the present time between 60-80% of the crop production is done with no-till system, this may be tending mainly to economic reasons (Alvarez and Steinbach, 2009). The big amount of the residue cover on the soil surface under no-till system reduces the wind erosion risk in agricultural soil comparing with the conventional tillage system (Mendez and Buschiazzo, 2010). No-till system has been mostly an efficient system for controlling wind erosion because it left a large amount of plant residues on the soil surface (Thorne et al., 2003; Merrill et al., 2004). The residue cover in the soil surface is reducing the soil erosion and increase the sustainability of cotton production (Nyakatawa et al., 2007). Conservation tillage systems such as no-till and mulch-till can reduce soil erosion, conserve soil moisture, replenish soil organic matter, and improve crop yields in the long term (Triplett et al., 1996; Reeves, 1997; Nyakatawa et al., 2001; Reddy et al., 2004).

2.4.4Tillage draught requirement:

The prediction of the draught requirements for the tillage operation is very important for tractor implement matching. There are different important parameters which effect on the draught requirements such as soil properties, tool geometry, working depth, forward speed and working width (Glancey et al., 1996). The soil properties which is effecting on the draught requirements is the soil moisture content, bulk density, soil texture and soil strength (Sahu and Raheman, 2006). Many researchers developed models for this prediction by using the collected data from the field experimental to help the manager to select the suitable machinery and to assist him to match the suitable implement with the suitable tractor and determine the predicted fuel consumption (Larson et al., 1968; Wang et al., 1972; Collins et al., 1978; Gee-Clough et al., 1978; Eradat-Oskoui and Witney, 1982; Eradat-Oskoui et al., 1982; Kepner et al., 1982; Kydd et al., 1984; Nicholoson and Bashford, 1984; Upadhyaya et al., 1984; Summer et al., 1986; Gebresenbet, 1989; Bashford et al., 1991; Harrigan and Rotz, 1995; Grisso et al., 1996; ASAE, 2000a ; Kheiralla et al., 2004).

(Upadhyaya et al., 1984) explain the draught requirement of any passive tillage implement as a function of working depth, forward speed, working width, tool geometry parameters (cutting angle, and tool length) and soil properties (bulk density and cone penetration resistance).

$$D = f(d, V, W_i, L_i, \alpha_i, \rho_w, R_c) \tag{33}$$

Where:

d: is the operating depth, m;

V: is the forward speed, km.h^{-1};

W_i: is the working width, m;

L_i: is the tool length (tool geometry), m;

α_i: is the cutting angle (tool geometry), degree;

ρ_w: is the soil bulk density, kg.m^{-3}; and

R_c: is the cone pentration resistance, kPa.

3. OBJECTIVES AND METHODOLOGY

3.1 Objectives:

The object of this study is the analysis of telematics system in agriculture by the analysis of the tractor-implement performance using the Telematics system data.

3.2 Methodology:

The location of study is the CULS farm in Lany-Czech Republic. The study starts by collecting the tractor and implements data manually from the farm and download the performance data from the telematics site.

The machines that are included in the study are a tractor with several kinds of cultivation implements.

The tractor type is John Deere 8320R, with rated power [97/68EC] without IPM 235kW and with IPM 261k, the maximum power [97/68EC] at engine speed 1900 rpm without IPM is 256 kW and with IPM 269 kW, the engine torque is 1419 Nm, rated speed 2100 rpm, fuel tank capacity 681 l and the speed range is 50 m.h^{-1} to 50 km.h^{-1}.

The cultivator implements specifications presented in the (Fermet; Terrano; Tiger; Kverneland) company's sites and brochures as shown in table (3.1)

Table (3,1) Tillage implements specifications.

Implement	Working depth [cm]	Actual working wepth [cm]	Working width [m]	Body weight [kg]	Number of tines	Spacing between tines [cm]	Spacing in one row [cm]	Power demand [kW]	Function
Farmet K 800	3-15	8	8	4200	--	--	--	180	Seedbed cultivator
Horsch Terrano 6FX	15-20	15	5,80	4780	19	30,50	91,50	175-265	Tillage
Horsch Tiger 4AS	35	25	4	5350	17	23,5	94	145-270	Cultivator
Kverneland PW100	--	25	2.5-4	5630	8	35-50	--	180	moldboard Ploughing

Source: (Farmet; Terrano Fx; Tiger AS; Kverneland; Author)

Figure (3.1) Farmet K 800 (http://www.farmet.de/zoom.php?fid=676&lang=de)

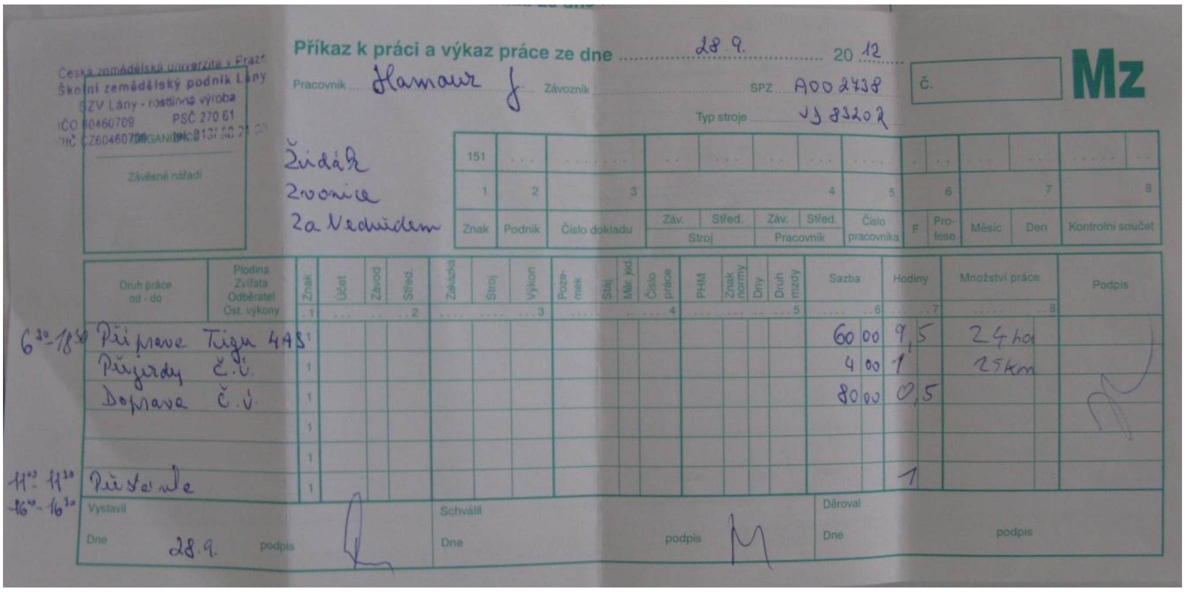
Figure (3.2) Horsch Terrano 6FX (Terrano FX)

Figure (3.3) Horsch Tiger 4AS (Tiger AS)

Figure (3.4): Kverneland PW (Kverneland).

3.2.1 Manual data collection:

Figure (3.5) shown the machine operating statement in the CULS farm. This sheet includes the operating data such as the time of working, number of hectares and the data of filling the fuel tank.



Česká zemědělská univerzita v Praze
Školní zemědělský podnik Lány
ŠZV Lány - rostlinná výroba
IČO 60460709 PSČ 270 61
DIČ CZ60460709

Závěsné nářadí

Příkaz k práci a výkaz práce ze dne 28.9. 2012

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Mz

Pracovník Hamour J. Závozník SPZ A00 2438

Typ stroje VJ 83202

Žiďák
Zvonice
Za Nedvídem

151								
1	2	3	4	5	6		7	8
Znak	Podnik	Číslo dokladu	Stroj (Záv. / Střed.)	Pracovník (Záv. / Střed.)	Číslo pracovníka	F / Profese	Měsíc / Den	Kontrolní součet

	Druh práce od - do	Plodina Zvířata Odběratel Ost. výkony	Znak	Účet	Závod	Střed.	Zakázka	Stroj	Výkon	Pozemek	Stáj	Měr. jed.	Číslo práce	PHM	Znak normy	Dny	Druh mzdy	Sazba	Hodiny	Množství práce	Podpis
6^{30}-18^{30}	Příprava	Tigu 4AS	1															60 00	9,5	24 ha	
	Příjezdy	Č.V.	1															4 00	1	25 km	
	Doprava	Č.V.	1															80 00	0,5		
			1																		
			1																		
11^{00}-11^{30} 16^{00}-16^{30}	Přestávka		1																1		

Vystavil Dne 28.9. podpis

Schválil Dne podpis

Děroval Dne podpis

Figure (3.5) Sheet of the Manual recording data, used in CULS farm (Author).

3.2.1 Data collection from the system:

Figure (3.6) shows the JD-Link site which is used for the data collection.

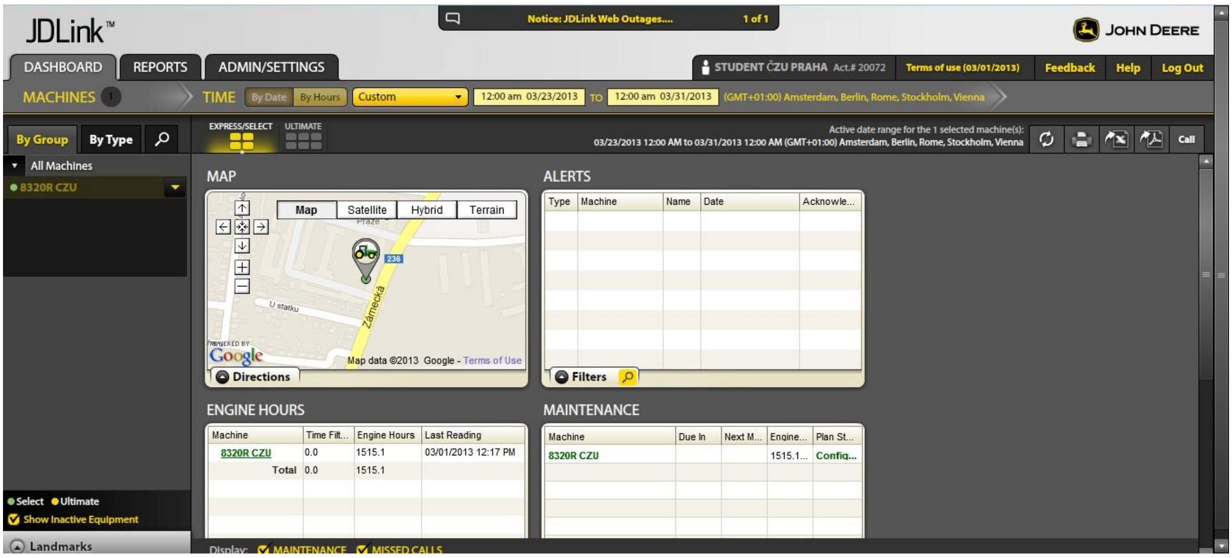

Figure (3.6) JD-Link site (JD-Link).

After log in to the site the figure (3.6) will be shown. The system will need to select the machine from the lift pan then the data of the machine will be appeared. The system including a data about machine position, alerts, utilization time, maintenance, missed call, machine utilization characteristics and other data.

This study used the data of the machine utilization. Figure (3.7) shows that part of data.

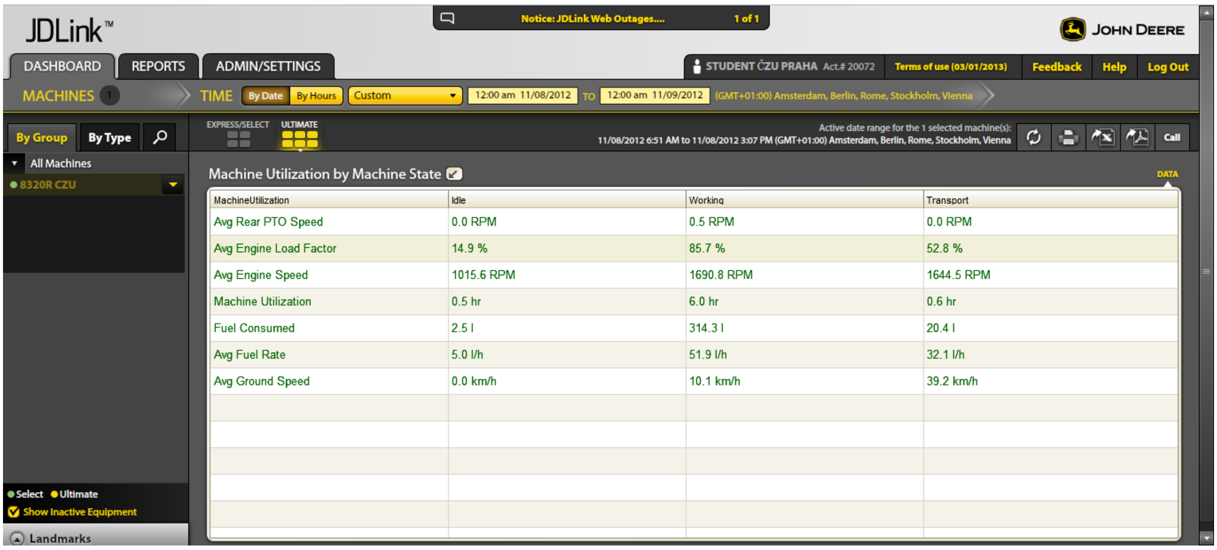

Figure (3.7) Machine utilization data. (JD-Link).

It could be select one part of these data to show how it is, or it's available to download all of these data according to the selected date and time.

This study used the data of average engine load factor, average engine speed, machine utilization, fuel consumption, average fuel rate and average ground speed.

3.2.1 Calculations:

By using the data of the served area, fuel consumption, machine utilization, machine working width and the ground speed, it can be calculated the following parameters.

3.2.1.1 Fuel consumption rate:

1. Fuel consumption rate in [$l.ha^{-1}$]: This parameter used to know how many liters of fuel are consumed to serve one hectare. It can be calculated using the following equation.

$$Q_a = \frac{Q}{A} \tag{34}$$

Where:

Q_a: is the fuel consumption rate, $l.ha^{-1}$;

Q: is the fuel consumption, l; and

A: is the served area, ha.

2. Fuel consumption rate in [$l.h^{-1}$]: This parameter used to know how many liters of fuel are consumed in one hour. It can be calculated using the following equation.

$$Q_i = \frac{Q}{t_w} \tag{35}$$

Where:

Q_i: is the fuel consumption rate, $l.h^{-1}$;

t_w: is the working time, h;

3.2.1.1 Field capacity and field efficiency:

These terms explained in sections (2.3.1.1 and 2.3.1.2). Field capacity can be calculated in two ways effective field capacity and theoretical field capacity.

Effective field capacity can be calculated by the following equation.

$$C_a = \frac{A}{t_w} \tag{36}$$

Where:

C_a: is the effective field capacity, $ha.h^{-1}$;

t_w: is the working time, h.

And for calculate the theoretical field capacity,

$$C_{th} = \frac{w.s}{10} \tag{37}$$

Where:

C_{th}: is the theoretical field capacity, $ha.h^{-1}$;

w: is the working width, m;

s: is the ground speed, $km.h^{-1}$.

The field efficiency is the division result of effective field capacity per the theoretical field capacity.

4. RESULTS AND DISCUSSION

In this chapter, comparison between the different tillage tools according to the fuel consuming rate, engine load factor, engine speed, forward speed, field capacity and field efficiency.

4.1 Implements results:

Appendix D, E and F show the comparison between the fuel rate, engine speed and engine load factors. These comparisons show that there is no big effective difference between the fuel rate and engine speed, as well between the engine speed and engine load factor. However the comparing of the data between the fuel rate and engine load factor is lined by matching. The results for each implement in the next subsections.

4.1.1 Implement I (Farmet K800):

The values of ground speed for implement 1 as shows in figure (4.1) are distributed around 12.3 km.h^{-1}. with maximum value 14.2 km.h^{-1} and minimum 10.2 km.h^{-1}

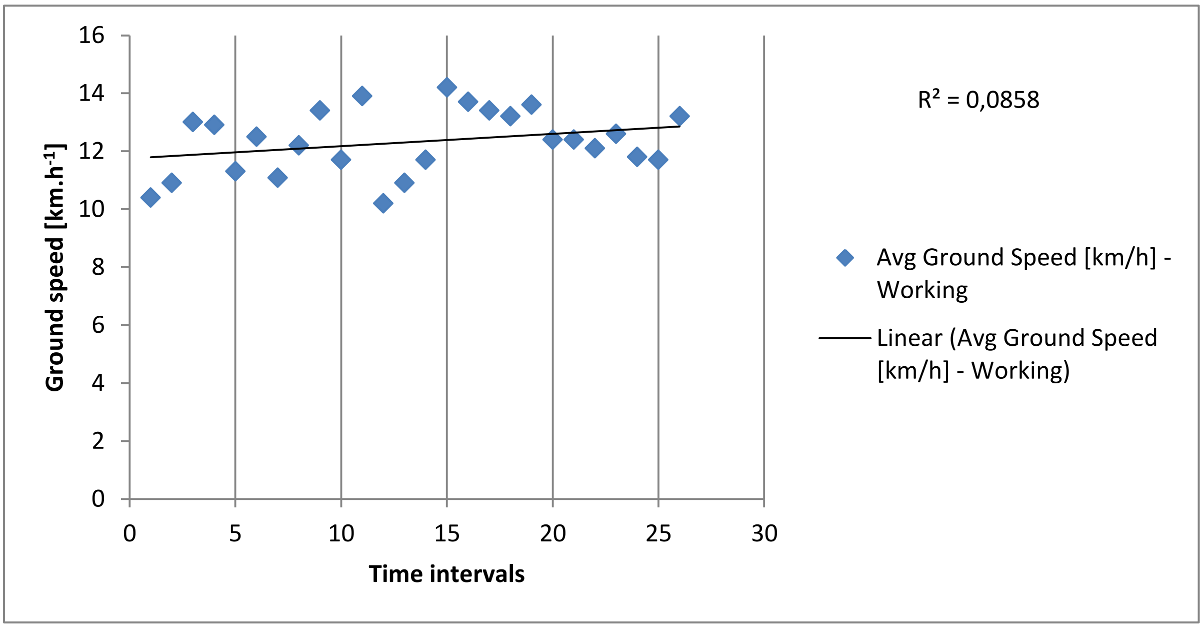

Figure (4.1): Ground speed for implement 1 (Author).

Field efficiency data shown a big variation during the study period, figure (4.2) showed this variation, most of the data are distributed around 64%, with maximum 96% and minimum 0.29%

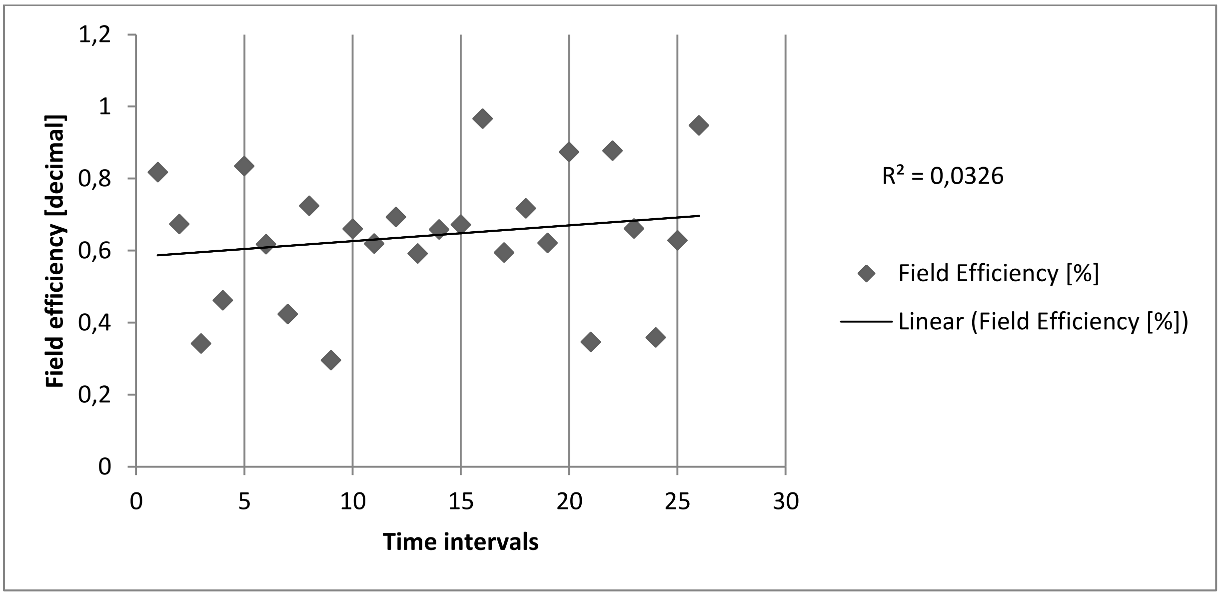

Figure (4.2): Field efficiency for implement 1(Author).

The field capacity data has been changed from 3.16 $ha.h^{-1}$ to 10.59 $ha.h^{-1}$ with average 6.31 $ha.h^{-1}$. As shown in figure (4.3).

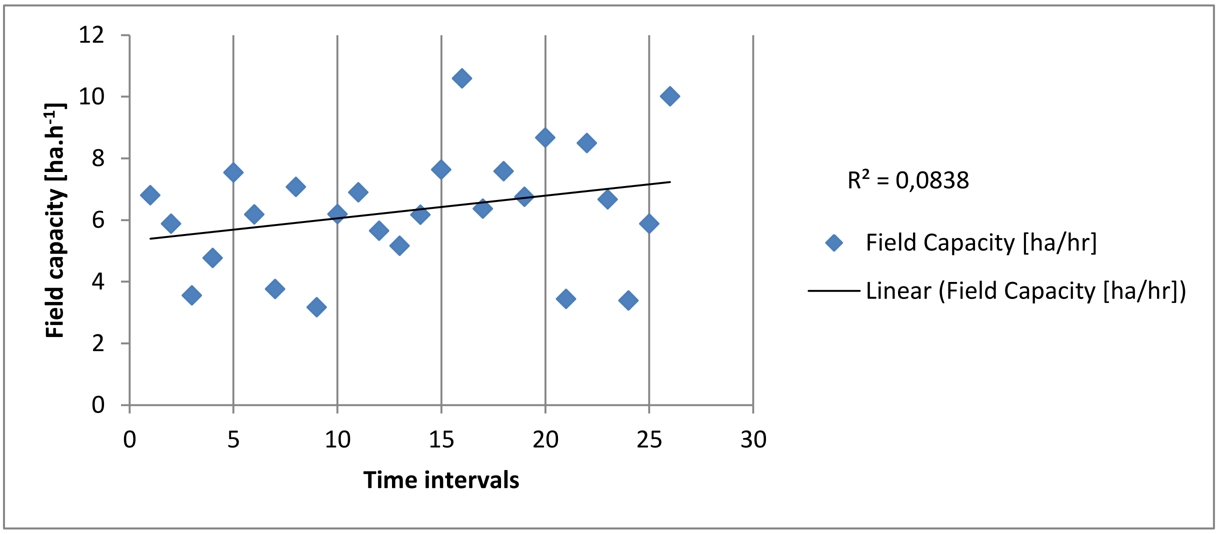

Figure (4.3): Field capacity for implement 1(Author).

The fuel consumption rate (according to the served area) is distributed around 8.85 $l.ha^{-1}$ with maximum value 16.73 $l.ha^{-1}$ and minimum 4.28 $l.ha^{-1}$.

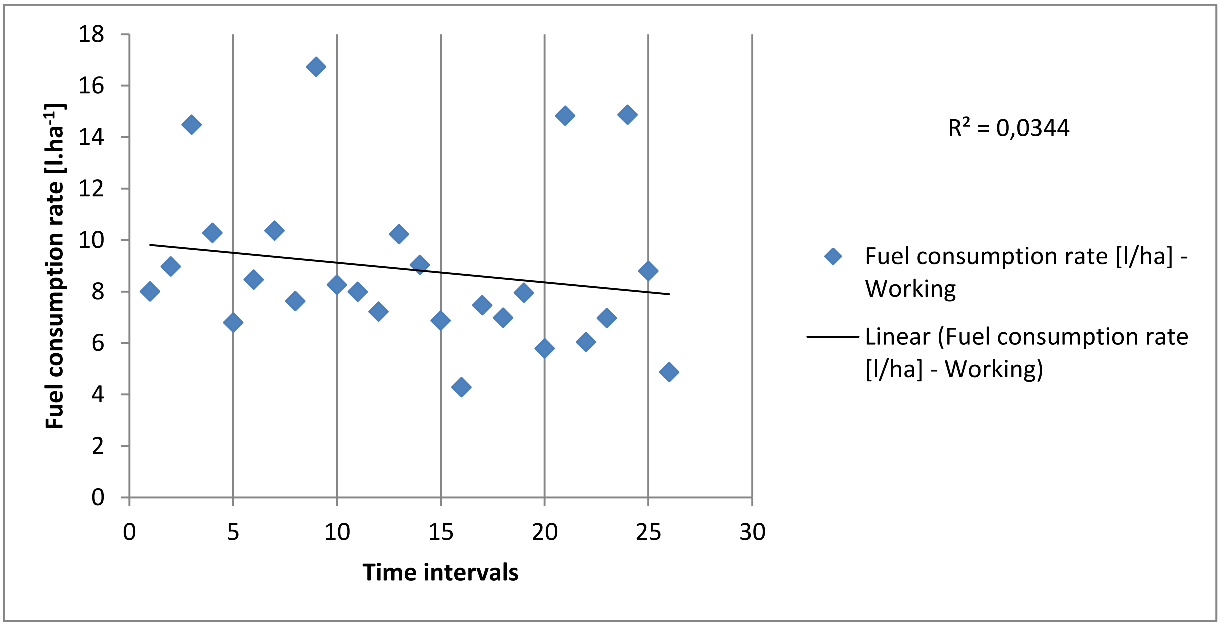

Figure (4.4): Fuel consumption rate (according to the served area) for implement 1(Author).

The data of fuel rate (according to the working time) is distributed around 50.1 $l.h^{-1}$ with maximum value 55.1 $l.h^{-1}$ and minimum value 26.46.

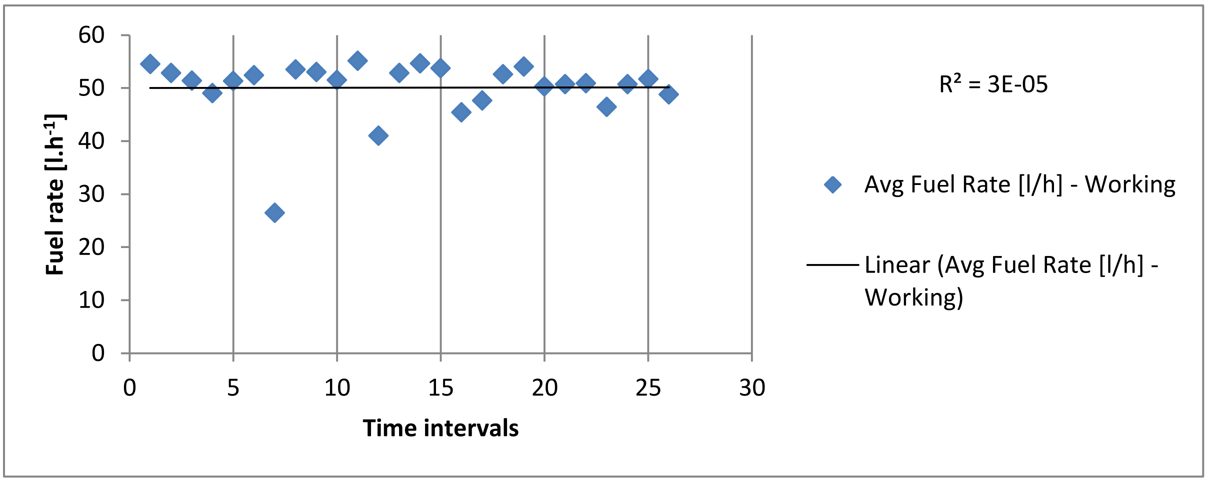

Figure (4.5): Fuel rate (according to the working time) for implement 1(Author).

Engine load factor has been changed around 82.85% with maximum value 90.4% and minimum value 47.43% as shown in figure (4.6).

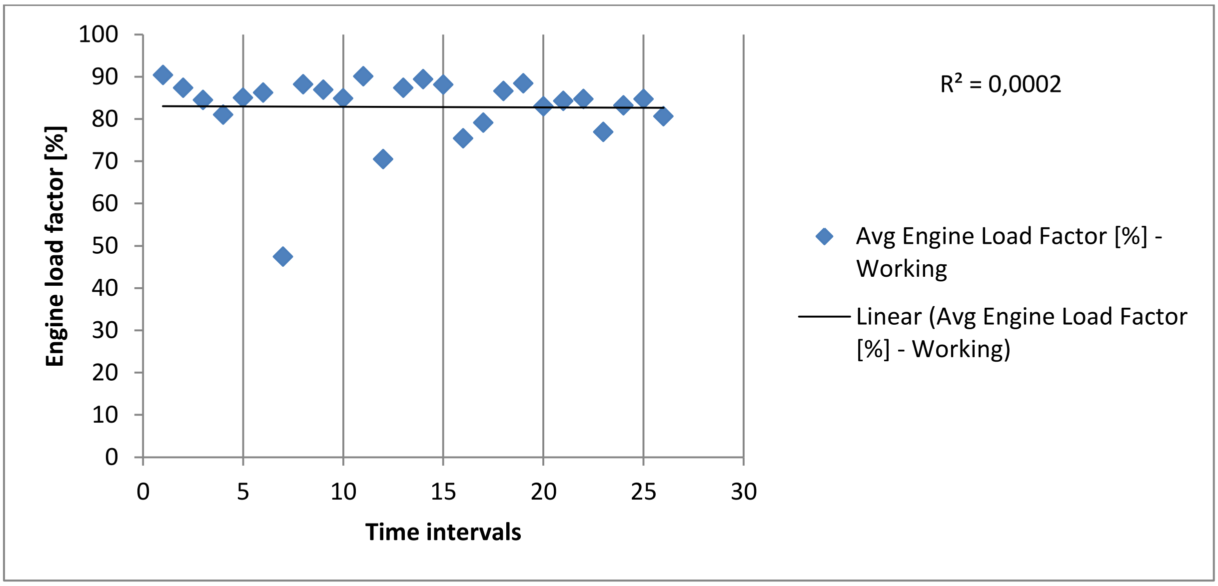

Figure (4.6): Engine load factor for implement 1(Author).

4.1.2 Implement II (Horsch Terrano 6FX):

During the studying period this implement has been registered only one row of data these data are shown in table (4.1)

Table (4.1): The recording data for the implement number 2

date	27.9.2012
total served area [ha]	9
Avg Ground Speed [km.h^{-1}] - Working	13,3
Field Efficiency [decimal]	0,41376907
Field Capacity [ha.h^{-1}]	4,732690622
Fuel consumption rate [l.ha^{-1}] - Working2	5,509550926
Avg Fuel Rate [l.h^{-1}] - Working	26,075
Avg Engine Load Factor [%] - Working	47,35

By (Author)

4.1.3 Implement III (Horsch Tiger 4AS):

Figure (4.7) shows the data of the ground speed it's distributing around 11.68 km.h^{-1} with maximum value 12.6 km.h^{-1} and minimum value 10 km.h^{-1}.

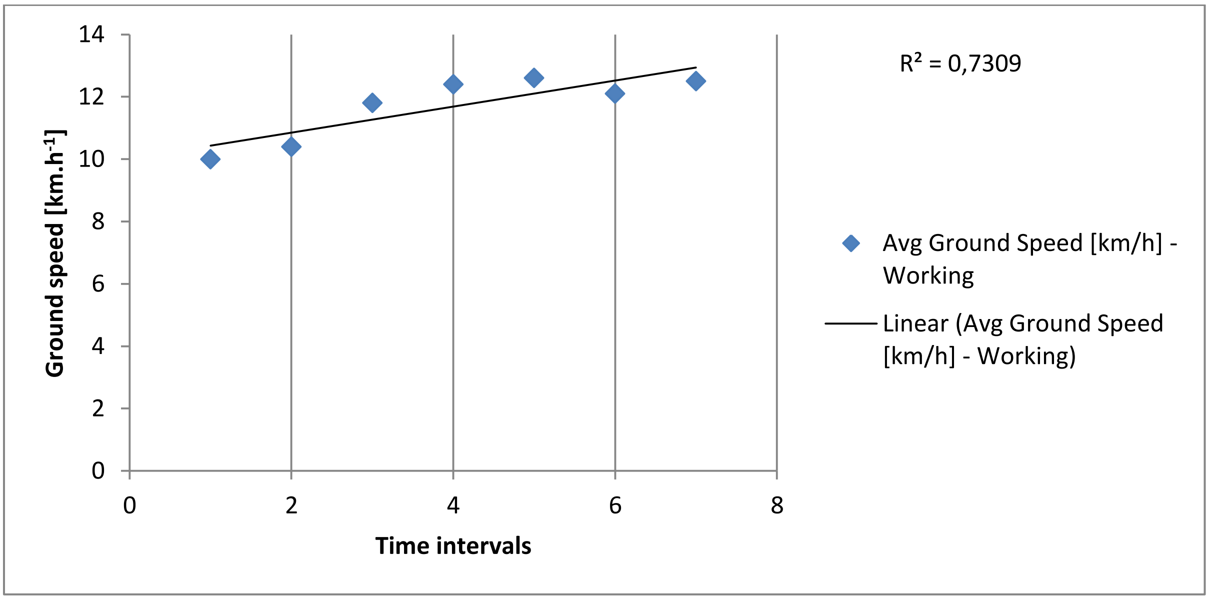

Figure (4.7): Ground speed for implement 3(Author).

The field efficiency has a variation in its values between 32.59% to 80.89% with average 50.80% as shown in figure (4.8)

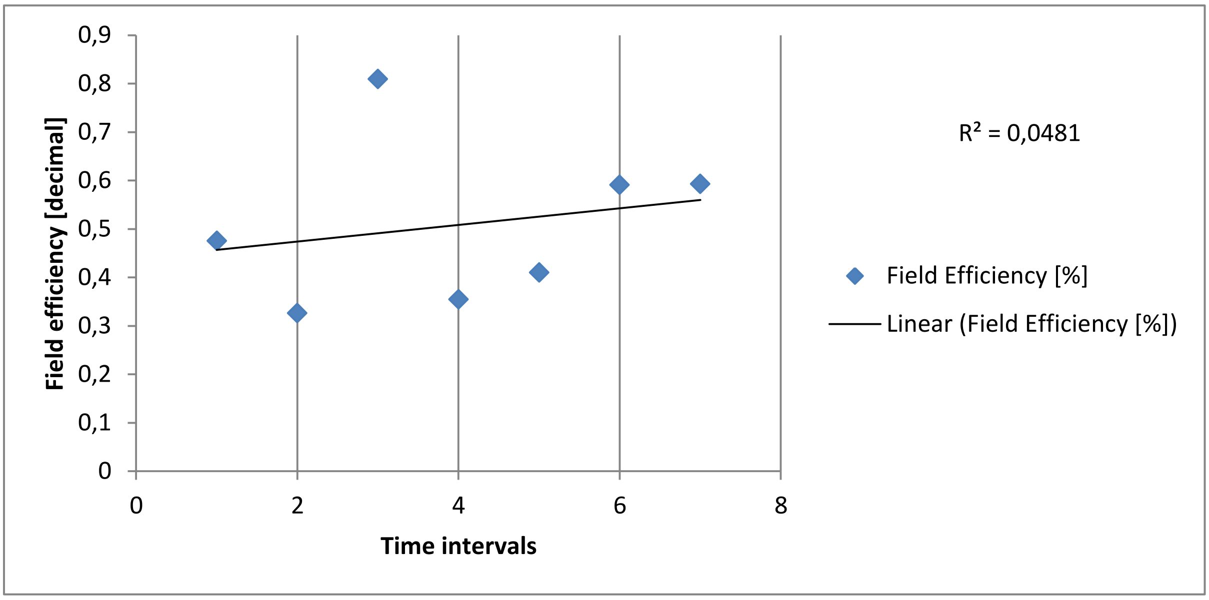

Figure (4.8): Field efficiency for implement 3(Author).

Field capacity is changing from 1.36 $ha.h^{-1}$ to 3.81 $ha.h^{-1}$ with average 2.39 $ha.h^{-1}$, as shown in figure (4.9).

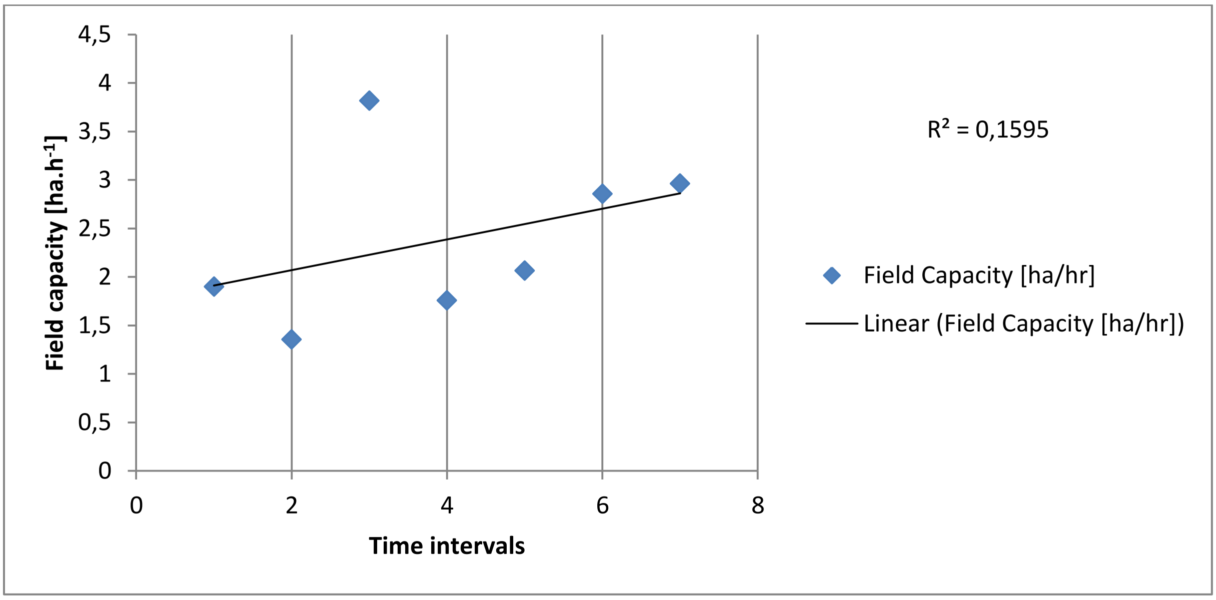

Figure (4.9): Field capacity for implement 3(Author).

Figure (4.10) is showing the fuel rate according to the served area. The fuel rate data is distribute around 25.08 l.ha^{-1} with maximum value 40.31 l.ha^{-1}, and minimum value 12.01 l.ha^{-1}.

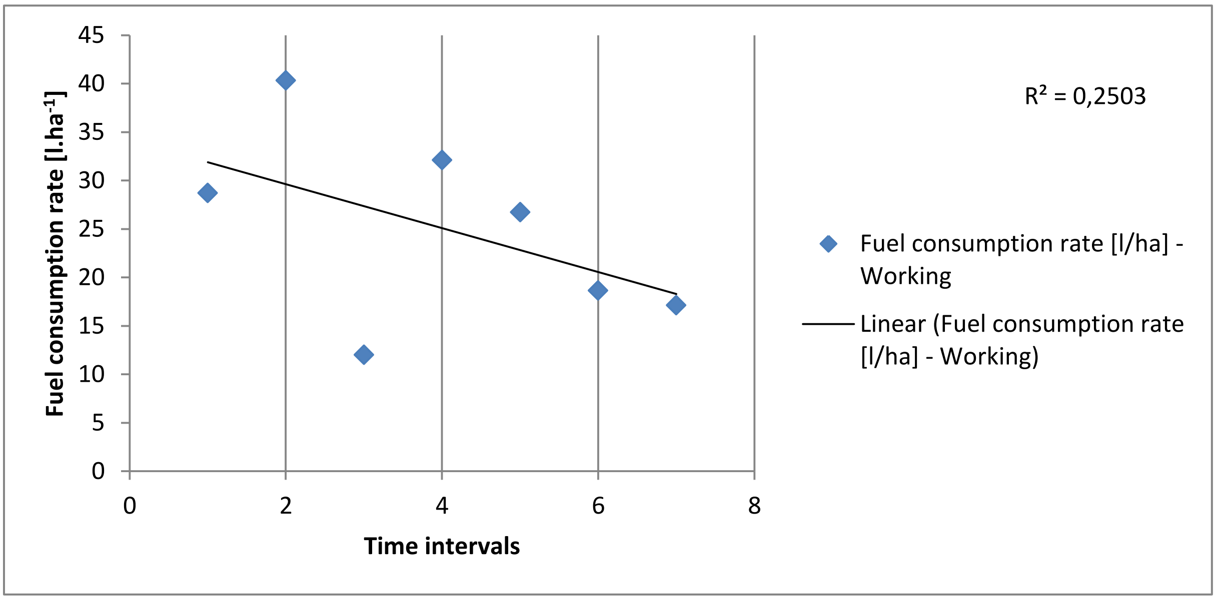

Figure (4.10): Fuel consumption rate (according to the served area) for implement 3(Author).

Fuel rate according to the working time has not very variable data as shown in figure (4.11). The average value of the fuel rate is 52.78 l.h^{-1}, the maximum value is 56.00 l.h^{-1} and the minimum value is 45.90 l.h^{-1}.

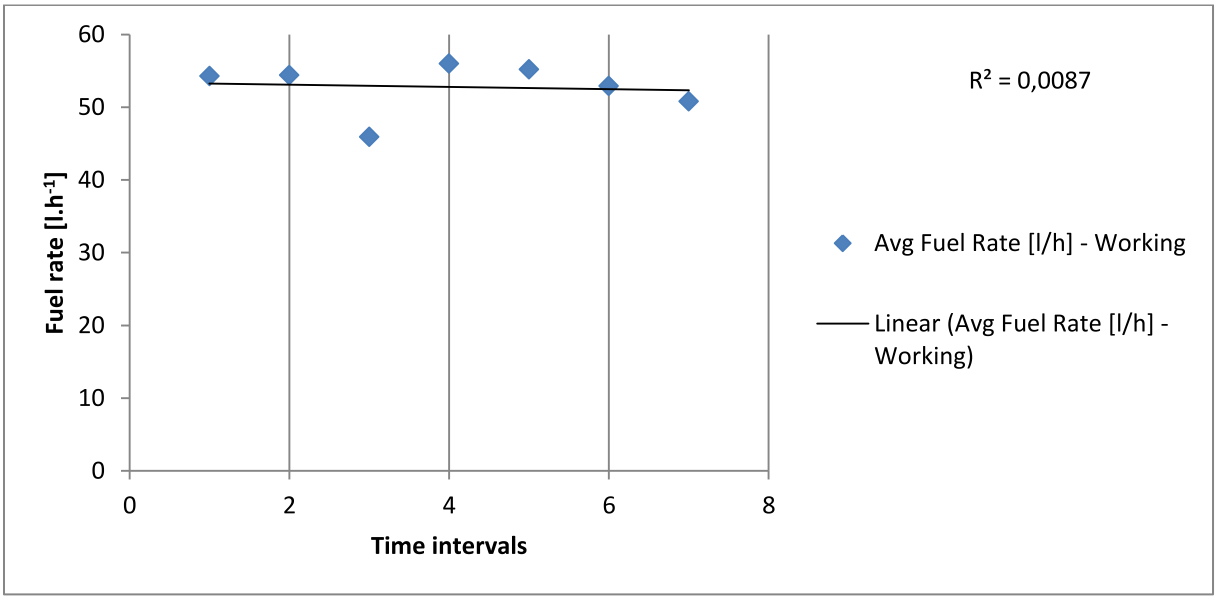

Figure (4.11): Fuel rate (according to the working time) for implement 3 (Author).

Engine load factor data is distributing around 86.78% with maximum and minimum values 91.60% and 76.90% respectively.

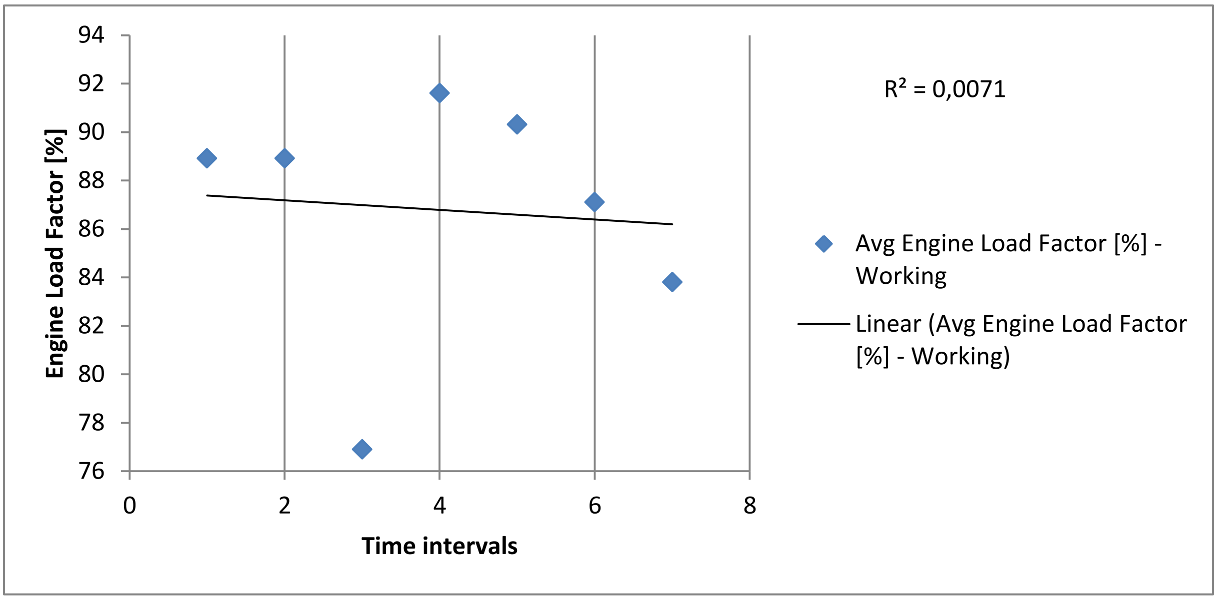

Figure (4.12): Engine load factor for implement 3 (Author).

4.1.4 Implement IV (Kverneland PW100):

The data of ground speed is distributing around 8.54 $km.h^{-1}$ with minimum speed 7.4 $km.h^{-1}$ and maximum 10.7 $km.h^{-1}$ as shown in the figure (4.13)

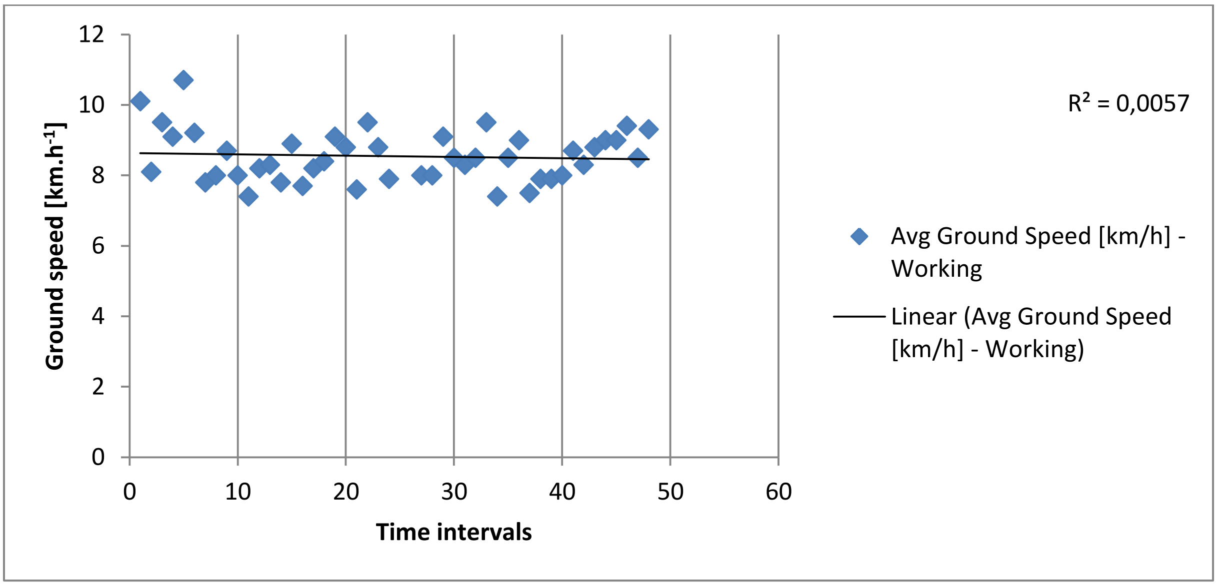

Figure (4.13): Ground speed for implement 4 (Author).

The field capacity data is distributed around 69.18% between 91.22% as a maximum value and 29.31% as a minimum value as shown in figure (4.14).

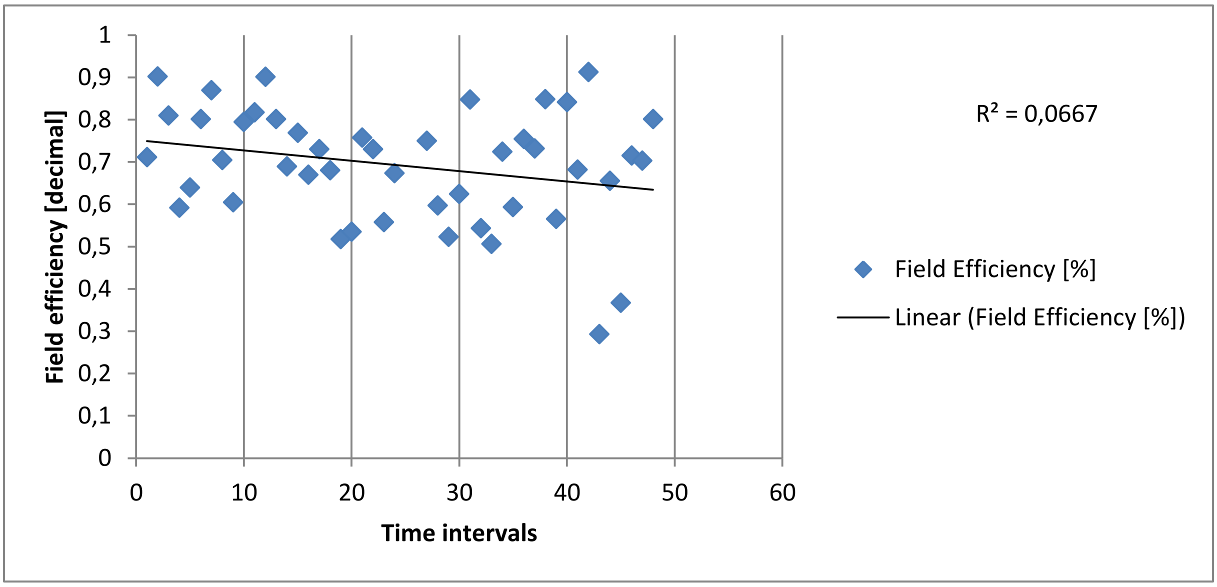

Figure (4.14): Field efficiency for implement 4 (Author).

Figure (4.15) shows the field capacity data. The average value is 1.91 ha.h^{-1}, the maximum value is 2.5 ha.h^{-1} and the minimum value is 0.84 ha.h^{-1}.

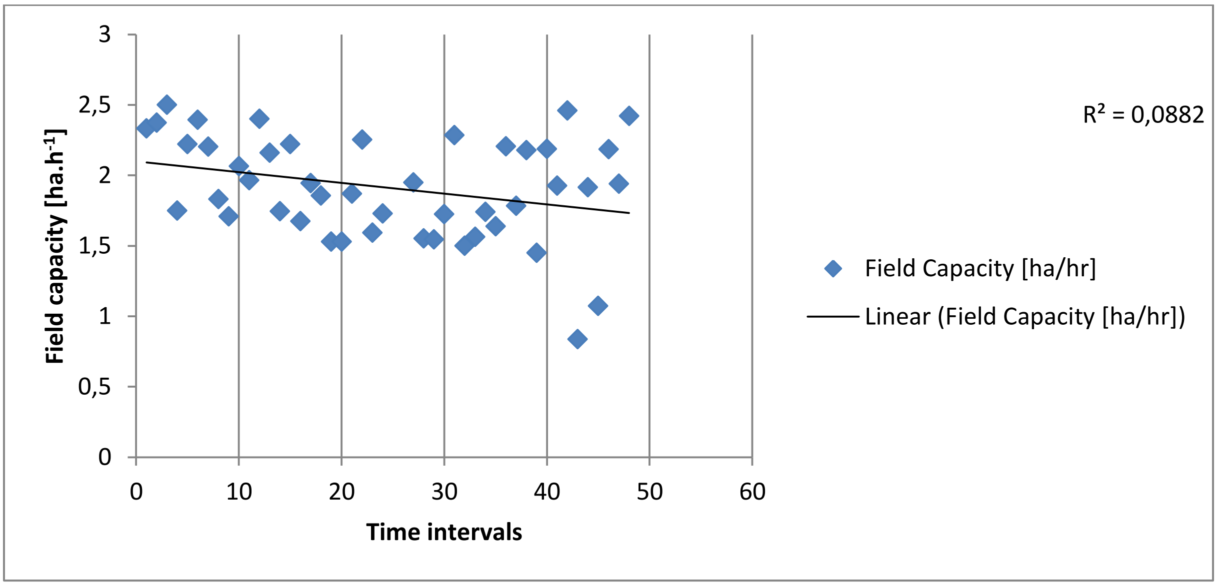

Figure (4.15): Field capacity for implement 4 (Author).

The fuel consumption rate data (according to the served area) is shown in figure (4.16) with average 21.94 $l.ha^{-1}$, maximum 55.71 $l.ha^{-1}$ and minimum 13.44 $l.ha^{-1}$.

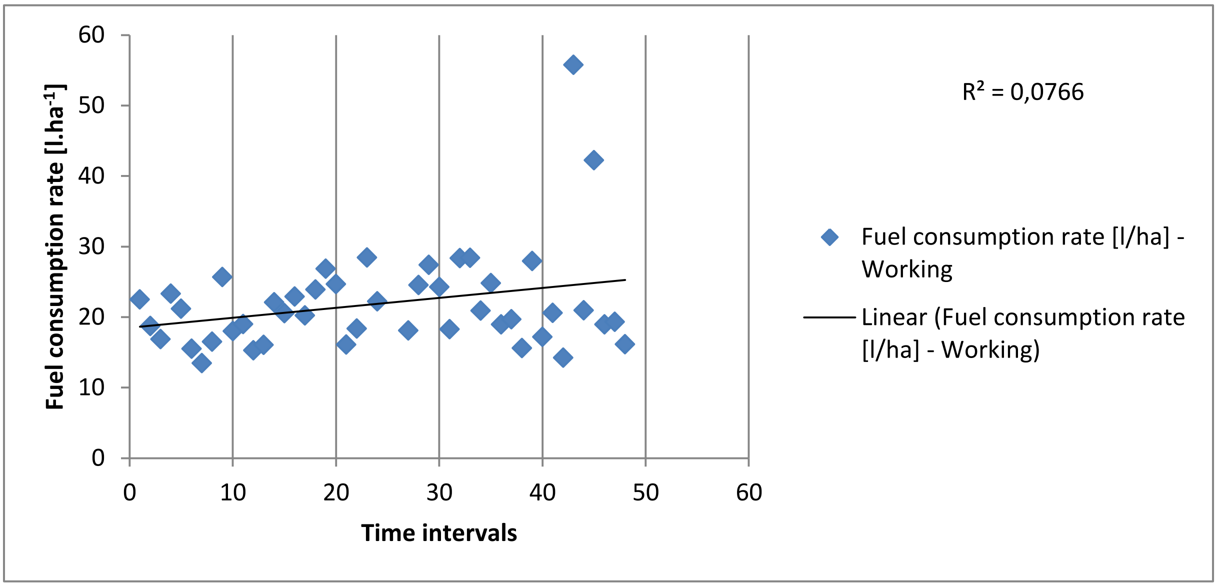

Figure (4.16): Fuel consumption rate (according to the served area) for implement 4 (Author).

The data of fuel rate according to the working time is distributed around 39.54 $l.h^{-1}$ between 29.60 $l.h^{-1}$ and 51.90 $l.h^{-1}$ as shown in figure (4.17).

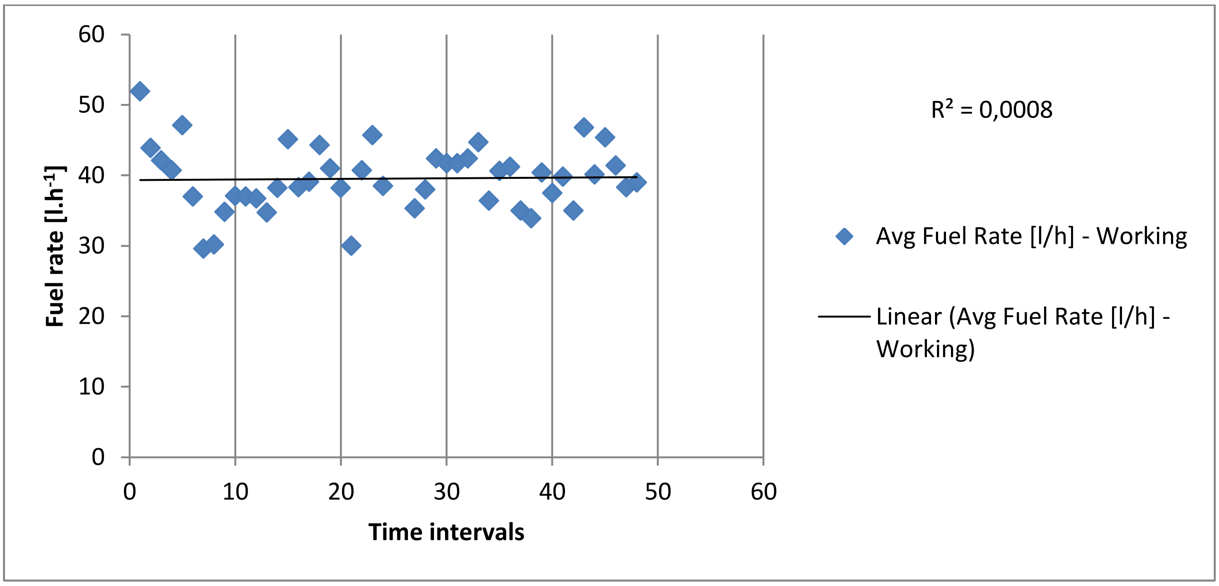

Figure (4.17): Fuel rate (according to the working time) for implement 4 (Author).

The data of engine load factor has 68.21% as average, minimum 54.00% and maximum 85.70%

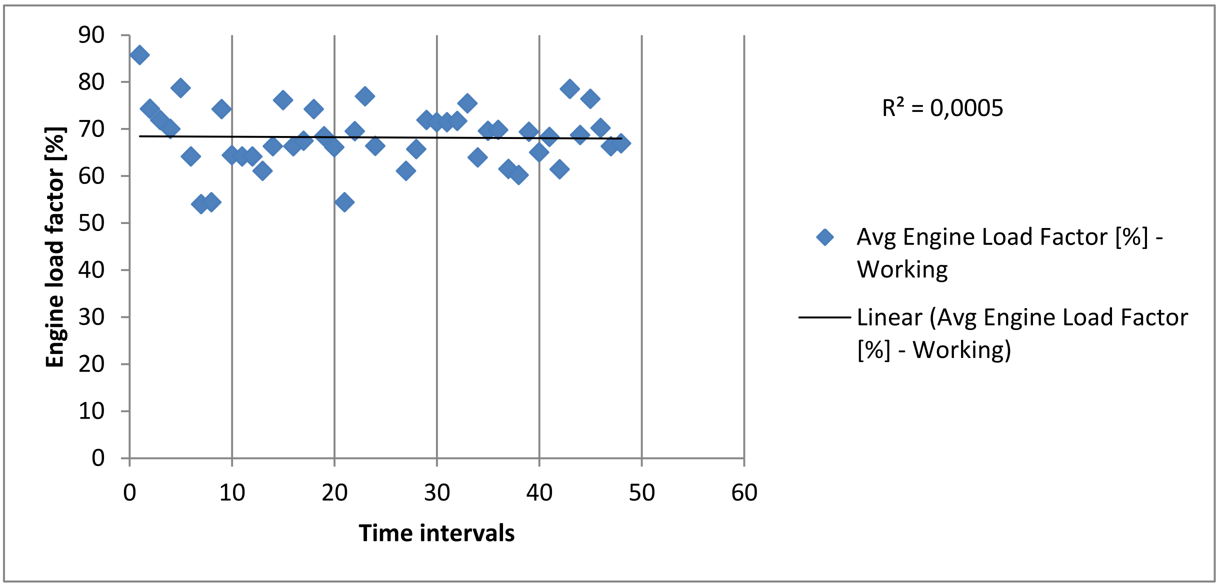

Figure (4.18): Engine load factor for implement 4 (Author).

4.1.5 Discussion:

The graphs of field efficiency and the graphs of the field capacity have the same shapes and the graphs of the fuel rate according to the served area are reflect the shapes of the previous graphs, because of all of them are using the same parameters in them calculations. The big variation in the data of field efficiency, field capacity and fuel consumption rate according to the area is goes to the different of the field and operating conditions in the working time (see section 2.3.1.2). The variation of soil resistance during working time has the main reason of these variations, as well the different of the land topography may effect on the field capacity and similarly in the field efficiency, or maybe there are some mistakes in the manual collecting data in the farm specially the data of served area.

The data of fuel rate (according to the working time), ground speed and engine load have approximately similar inclination and small amount of variation.

4.2 Comparison between the implements:

From the previous the implement number 3 shows the largest amount of fuel consumption according to the working time 52.78 $l.h^{-1}$ and according to the served area 25.08 $l.ha^{-1}$ as shown in figure (4.19).

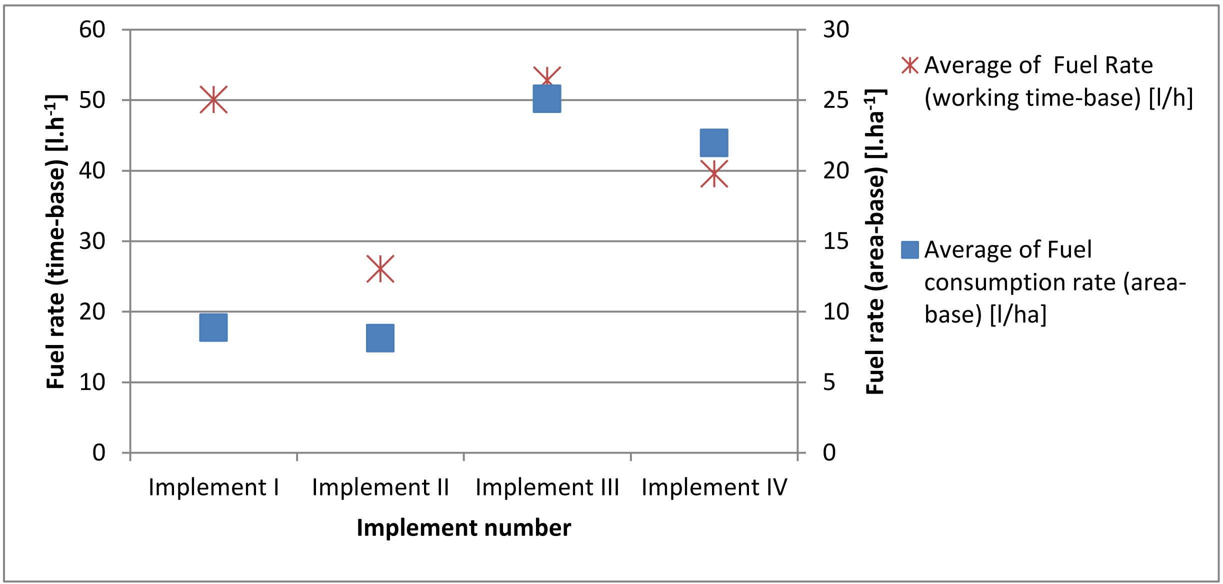

Figure (4.19): Fuel rate area-base and time-base for the 4 implements (Author).

The comparing between average engine load factor and average ground speed for the implements shows that: Implement 3 has the maximum value of engine load factor. However, the implement 2 has the maximum value of the ground speed and implement 4 has the lowest value of the ground speed as shown in figure (4.20).

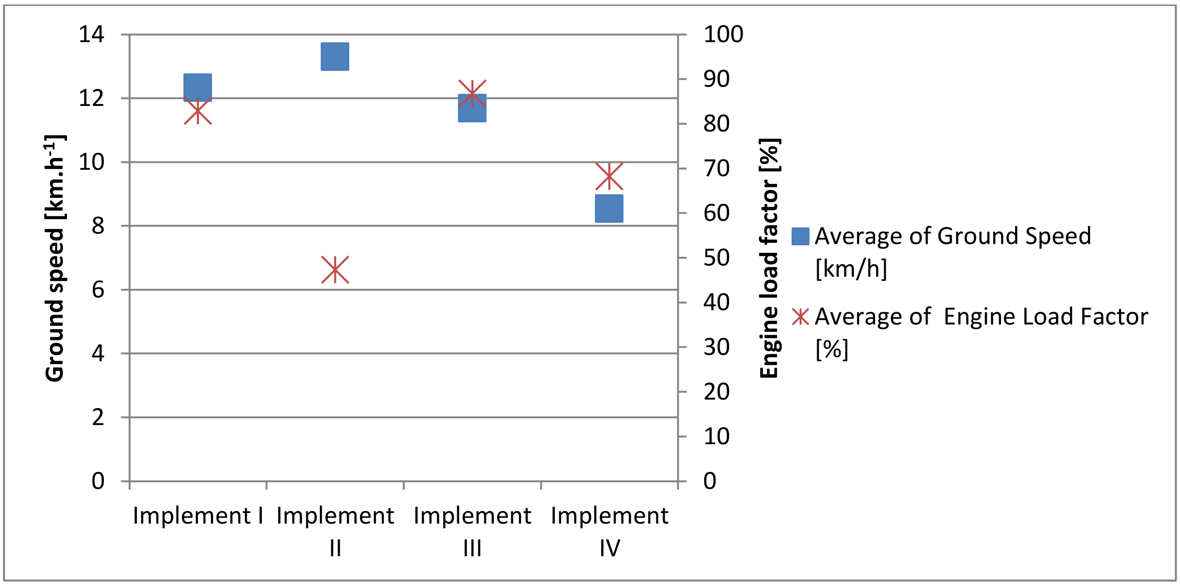

Figure (4.20): Fuel rate area-base and time-base for the 4 implements (Author).

The comparing between the average field capacity for the four implements in figure (4.21) shows that: The implement 1 achieved the highest value of field capacity. However, implement 4 has the lowest value.

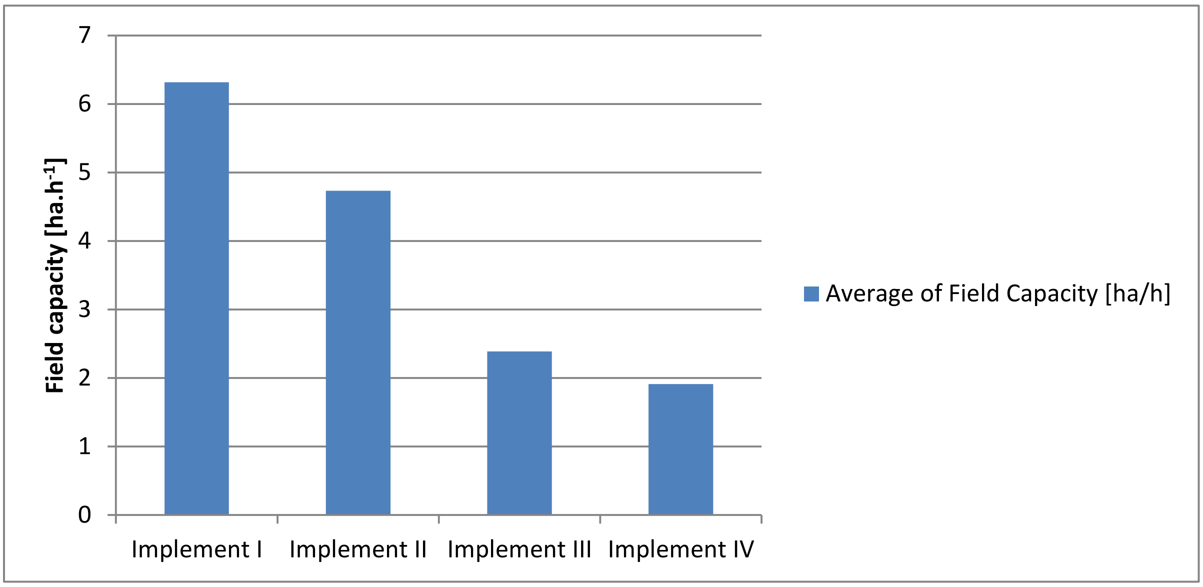

Figure (4.21): Average field capacity for the 4 implements (Author).

In figure (4.22) the comparing between the average field efficiency shows that: implement number 4 achieved the best field efficiency. However, implement 2 has the lowest value.

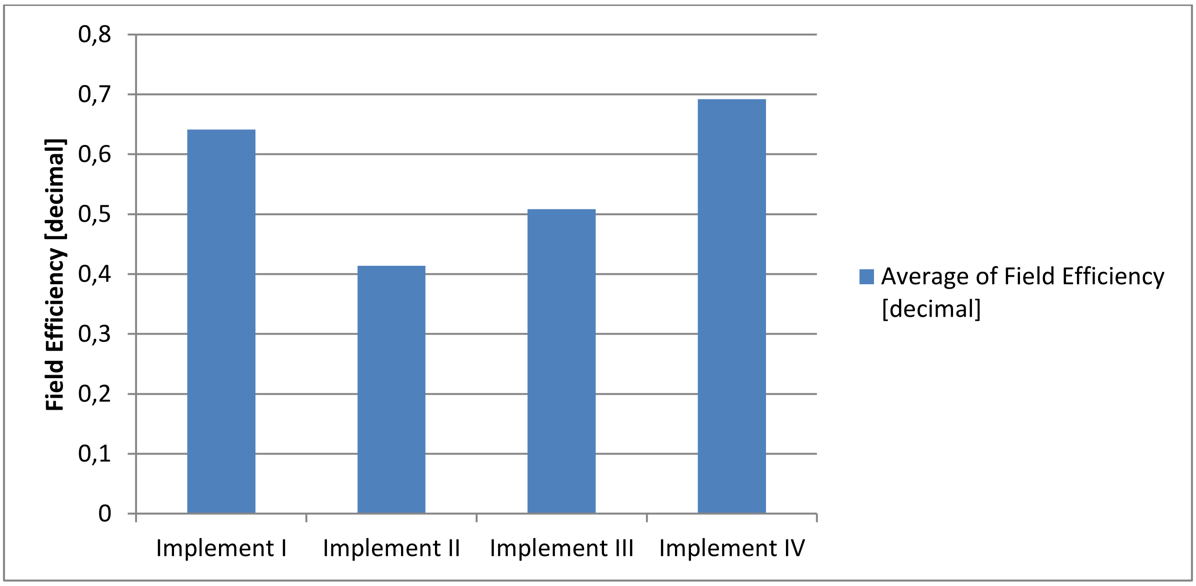

Figure (4.22): Average field efficiency for the 4 implements (Author).

4.2.1 Discussion:

The fuel consumption is strongly influenced by the engine load factor, the higher is the engine load the higher is the value of fuet consuption per hour.There are no effective difference between the engine load factor, and the fuel consumption for the comparison among the implements according to the energy demands. (Appendix-H (a)) shows the relationship between the engine load factor and the fuel rate, this figure shows the strong correlation between these two factors with r square value 0.98 (Appendix-H (b)). As well between engine load and engine speed r square is 0.94 and between engine speed and fuel rate 0.934 (Appendix-H (c)).

Horsch Tiger 4AS achieved the biggest amount of fuel consumption rates and engine load factor because of this implement has the highest amount of the power demand to overcome the soil cutting resistance. As shown in section (2.4.2) the draft requirement for the tillage tools is a function of many parameters. These parameters are (working depth and width, ground speed, tool geometry parameters, soil bulk density and soil cone index). Some of these factors we don’t have a chance to change it such as the soil parameters. However, the implement Horsch Tiger 4AS has 35 cm of working depth, 4 m width, when the minimum value of the energy consumption goes to Horsch Terrano 6FX which has 15-20 cm of working depth and 5.8 m of working width.

The explanation for the value of the field capacity is because of the variation among the ground speed for each implement is not much high so that the effective factor of the field capacity is the working width. In that case Farmet K 800 with 8 m working width will achieve the first grade according to the field capacity; the second will be for Horsch Terrano 6FX with width 5.8 m, the third level will be for Horsch Tiger 4AS with width 4 m and finally the last grade for Kverneland PW100 with average width 3.25 m.

Horsch Terrano 6FX is not suitable to match with the tractor John Deere 8320R which has 235 kW, because it uses only 47.35% from the engine load as shown in figue (4.24).

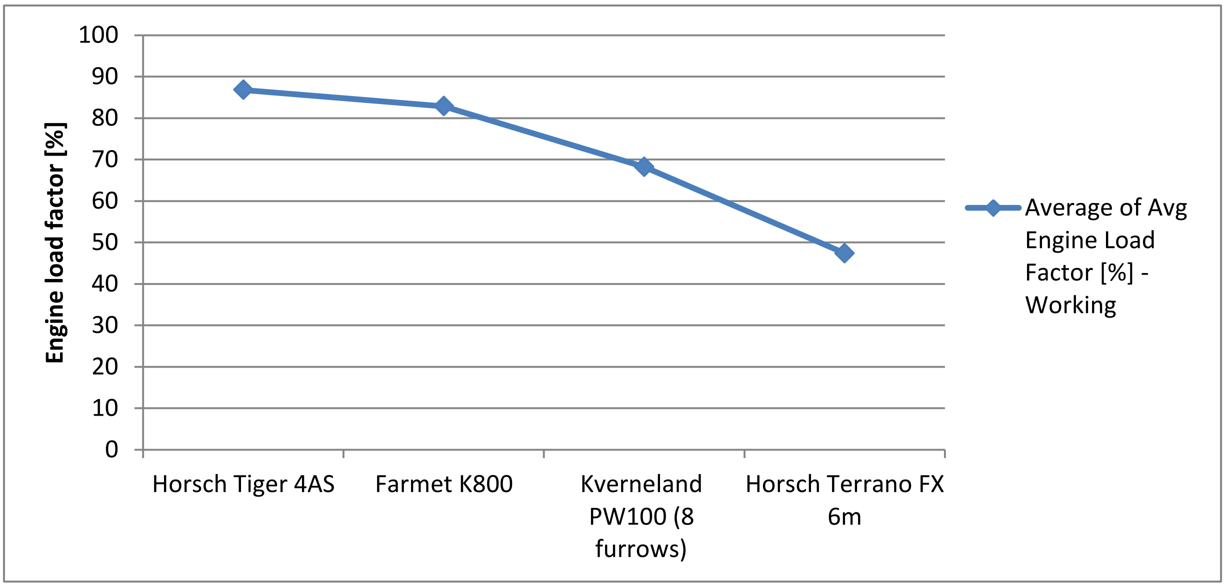

Figure (4.23): Engine load factor for the 4 implements (Author).

5. CONCLUSIONS

- The work shows how the telematics system data can be used to improve the machine performance and improve the productivity of the operation, and how to manage the farm by matching the suitable tractor with the selected implements. As well the work shows how to judge the management method which is used in the farm.
- The telematics system data is very good indicator to the performance of the machine and the operator.
- The improving in telematics systems will lead to reduction of the impacts on environment.
- I recommend to develop a tools that can facilitate the recording of the field acreage covered by the machinery, tank fillingvalues and the operator identity side-by side to the data which are allowable on the system. Also the weather conditions are sometimes considered as the limiting factor which has effect on the performance of the machine and operator, as well the field parameters such as soil properties and the shape and topography of the field.
- The good tractor-implement matching enables savings in terms of costs spent on the energy requirements.

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APPENDICES

Appendix-A: Draft parameters and an expected range in drafts estimated by the model parameters for tillage and seeding implements.

Appendix-B: Draft parameters and an expected range in drafts estimated by the model parameters for tillage and seeding implements.

Appendix-C: Field efficiency, field speed, and repair and maintenance cost parameters.

Appendix-D: Comparing between the fuel rate and engine load factor.

Appendix-E: Comparing between the fuel rate and engine speed.

Appendix-F: Comparing between the engine speed and engine load factor.

Appendix-G: Chart for all of the collected data.

Appendix-H: The relationships between a) engine load factor and fuel rate; b) Engine load factor and engine speed; c) Engine speed and fuel rate.

Appendix A

Draft parameters and an expected range in drafts estimated by the model parameters for tillage and seeding implements

Implement	Width units	Machine Parameters			Soil Parameters			Range ±%
		A	B	C	F1	F2	F3	
MAJOR TILLAGE TOOLS								
Subsoiler/Manure Injector								
narrow point	tools	226	0,0	1,8	1,0	0,70	0,45	50
30 cm winged point	tools	294	0,0	2,4	1,0	0,70	0,45	50
Moldboard Plow	m	652	0,0	5,1	1,0	0,70	0,45	40
Chisel Plow								
5 cm straight point	tools	91	5,4	0,0	1,0	0,85	0,65	50
7.5 cm shovel/35 cm sweep	tools	107	6,3	0,0	1,0	0,85	0,65	50
10 cm twisted shovel	tools	123	7,3	0,0	1,0	0,85	0,65	50
Sweep Plow								
primary tillage	m	390	19,0	0,0	1,0	0,85	0,65	45
secondary tillage	m	273	13,3	0,0	1,0	0,85	0,65	35
Disk Harrow, Tandem								
primary tillage	m	309	16,0	0,0	1,0	0,88	0,78	50
secondary tillage	m	216	11,2	0,0	1,0	0,88	0,78	30
Disk Harrow, Offset								
primary tillage	m	364	18,8	0,0	1,0	0,88	0,78	50
secondary tillage	m	254	13,2	0,0	1,0	0,88	0,78	30
Disk Gang, Single								
primary tillage	m	124	6,4	0,0	1,0	0,88	0,78	25
secondary tillage	m	86	4,5	0,0	1,0	0,88	0,78	20
Coulters								
smooth or ripple	tools	55	2,7	0,0	1,0	0,88	0,78	25
bubble or flute	tools	66	3,3	0,0	1,0	0,88	0,78	25
Field Cultivator								
primary tillage	tools	46	2,8	0,0	1,0	0,85	0,65	30
secondary tillage	tools	32	1,9	0,0	1,0	0,85	0,65	25
Row Crop Cultivator								
S-tine	rows	140	7,0	0,0	1,0	0,85	0,65	15
C-shank	rows	260	13,0	0,0	1,0	0,85	0,65	15
No-till	rows	435	21,8	0,0	1,0	0,85	0,65	20
Rod Weeder	m	210	10,7	0,0	1,0	0,85	0,65	25
Disk-Bedder	rows	185	9,5	0,0	1,0	0,88	0,78	40
MINOR TILLAGE TOOLS								
Rotary Hoe	m	600	0,0	0,0	1,0	1,00	1,00	30
Coil Tine Harrow	m	250	0,0	0,0	1,0	1,00	1,00	20
Spike Tooth Harrow	m	600	0,0	0,0	1,0	1,00	1,00	30
Spring Tooth Harrow	m	2000	0,0	0,0	1,0	1,00	1,00	35

Roller Packer	m	600	0,0	0,0	1,0	1,00	1,00	50
Roller Harrow	m	2600	0,0	0,0	1,0	1,00	1,00	50
Land Plane	m	8000	0,0	0,0	1,0	1,00	1,00	45
SEEDING IMPLEMENTS								
Row Crop Planter, prepared seedbed								
mounted								
seeding only	rows	500	0,0	0,0	1,0	1,00	1,00	25
drawn								
seeding only	rows	900	0,0	0,0	1,0	1,00	1,00	25
seed, fertilizer, herbicides	rows	1550	0,0	0,0	1,0	1,00	1,00	25
Row Crop Planter, no-till								
seed, fertilizer, herbicides								
1 fluted coulter/row	rows	1820	0,0	0,0	1,0	0,96	0,92	25
Row Crop Planter, zone-till								
seed, fertilizer, herbicides								
3 fluted coulters/row	rows	3400	0,0	0,0	1,0	0,94	0,82	35
Grain Drill w/press wheels								
<2.4 m drill width	rows	400	0,0	0,0	1,0	1,00	1,00	25
2.4 to 3.7 m drill width	rows	300	0,0	0,0	1,0	1,00	1,00	25
>3.7 m drill width	rows	200	0,0	0,0	1,0	1,00	1,00	25
Grain Drill, no-till								
1 fluted coulter/row	rows	720	0,0	0,0	1,0	0,92	0,79	35
Hoe Drill								
primary tillage	m	6100	0,0	0,0	1,0	1,00	1,00	50
secondary tillage	m	2900	0,0	0,0	1,0	1,00	1,00	50
Pneumatic Drill	m	3700	0,0	0,0	1,0	1,00	1,00	50

Source: (ASABE D497, 2011)

Appendix B

Rotary power requirement parameters

Machine type	Parameter a [kW]	Parameter b [kW/m]	Parameter c [kWh/t]	Range[1)] ±%
Baler, small rectangular	2.0	0	1.0[2)]	35
Baler, large rectangular bales	4.0	0	1.3	35
Baler, large round (var. chamber)	4.0	0	1.1	50
Baler, large round (fix. chamber)	2.5	0	1.8	50
Beet harvester[3)]	0	4.2	0	50
Beet topper	0	7.3	0	30
Combine, small grains	20.0	0	3.6[4)]	50
Combine, corn	35.0	0	1.6[4)]	30
Cotton picker	0	9.3	0	20
Cotton stripper	0	1.9	0	20
Feed mixer	0	0	2.3	50
Forage blower	0	0	0.9	20
Flail harvester, direct-cut	10.0	0	1.1	40
Forage harvester, corn silage	6.0	0	3.3[5)]	40
Forage harvester, wilted alfalfa	6.0	0	4.0[5)]	40
Forage harvester, direct-cut	6.0	0	5.7[5)]	40
Forage wagon	0	0	0.3	40
Grinder mixer	0	0	4.0	50
Manure spreader	0	0	0.2	50
Mower, cutterbar	0	1.2	0	25
Mower, disk	0	5.0	0	30
Mower, flail	0	10.0	0	40
Mower-conditioner, cutterbar	0	4.5	0	30
Mower-conditioner, disk	0	8.0	0	30
Potato harvester[3)]	0	10.7	0	30
Potato windrower	0	5.1	0	30
Rake, side delivery	0	0.4	0	50
Rake, rotary	0	2.0	0	50
Tedder	0	1.5	0	50
Tub grinder, straw	5.0	0	8.4	50
Tub grinder, alfalfa hay	5.0	0	3.8	50
Windrower/swather, small grain	0	1.3	0	40

[1)]Range in average power requirement due to differences in machine design, machine adjustment, and crop conditions.

[2)]Increase by 20% for straw.

[3)]Total power requirement must include a draft of 11.6 kN/m (40%) for potato harvesters and 5.6 kN/m (40%) for beet harvesters. A row spacing of 0.86 m for potatoes and 0.71 m for beets is assumed.

[4)]Based upon material-other-than-grain, MOG, throughput for small grains and grain throughput for corn. For a PTO driven machine, reduced parameter a by 10 kW.

5)Throughput is units of dry matter per hour with a 9 mm (0.35 in.) length of cut. At a specific throughput, a 50% reduction in the length of cut setting or the use of a recutter screen increases power 25%.

Source (ASABE D497, 2011)

Appendix C

Field efficiency, field speed, and repair and maintenance cost parameters.

Machine	Field efficiency		Field speed		Estimated life	Total life R&M cost	Repair factors	
	Range %	Typical %	Range [km/h]	Typical [km/h]	h	% of list price	RF1	RF2
TRACTORS								
2 Wheel drive & stationary					12 000	100	0,007	2,0
4 Wheel drive & crawler					16 000	80	0,003	2,0
TILLAGE & PLANTING								
Moldboard plow	70-90	85	5,0-10,0	7,0	2 000	100	0,29	1,8
Heavy-duty disk	70-91	85	5,5-10,0	7,0	2 000	60	0,18	1,7
Tandem disk harrow	70-92	80	6,5-11,0	10,0	2 000	60	0,18	1,7
(Coulter) chisel plow	70-93	85	6,5-10,5	8,0	2 000	75	0,28	1,4
Field cultivator	70-94	85	8,0-13,0	11,0	2 000	70	0,27	1,4
Spring tooth harrow	70-95	85	8,0-13,0	11,0	2 000	70	0,27	1,4
Roller-packer	70-96	85	7,0-12,0	10,0	2 000	40	0,16	1,3
Mulcher-packer	70-97	80	6,5-11,0	8,0	2 000	40	0,16	1,3
Rotary hoe	70-85	80	13,0-22,5	19,0	2 000	60	0,23	1,4
Row crop cultivator	70-90	80	5,0-11,0	8,0	2 000	80	0,17	2,2
Rotary tiller	70-90	85	2,0-7,0	5,0	1 500	80	0,36	2,0
Row crop planter	50-75	65	6,5-11,0	9,0	1 500	75	0,32	2,1
Grain drill	55-80	70	6,5-11,0	8,0	1 500	75	0,32	2,1
HARVESTING								
Corn picker sheller	6075	65	3,0-6,5	4,0	2 000	70	0,14	2,3
Combine	60-75	65	3,0-6,5	5,0	2 000	60	0,12	2,3
Combine (SP)[1)]	65-80	70	3,0-6,5	5,0	3 000	40	0,04	2,1
Mower	75-85	80	5,0-10,0	8,0	2 000	150	0,46	1,7
Mower (rotary)	75-90	80	8,0-19,0	11,0	2 000	175	0,44	2,0
Mower-conditioner	75-85	80	5,0-10,0	8,0	2 500	80	0,18	1,6
Mower-conditioner (rotary)	75-90	80	8,0-19,0	11,0	2 500	100	0,16	2,0
Windrower (SP)	70-85	80	5,0-13,0	8,0	3 000	55	0,06	2,0
Side delivery rake	70-90	80	6,5-13,0	10,0	2 500	60	0,17	1,4
Rectangular baler	60-85	75	4,0-10,0	6,5	2 000	80	0,23	1,8
Large rectangular baler	70-90	80	6,5-13,0	8,0	3 000	75	0,10	1,8
Large round baler	55-75	65	5,0-13,0	8,0	1 500	90	0,43	1,8
Forage harvester	60-85	70	2,5-8,0	5,0	2 500	65	0,15	1,6
Forage harvester (SP)	60-85	70	2,5-10,0	5,5	4 000	50	0,03	2,0
Sugar beet harvester	50-70	60	6,5-10,0	8,0	1 500	100	0,59	1,3
Potato harvester	55-70	60	2,5-6,5	4,0	2 500	70	0,19	1,4

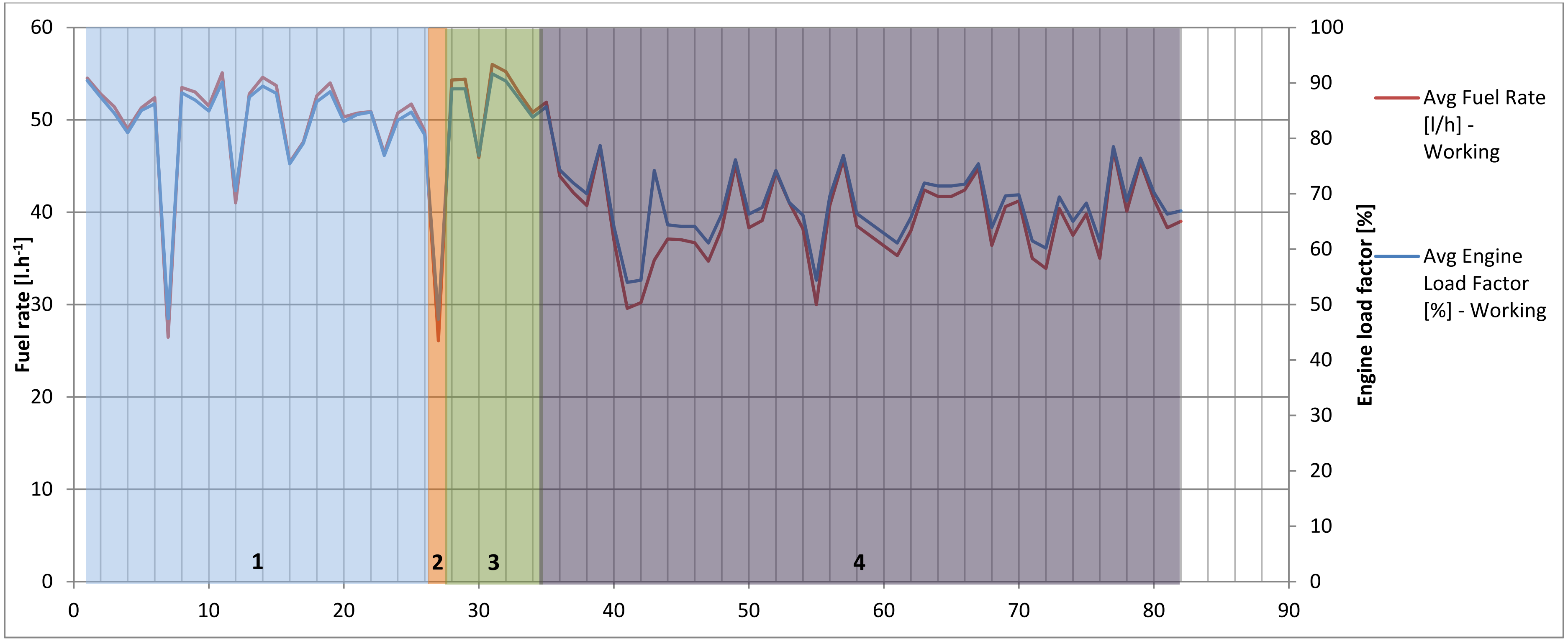
Cotton picker (SP)	60-75	70	3,0-6,0	4,5	3 000	80	0,11	1,8
MISCELLANEOUS								
Fertilizer spreader	60-80	70	8,0-16,0	11,0	1 200	80	0,63	1,3
Boom-type sprayer	50-80	65	5,0-11,5	10,5	1 500	70	0,41	1,3
Air-carrier sprayer	55-70	60	3,0-8,0	5,0	2 000	60	0,20	1,6
Bean puller-windrower	70-90	80	6,5-11,5	8,0	2 000	60	0,20	1,6
Beet topper/stalk chopper	70-90	80	6,5-11,5	8,0	1 200	35	0,28	1,4
Forage blower					1 500	45	0,22	1,8
Forage wagon					2 000	50	0,16	1,6
Wagon					3 000	80	0,19	1,3

1)SP indicates self-propelled machine.

Source ASABE Standard D497 (ASABE, 2011)

Appendix D

Comparing between the fuel rate and engine load factor (Author).



Appendix E

Comparing between the fuel rate and engine speed (Author).

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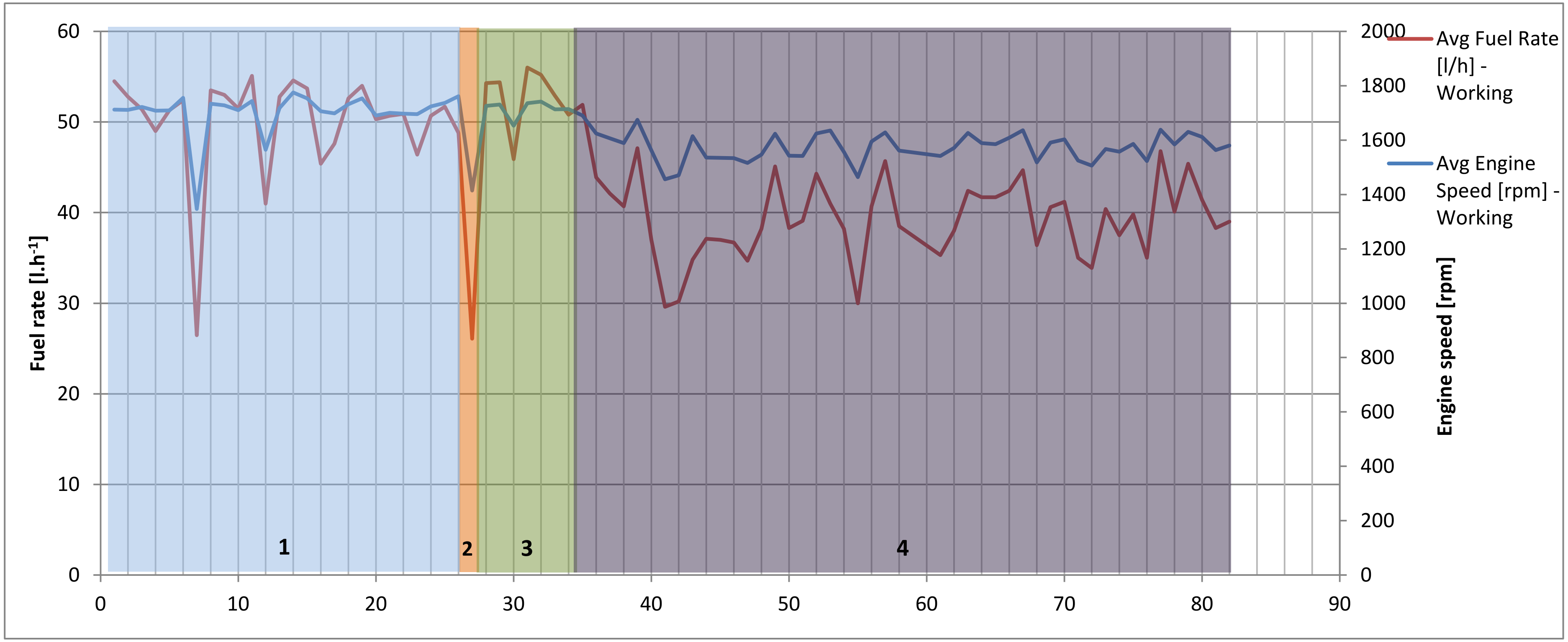
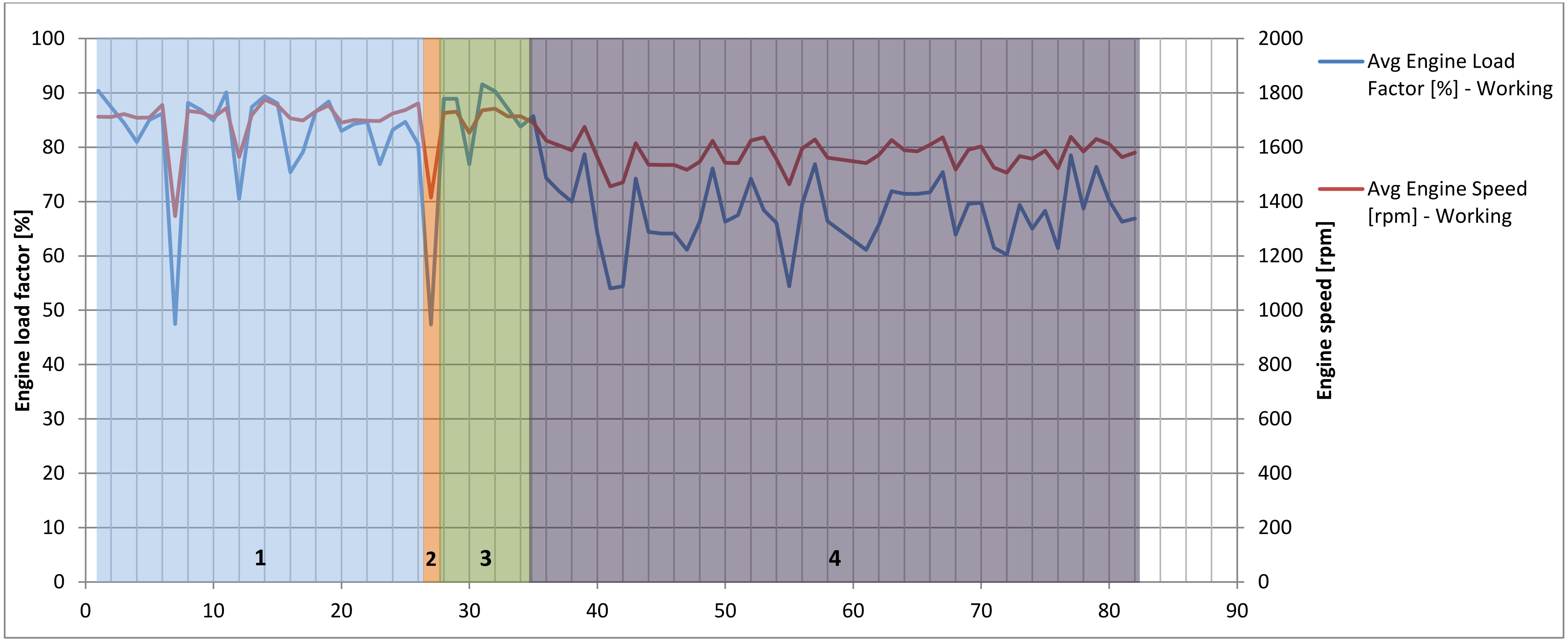


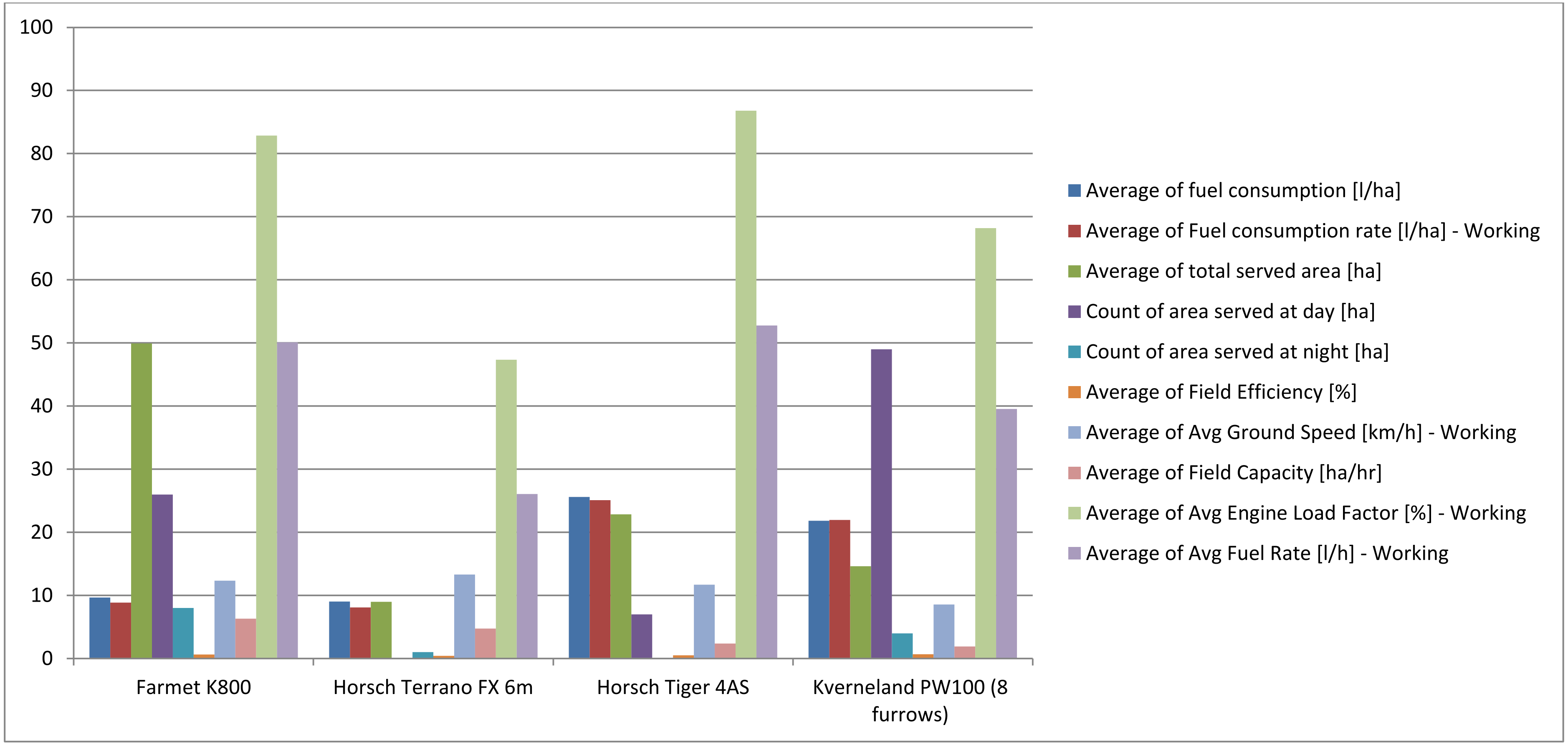
Appendix F

Comparing between the engine speed and engine load factor (Author).

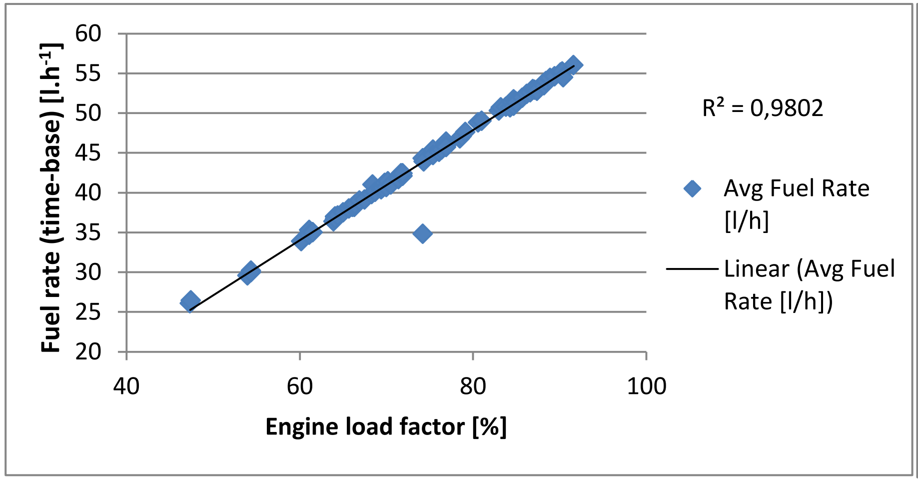


Appendix G

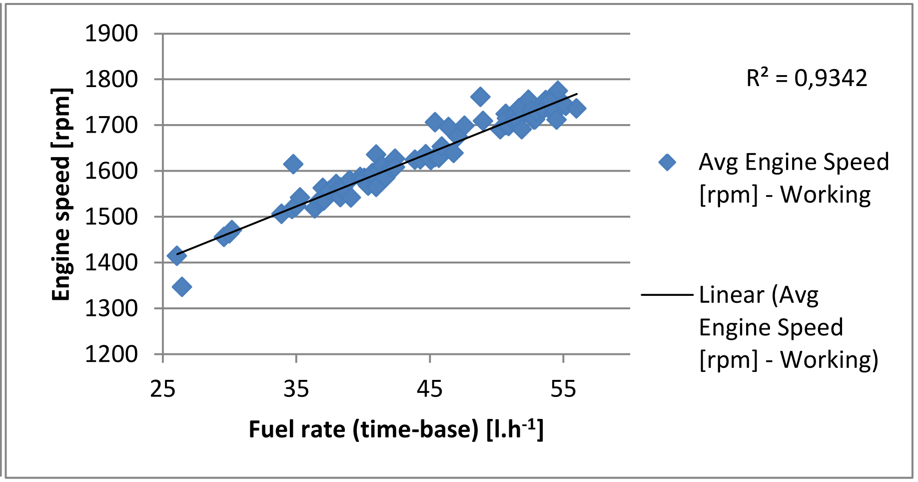
Chart for all of the collected data (Author).



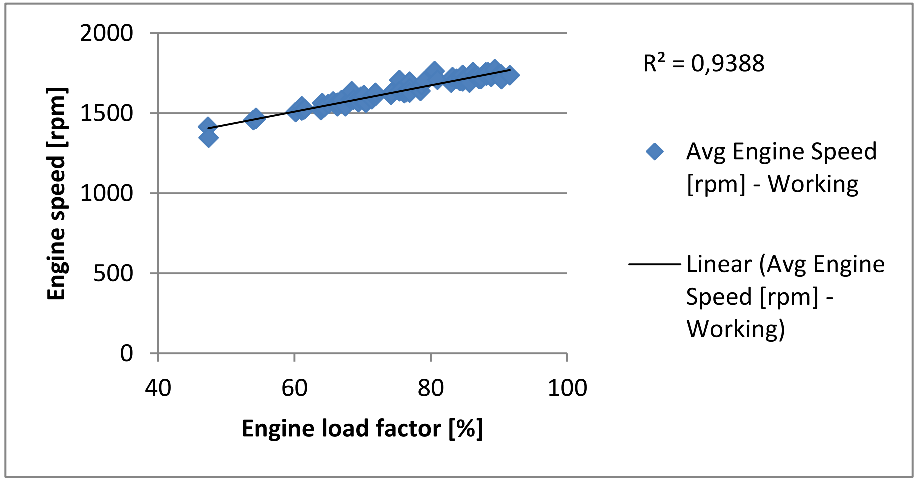
Appendix H



(a) The engine load factor and fuel rate (time-base) relationship (Author).



(b) The engine speed and fuel rate (time-base) relationship (Author)



(c) The engine load factor and Engine speed relationship (Author).