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Efficient20 project
Task 2.5: Data analysis - Final report

On-field measurements during agricultural operation and related fuel consumptions of tractors: references and parameter analysis

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Abstract

Efficient20 project aims to help farmers and foresters reduce their fuel usage and one part of it deals with collecting fuel consumption measurement related to tractor's use and gathered them in a database. This report presents some analyses using these records collected in several typical agricultural and forestry operations. Two indicators were proposed to characterize the tractor efficiency: flow fuel consumption is used to establish fuel need with regard to the cultivated area. It is associated with the productivity indicator dealing with the corresponding time budget for a tractor's activities. The database content is firstly described, giving a picture about the farm, tractor fleet, methods of measurement and operations. The median European farm has 120 ha and consumes about 15,000 litres of fuel per years. Using multivariate analysis, it is shown that the measurement method affects efficiency indicators and that a "'by implement"' analysis is the best way to explain the variance of records. Using examples, we discuss the difficulties in defining a reference case to quantify the effect of fuel saving techniques, called hereafter "'eco-solution"' effects, on fuel consumption. Therefore, "'Eco-solution"' tests are added to the reference sample and are used for analyzing setting effects on fuel consumption. Then, reference fuel consumption and productivities are computed for a large list of the implements. Details describing the usual practice are given for the implements for which many fuel measurements have been recorded. This gives a tool for advisers to discuss about the representativeness of field measurements and comparative tests. Then, comparisons are carried on to extract the influence of settings on fuel consumption and productivity. This allows quantifying impacts of soil, engine power or speed on the fuel and time budget during tractor's use. Results also give some quantitative elements about the increase of fuel costs and their related productivity gain when engine power is increased. At the end, an annual balance of fuel and time budget is presented which shows how to use results for assessing the benefits of some logistics "'eco-driving"' solutions. The transport effects are presented for light and heavy works, quantifying fuel and fuel increase with longer distances. This huge database about the European agricultural practices for mechanized work is designed to study and optimize the operational parameter settings during a tractor's activities but further work is need to facilitate data feeding and increase accuracy of reporting.
Keyword:
Fuel consumption, agricultural operations, productivity, european network, field measurments, implement settings

Introduction

Energy cost increases lead farmers to limit their fuel consumption for both economic reasons as well as environmental consideration. In the agriculture sector, the most important direct energy budget lies commonly in the fossil fuel used in farm machines. This effectively contributes to about two thirds of the direct energy used in the French and spain farms. Increasing technological improvements and incentives to use of energy efficiency technologies are some of the most effective tools by which the European Community aims to reduce its dependence on imported oil. While manufacturers are working on technological issues that would allow energy savings, consumers are also requested to reduce energy losses through good energy management practices. Due to inertial effect of technology penetration, the fuel reduction through the technological path is somewhat long to achieve, whereas modifying practices often provides an easier way to achieve valuable reductions. Therefore, the EFFICIENT20 project aims to promote some advice and guidelines to save fuel by an adapted driving method of agricultural tractors. Beyond gathering guidelines about the fuel efficient driving, a part of the project is also dedicated to establish actual fuel need and saving related to energy management advices. This is the main concern of the present report. Attention was often paid to the energy performance of agricultural machinery in the 1990's and authors focus on the average values of fuel consumption for agricultural operations, like in [1]. The assessment of energy needs was built on reduced sets of field measurements made in different European countries and an average description of practices. Energy budget was computed in relation with the crops amount and this kind of assessment determines fuel cost or green house gas emissions cost per unit of crops [2]. In [3], [4], fuel consumptions are assessed to compare the energy efficiency of tractors: in this approach, it is necessary to define a general and comparable use, without taking into account the driver behavior. Specific campaigns were also dedicated to establish fuel consumption for some agricultural operations [5, 6]. In these papers, the approach consists in evaluating the energy (l of fuel by ha) for a given agricultural operation and combines it with the working capacity, also called productivity or time efficiency (ha/h). Being easy to measure, these are the most convenient indicators for looking for performance of materials and practices at the farm management level. These were retained in the following analysis as the indicators for the operation performance. These indicators are commonly used for life cycle assessment where environmental impacts are estimated with regard to the service of products. Considering the driving style, works were already carried on in transportation research, mainly for automotive application or road management. One part of these works is dedicated to assess the driver effect on the related fuel consumption, or its equivalent "CO2 emissions". The objective is in this case to quantify uncertainties on real-world fuel consumptions and give an idea of some adverse impacts on the fuel prediction related to a given activity. On other part, the driving optimization consists either in learning eco-driving strategies, giving information to the driver by using fuel gauge, or implementing systems and computational resources that could help to choose the optimal functioning according to the fuel consumption criteria ([7, 8]). If the system acts directly on the driver, the reported efficiency gain is about zero in [9], [10] up to 4-7% [7, 11]. Other works are mainly dedicated to automation that could enhance the driving according fuel criteria and without any driver intervention. Here, the driving style is defined by the way used by the farmer to reduce its fuel consumption: some well known eco-driving solutions were defined and their use after eco-training sessions defined the fuel-efficient driving style. EFFICIENT20 is designed to encourage farmers and foresters to contribute to reaching the target set by the European Union of 20% energy savings compared to the projections by 2020. The focus is put on fuel oil used in farming machinery, which represents more than 50% of the direct energy consumed in agriculture. Field measurements are collected within the efficient 20 project to document the actual fuel needs. These continuous records are also carried on by the

so-called "pilot group leaders". These are in charge of the monitoring of fuel consumption devices used in the project. But they are also involved in advising farmers and their teaching skills are used here to demonstrate the effectiveness of some solutions leading to fuel reduction. The EFFICIENT20 project aims to define good driving style according to fuel criteria: a first way in comparing the driving style is therefore to compare drivers before and after eco-driving training sessions.
This report deals with the analysis of the EFFICIENT20 data gathered along the project. The first section introduces the details about the database content. Attention is paid first to the general data related to farms, tractors and pilot leaders involved in the measurement campaigns. Then, the records of agricultural operations are described and information about variable is given, allowing excluding some of badly known parameters. Multivariate analyses are conducted on the whole or subsets of data, in order to present trends and correlation between the measurement parameters. Along with these results, explanations are given on the way to build up groups for the reference values. At the end of this chapter, the focus is put on the ecodriving analysis. As the number of paired records is low, some analysis were made in order to compare the paired and unpaired records to the reference state. This is done in addition to the D3.7 report [12] dealing with direct paired comparisons about "‘with"’ and "‘without"’ solutions. The following section is dedicated to the reference results: different agricultural operations are described by using as much as possible the details stored in the database. The last part of this section presents two examples of dealing with the outputs of the report.

Chapter 1

Database content

The database was designed by RuralNetfutures working with and following specification and data model provided by the CRAB. It was developped by the Nvisage Ltd. The main components of the database lies on measurements, that are organised by agricultural operations. Each operation correspond to one measure of fuel. Other parameters related to the pilot group leader conducting measurements, farms and equipements are also gathered in lists. A documentation manual addressed to Pilot's Group leader is provided in [13]. A sql web interface was also developed in order to ensure data extraction for analysis. Analysis scripts were then developed using Matlab and R scripts: some details are provided in the Annex section. The last Sql request on the EFFICIENT20 database was made the 28th February 2013.

1.1 Farm, tractors, pilot groups, measurements

The 46 pilot groups gather farmers that were volunteers into participate in the EFFICIENT20 project: they provide information on their fuel consumption by measuring the energy consumed on different agricultural operations. The 101 farms involved in the project represent a large range of situation: from cereals to livestock's, farms area are distributed within 20 ha and 2,270 ha, the median being around 120 ha/farms. This area is distributed on around 20 fields in the most common case. Their estimated annual fuel consumption varies from 2,000 liter/year up to 380,000 liter/year, with a median value around 15,500 liter/year. It is to notice that traditionnal farms represents a half of the farm_id: others farm_id are made of equipment society or/and cooperatives and forestry material. 15 operations were generally recorded on each farm and detailed data are given in 1.1.
261 tractors or self-propelled machines were observed. A lot of manufacturers (33 including some old

	area (ha)	fields	area by field (ha)	fuel annual (l)	operations
Min.	18	2	0	2,000	1
1st Qu.	45	16	2	6,000	6
Median	119	20	4	15,000	15
Mean	271	53	164	45,254	23
3rd Qu.	250	42	83	32,500	27
Max.	2270	450	2,270	380,000	234
Na	79	67	52		

Table 1.1: Detailed about farms involved in the project

manufacturers) are represented within the sample. Being sold from 0 to 24 years ago, the average age of these is about 5 years. But the age information seems not so easy to get, because more than an half of the tractor ages are missing. Some of technical datas were also difficult to collect, like transmission technologies or engine power reference. Engine power begins at 30 Hp and goes up to 480 Hp: the ECE R24 is the frequently used after the commercial/ farmers answer. Median and mean powers are about 140-150 Hp. 4 operations per tractors is the most common case. It is to notice that a preparative work was carried on along the project: tractors and farms were often described before any operation records. Therefore, we found out some discrepancies between tractor files and operation files with unused tractors.

1.2 Operation records

The operation extracted the 28^{th} of February 2013 corresponds to 2,311 records. Most of these records deal with reference creation (1992 records) and the rest for eco-solutions. The soil tillage is the most represented activity with 985 operations. Just after comes the harvesting (forest: 321 and fields: 514) and then, transport. The related duration of measurements is in most of the case around 5 hours, that gives an idea of hours spent for the survey. Some tractors were surveyed on very long period (131 hours) through embedded devices storing and monitoring all the tractor works. Poor details are reported on the measurement method: 1600 data are missing. But the method seems well distributed between fuel tank measurements (367) and plot measurements (250) whereas instantaneous measurement (98) is less used. The hourly fuel consumption of an engine is directly related to the mechanical power for traction and implements. Due to the effect of engine size, it is very difficult to compare the hourly fuel consumption between tractors: indeed, it doesn't take into account the increase of time efficiency related to high powered tractors. Therefore, we only used the flux fuel consumption in this report: it is related to the area covered during the operation, ie the litre of fuel per hectares. It is always presented with its associated productivity indicator, called here time efficiency (ha/h). These both indicators were chosen in relation with the service, ie the agricultural operation. The indicators have to be adapted for specific operations: those related to transport were expressed according to the travel distance, in l/km, like for cars. For forestry harvesting operations, the cubic meter of wood was found to be the best measurement of work. For all the data, the work duration is taken to compute time efficiency, if this value is not null. In this latest case, we used the global duration instead. Being aware

Tractor power (Hp)	$<$100	100-130	130-160	160-220	$>$220
Op. number	191	219	295	195	224
Duration (h)	4.0	6.0	4.5	3.2	3.9
Fuel (l)	31	70	81	68	315
Area (ha)	5.0	6.5	5.75	5.5	5.3
Area's Consumption (l/ha)	7.9	10.3	13.0	12.95	38.2
Hourly Consumption (l/h)	9.1	10.7	16.6	18.0	38.4
Productivity (ha/h)	0.70	1.09	1.20	1.48	2.07

Table 1.2: Typical tractor works according to the tractor size - all implements and activities on fields excluding transport and forestry activities

about the measurement accuracy, additional analysis was made to compare this parameter. Results are given in the table 1.2. The measurement method was poorly reported and 70% of the values are missing. Plot measurements and instantaneous systems shows smaller duration and area and thus, were more often used for small operations. Unknown records, ie records where measurement method is not specified, are near plot measurements for fuel area consumptions and productivities. Tank productivities are lower and this could be related to the transport part, which is included in the operation.

	Tank	Plot	Inst	Unknown
Amount	326	119	58	1078
Power (hp)	116	200	153	145
Duration (h)	9	2.5	2.4	3.85
Area (ha)	7	4	3.5	6
Fuel Consumption (l/ha)	12.7	10.9	15.4	11.3
Productivity (ha/h)	0.84	1.70	1.41	1.50

Table 1.3: Measurement methods and related operations characteristics

Chapter 2

Analysis methods

2.1 Data and samples

The data are analyzed using the agricultural operation to define populations. One individual or observation is one operation and it is described by multiple variables. In each operation, some variables are continuous (fuel, time, area, tractor power) whereas others are discrete (soil texture, depth, width, forward speed). Others are included in a dedicated comment line. These lines are often checked for explanations. Preliminary checks shows that the continuous variables are generally distributed according a normal law.
Sometimes, it was necessary to group some factors in order to increase the amount of operation in subsamples. For example, we used tractor class instead of tractor power. The tractor class is a tractor category defined according to its engine power, in label 1 if $P < 100$ hp, label 2 for $100 \leq P < 130$ hp, label 3 for $130 \leq P < 160$ hp, label 4 for $160 \leq P < 220$ hp and label 5 above. Concerning depth and speed, values were often grouped into classes. Depth and width levels are chosen according to implement features. When the classification is needed, the definition is then given in figures and text. Both continuous and discrete variables are used for the statistical analysis. First, principal component analysis (pca) was conducted in order to class variables into groups and see how to conduct statistical comparative tests, using non parametric tests. The latest were used to study the "‘reference"’ population: some of these operational parameters were studied in this sample. They also give indications on the way to assess the "‘ecosolution"’ operations.

2.2 Principal components analysis

We propose a multivariate approach to study the data set about fuel, tractors and operations. The Smith and Hill analysis was first used to find out rules or guidelines in order to build subset of data that could be used for establish reference. This kind of approach is a mix of principal components analysis (pca) for numerical data and factorial analysis for the qualitative data. The so-called contextual factors characterize groups of people rather than individual characteristics. Many studies have noted that taking into account contextual factors in the analysis, in addition to individual characteristics, could allow a better identification of groups. Comparing the group-level variance before and after introduction of individual-level characteristics allows assessing the extent to which between-group variability is linked to compositional effects. Multilevel models can also help examine whether the between-group variations affect all the members of the groups, or only specific sub-groups. Finally, they can estimate how much of this complex between-group variability is explained by the contextual factors included in the model.
As this approach doesn't work with an irregular matrix, we used only a subset with complete data. That's why the amount of observation is rather below the number of operation stored in the database. In our samples, numerical data are the tractor power (hp), the operation duration (h), the operation area (ha), the fuel efficiency (l/ha) and the working capacity (ha/h). The measurement method, the ecodriving solution, the activity and the implement were all treated as factorial variable. Amount of data per implements were checked and are reported in table 2.2. In the pca, only implement having more than 20 observations were

retained.
When the whole set of field operations is considered, the first principal component is mainly correlated with

Operation	index	amount	total fuel (l)	mean power (hp)
Baler	1	40	3840	116
Combine	3	67	123450	290
Complete beet harvester	4	147	55897	361
Cultivating and sowing combination	6	213	26503	125
Fertilizer spreader	12	37	1022	97
Forage harvester	14	59	52341	432
Front loader	16	24	139	54
Heavy cultivator	19	61	5729	172
Light cultivator	22	136	6398	162
Moving harrow	27	57	5201	137
Mower	28	112	4862	186
Muck spreader	29	41	2290	111
Plough	33	300	29983	150
Seed drill	41	22	1441	122
Slurry spreader	53	143	5629	141
Sprayer	57	43	951	64
Stubble discs cultivator	59	51	2259	157
Tine stubble cultivator	60	48	3058	133

Table 2.1: Amount of measurements per implement - only values above 20 are considered in the pca analysis

the automotive power. A small subsample of harvesting operation clearly presents very low fuel efficiency with a working capacity within the regular values. The tractor size effect is less pronounced when the beet harvesters are considered separately. Indeed, the variance of tractor sizes and fuel efficiencies are greatly reduced if complete beet harvesters are excluded: the power and fuel consumption of these latest are clearly out of the range of other records. When excluding self-propelled machines, pca results give an idea of the structure of the data cloud by looking at the correlation between variables and the 3 principal components. The first principal axis is clearly related the operation duration: this size effect could be avoided by reducing data, but it also has a physical meaning related to the working speed (or the forward speed, ie the speed along furrow). Therefore, non reduced variables were kept. The second axis is positively correlated with the time efficiency whereas it is negatively correlated with the fuel consumption. It opposes two kind of work: some so-called light operations, rapid and corresponding to small fuel consumption are opposed to heavy operations needing more time per hectare and consuming high fuel. The third axis were not examined, as it doesn't explain a huge amount of variance. Implements have also a good correlation with the first axis, and also the second axis: its correlation with the principal components is always higher than those of the activity: therefore, it appears more significant and better to split analysis by implement rather than by activities. The measurement method also contributes to the first axis: attention should then be paid to this point. The second axis is explained by operation corresponding to high fuel consumption and long work: this splits data into 2 classes of operation: slow and heavy works on one hand and light and fast works on the other. The third axis is related to the tractor size: it is also correlated with the implement and activity, rather than the fuel components. The figure 2.1 illustrates the result of the Smith and Hill analyses. The number of axes does not play much, the first two being related to fuel and work duration. From this analysis, it comes out that:

- the implement is more significant than the activity: values will be therefore given by implement rather than by activities
- there is a size effect: measurements are sensitive to the duration: this could be related to accuracy of measurement methods. It could also be related to the transport part. Although the database is designed in order to collect data about the travel part related to operations, very few data were given about it.

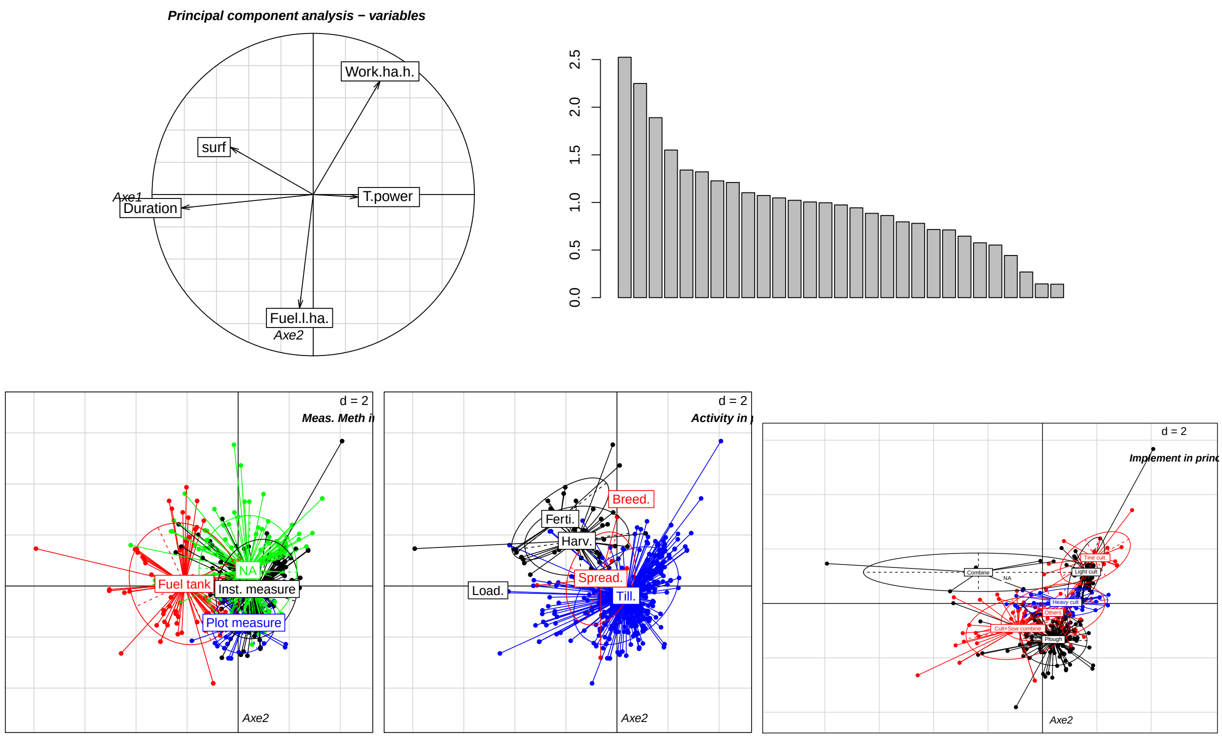

Figure 2.1: Mixed factorial and components analysis - dataset without beet harvester - no correction for transport

- the engine powers are negatively correlated with duration, indicating that powerful tractors works somewhat quicker than the smallest ones. This trend is detected even if we mixed heavy or light works in the same sample.

2.3 Eco-driving solutions

Although many solution are proposed in the literature or are known by advisers to reduce the fuel consumption, their real impact is not well documented and the project aims to establish guidelines with quantified values of fuel reduction related to changes in tractor use. At the beginning of the project, an "‘ecosolution"’ list was proposed to check all what could be used to decrease the fuel consumption during agricultural operation. This is described below and commented with afterwards remarks about the ease to carry on measurements or to analyze impact. Just after, the energy balance of tractor is introduced and then analysis of some solutions is presented.

2.3.1 Solution list

Many solutions were proposed within the project and discussions were also raised during working meetings on what was behind proposed solutions. These are listed below with some details and explanations are added on the way to handle with the solution advantage and its comparison with reference cases.

1. Save tractor's use: in fact, this solution was not clearly defined at the beginning. After discussions, it corresponds in fact to reduce tillage and use "combine seed" plough instead 2 operations. This solution should not be directly compared with another one and it can't be paired with something. As it reduced the number of operations, its efficiency should be appreciated within a cultural practice (cultural choice). In the database, the solution 'Save tractor's use' refers mainly to operations concerning

soil tillage: implement working depths were reduced. For these, values were transferred to "‘adapt implement settings"’. 2 operations were related to use of combine. These were changed into ’without solutions’ for cultivator and sowing combines. After these corrections, no case is remaining for this solution.

2. Lower travel part: this solution consists in reducing the transport distance (km per hectare). It refers to farm management rather than to the driving style. Like the previous one, it should be appreciate within a cultural practice. This can be done be reducing the fuel consumption dedicated to transport using the reference values. In the database, 5 operations are related to this solution: one concerning soil tillage whereas the others are related to harvesting and implies different distances between fields. No details were given about the travel distance and time dedicated to transport for these operation. The analysis was therefore impossible but at the end of report, the reader will find an application about lowering the transport part and impact on fuel and productivity.

3. Eco-Driving:
This solution, also known as GUTD (Gear Up, Throttle down) consists in choosing the gearbox ratio that reduces the engine speed: this choice allows the tractor to deliver the same power output with a lower rotation speed. Then friction losses are decreased.

4. Economic Power Take Off :
Some tractors are equipped with adapted shafts or programs that allow the decrease of the engine speed while the PTO take-off is running. A detailed analysis is presented in the paragraph dedicated to ecosolutions. Due to the conclusions, these measurements were also added to the reference sample.

5. Match tractor/implement: it consists in adapting the size of tractors for works that doesn’t need as much a power as the tractor had. Or inverse, it consists in adapting the tractor size in order to work near the full capacity of the tractor. This solution is proposed by the pilot group leader in farms having many tractors. The corresponding parameter lies in the tractor power.

6. Get working sequences longer: it consists in doing more work (many fields) in one operation and hence, lowering transport. This solution also belongs to the ’logistic’ group of solutions.

7. Adapt weights: this consists in optimizing weight and adding mass in front or behind the tractor in order to get much adherence. Increasing the weight of tractor generally leads to improve its traction capacities and reduced slippage.

8. Adapt implement: Here, the action acts only on the implement settings. As it will be seen in the analysis, adapt setting recovers in fact a lot of parameters: adapt depth for plough, or speed, or width...

9. Use front implement: In some cases, front implement were add and then, the solution allows reducing operations. This solution is put inside the ’logistic’ group of solutions.

10. Tyre management: Tyres have an important effect, especially for operation that’s need high traction forces. In fact, the traction force depends on the forward speed and the corresponding energy is related to the product of forces by energy. Looking at the tractor, this energy demand is increased by the slippage, that’s, the quantity of useless wheel rotation. The traction capacity of a tractor is related to its weight and geometry. But it is modulated largely by the tyre adherence: thus, tyre pressure enables to increase or decrease the slippage and has then a direct impact on transmission power. tyres effects were observed for all operations having hard traction demand: these are mainly related to soil tillage operation.

The logistic group of solutions refers to solution leading to reducing fuel though the agricultural pratices at the farm level. For these, it has no sense to study result at the agricultural operation level. Apart from the logistic solutions, some of these solutions aims to reduce frictions losses in the machine (economic pto, eco-driving) whereas other are more oriented into the improvement of the traction efficiency. This difference is an important idea to keep in mind for the analysis and it is discussed hereafter.

2.3.2 Ecosolution analysis

First, some preliminary ideas are reminded here to better explain the efficiency indicators used in the analysis. Tractor use is often presented in different activities related to the road displacement, called in the following the transport contribution, and the field part. This latest is also divided into productive time along field lines and so-called unproductive duration dedicated for turns or settings. Transport corresponds to special settings because the power demand to engine is very dynamic, the forward speed is much higher than in field activities and even setting, for transmission by example, notably differs. Also the service unit is not the same as for field activity, that's why it was considered on its own. For field activities, engine is more regularly solicited along the field lines: the load depends on many parameters that are decomposed in the energy balance (figure 2.2): the traction effort is one of the biggest tasks for the machine and it has to overcome adherence, rolling resistance and traction drag for some implements. It is necessary to propel the tractor and is complicated to describe because it lies on the mechanical equilibrium of the machine (mass weighting) and soil properties for tyre adherence. The forward speed during line is therefore a key parameter to describe the energy need because it governs the traction draft. That's why we are interested into an indicator dealing with the working speed, ie with the time need to do the work. However, there is tight difference between the forward speed and the speed target (ie,the speed guess by the farmer used for settings), whereas the working speed includes the unproductive durations and is more different. The fuel consumption during the unproductive durations is very low compared to the field values: therefore, the dual analysis with fuel consumption and productivity is a way to identify the benefits of the mechanized work, ie a higher working speed. Some implements also need power coming either from the pto or the

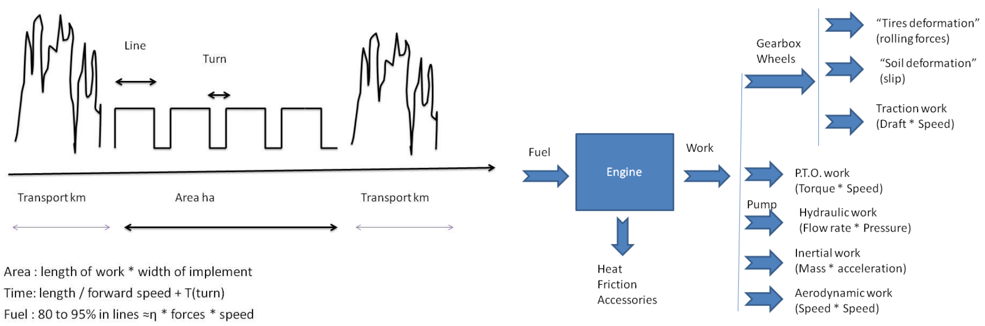

Figure 2.2: Schematic organisation of an agricutural operation (left) and energy balance of tractor during field activity (right)

hydraulics circuits. The pto power may represent more than 60% of the energy needs by the implement to work. When energy serves for both traction and pto, all the solutions connected with adherence (adapt weight or tyre management) may have less effect than for pure traction work. It is therefore very important to keep the "'by implement"' division in ecosolution analysis. But keeping "'by implement"' sorting leads to deal with very small samples. It is shown on the figure 2.3, where each symbol represents an implement. Black symbols represent the median value of the implement. White symbols are for the paired reference measurements, ie measurements that are paired with an ecosolution. Looking at diamonds for stubble disc cultivators, it appears clearly that the average in black can't be used as the reference value: it is too far from paired values as well as from ecosolution values: too many parameters could explain these differences that are not only brought about by the solution. When looking at the circles (plough) or vertical triangles (heavy cultivators), it comes also out from this figure that the paired references are more numerous than the ecosolution measurement. This point has to be discussed. Plough is one the most studied operations in fields and forms the bigger subset of "'adapt implement setting"' with 9 operations reported in the figure 2.4. Here, paired measurements were bordered with the same colored symbol. The colour of the central symbols have the same meaning as before, black for eff20 reference, gray for ecosolution and white paired measurements. Looking at the blue crosses, 10 paired references stand for one ecosolution measurement: the ecosolution

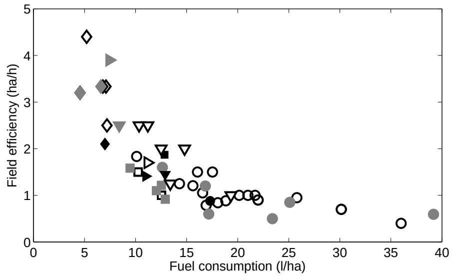

Figure 2.3: Measurements of fuel efficiency versus work efficiency - Ecosolution adapt implement settings - square for spacing drill, circle for plough, vertical triangle for heavy cultivator, diamond for stubble disc cultivators and horizontal triangle for tine stubble cultivator

result stands in the middle of this set of measurement. This is because the farmer was very involved in this project and recorded a lot of measurements for ploughing in order to increase reference measurements. For the "‘ecosolution"’ measurements, the "‘pilot group leader"’ was always on the spot for both advising and ensuring proper and complete reports. Other problems related to missing data also appears: we reported above the symbol numbers indicating speed on right and depth on left. For circle, the setting is about the speed but nothing is given about depth. For other, depth was studied and no details are given about speed. Pilot group leader didn't adopt the same strategy to fill the "‘ecosolution"’ measurement: on one part, leader have made experiment design with setting and stored the whole operations in "‘ecosolution"’ measurement whereas others has change many settings for one "‘ecosolution"’.

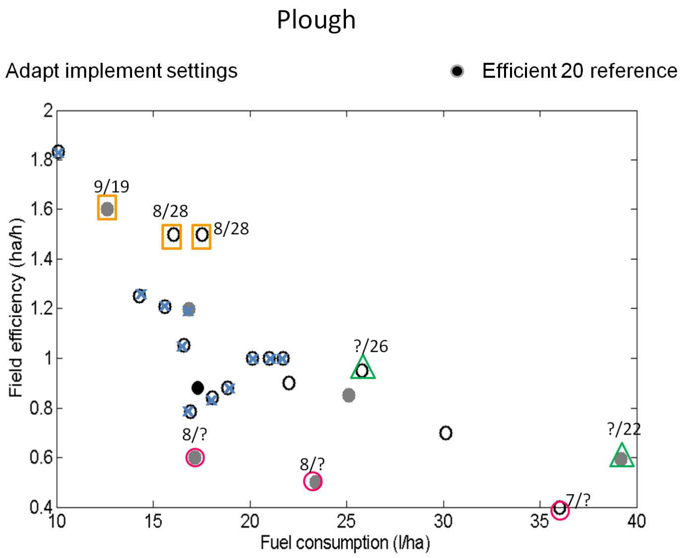

Figure 2.4: Measurements of fuel efficiency versus work efficiency - Ecosolution adapt implement settings

As setting and speed have a great impact on both fuel and time efficiency, it was very difficult to separate parameters effects. This is shown in the following analysis about the "‘pto economic"’. Hereafter, in the table 2.3.2, are given the measurements for the "‘pto-eco"’ solution. These are compared to the so-called "‘paired reference"’ values, ie the average of operation carried on with the same tractor and the same implement and identified as "‘without ecosolution"’. We observed that the fuel consumption sometimes increases compared with the reference's one, like for the third baler. At the opposite, the first baler has decreasing fuel consumption. The trend is difficult to assess for all implement as well as implement by implement. The same remark also applies for the productivity. Moreover, missing values about the area also prevent comparison in some cases. For available measurement, we compared in figure 2.5 differences in the fuel consumptions on the x-axis and in productivity in the y-axis. Differences were expressed in percentage of the reference values. It shows a noticeable linear correlation bewteen fuel and productivity changes; Productivity changes indicate that speed were not equal between the "‘without test"’ and its "‘paired pto"’ value. Though a strict comparison of "‘pto-eco"’ solution should have been carried on at the same speed to affect fuel change only on the pto mode. This is of course very difficult to handle this in field. The linear relation between productivity and fuel shows that fuel changes are here mainly related to traction power changes rather than pto mode. At the end, statistical comparisons for ecosolution were not very conclusive.

Implement	PTO Fuel (l/ha)	Reference fuel (l/ha)	PTO prod (ha/h)	Ref prod (ha/h)	Power (hp)
Baler	2.6	5.4	4.00	2.69	160
Baler	4.1	7.0	2.73	1.98	160
Baler	10.3	7.0	1.11	1.98	160
Cult/sowing comb.	7.6	7.5	NULL	1.10	117
Cult/sowing comb.	11.3	7.5	NULL	1.10	117
Cult/sowing comb.	9.6	7.5	NULL	1.10	117
Cult/sowing comb.	15.0	15.0	0.95	0.95	160
Moving harrow	8.6	11.6	1.05	0.86	70
Moving harrow	12.9	11.6	0.73	0.86	70
Moving harrow	10.0	11.6	1.00	0.86	70
Moving harrow	15.0	11.6	0.67	0.86	70
Slurry tanker	7.6	11.4	1.00	1.02	160

Table 2.2: P.T.O. ecosolution - comparison between results without and with solution for the 12 operations on fields

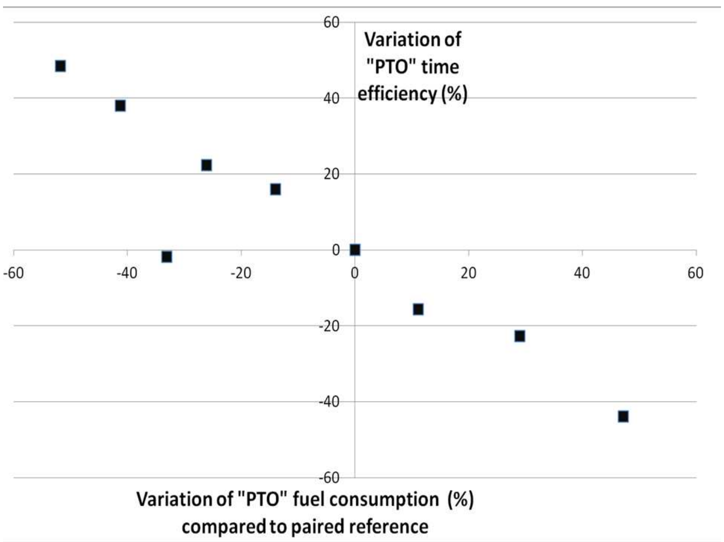

Figure 2.5: Difference between the paired reference and the pto-ecosolution for fuel consumption and time efficiency

Either differences were significant for all the parameters or the size of sample was too small to proceed to comparison. Therefore, all ecosolution were gathered with reference values in order to study parameter effects with sample as large as possible. The reader should refer to report 3.4 of this project dealing with the comparative tests.

2.4 Variance analysis and non parametric tests

At the end, all values were gathered and studied implement by implement. For each implement, general information is given about the total fuel and area covered within the project. It was often necessary to exclude extreme data. The sorting is done on the basis of fuel consumption and lower productivities and the 5 percentile values (respectively above the 95th percentile) are rejected. Individual implement are then divided into classes according to operational parameters: soil, depth, width, speed, tractor power were generally examine for all implements having more than 20 operations. Classes are considered when the population inside is above 7 measurements. The classe's definition varies for each implement in order to build compromise between the size and the meaning of the subdivision. Then, comparison tests are carried using statistical method. Non parametric tests, like χ^2, were widely used during the analysis. They were preferred to parametric tests because they better suit the data, especially for incomplete data set or small samples. Indeed, there is no need to forecast the distribution law of the variable and are more adapted to small subsamples. They applied to qualitative and quantitative factors. They are less powerful than the Anova method which gives precise ideas of significant or unsignificant values. These tests are applied to the following variables: duration, area, engine power, speed, fuel efficiency, productivity. Although we know that our variables are well correlated, covariance analysis was not carried on because of the huge amount of missing data.

Chapter 3

Fuel consumptions and productivites by implements

In this section, efficiency indicators are computed for all the available measurements. Those are considered as the reference values of the project. Results are expressed using the area fuel consumption versus the field efficiency. First, the table for all field activities is given. Then, the implements with more than 20 measurements are studied with more details: the impact of some operational parameters is also checked as soon as the subsample size is enough. At the end, fuel consumption are given for the activities that are not expressed in relation with the area.

3.1 Detailled fuel consumption by implements

The table 3.9.2 in Annex summarises the results of the EFFICIENT20 project. Fuel consumption and productivity is given for each implement type. These values were reported on the figure 3.1. The median values were used instead of the average to avoid the impacts of extreme individuals: these extremes often corresponds to very small operation were accuracy of measurement is not sufficient. Bad reporting might also explain some values that were found clearly out of range. Sorting on percentiles is not always enough to ensure proper data sets. This choice explains changes of values along the project. In the table, the amount of measurements is also detailled and the global area and fuel covered by the project is computed, showing the energy spent in this project.

3.2 Plough

309 operations are stored in the database. These correspond to 2,331 hours of ploughing 1,760 hectares of fields. It needed therefore 30,224 liter of fuel. Reference efficiency indicators for ploughing are median values 17.0 l/ha and 1.00 ha/h (see table 3.2) and corresponding operating conditions are given. The parameters related to plough operations are numerous: soil, depth, width were investigated. Due to the significant amount of missing values, it was impossible to conduct multivariate analysis in order to classify parameter hierarchy. Therefore, each parameter was analyzed separately. The mean tractor power is about 150 hp for ploughing. The effect of the measurement method isn't studied because the measurement method is unknow for 231 records. Indeed, we observed during the analysis that small operations (less or eqal than one hour or less or eqal to one ha) were very often leading to extreme values for fuel consumption and/or time related field efficiency. It is therefore to notice that field measurements differ when the observation period is small: this can be related to the accuracy of measurement and/or difficulties in reporting of the right times and areas. Operations are reported in figure 3.2 where fuel and field efficiencies are reported. EFFICIENT20 measurements are compared to historical data found in [1]. Expert old values show a field efficiency of 0.86 ha/h, what is 14% below current one, whereas the area consumption of 15.8 l/ha is 10% less than today measurements. If the power increase of tractors over 2 last decades could explain the increase of fuel needs,

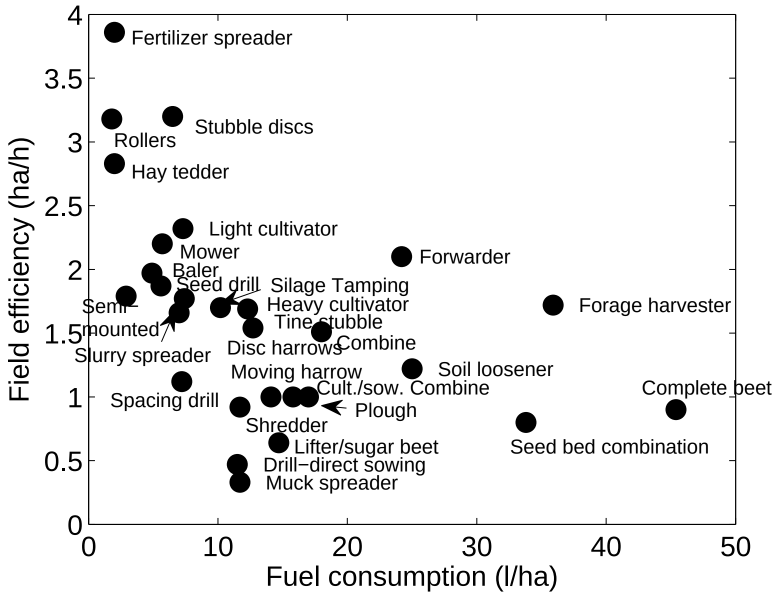

Figure 3.1: Measurements of fuel efficiency versus work efficiency - Median values of implement list

Area (ha)	Field efficiency (ha/h)	fuel consumption (l/ha)	width (m)	depth (cm)	soil -	power (hp)	speed (km/h)
5	1.00	17.	2.0	20.	loam and soft	145	7.5

Table 3.1: Medians or most common values for ploughing

it could explain these changes. Indeed, we observed in the adjacent curve more tractors are powerful, the more efficient tillage is. Above 100 hp, the gain is mainly observed on productivity, while consumption is less affected. Beyond 220 hp, the productivity is still growing but fuel costs also increase noticeably.
Looking at speed, we notice that speed increase corresponds to a fuel reduction and has few outcome on work efficiency under 8 km/h. Beyond 8 km/h, the trend changes and fuel stays roughly constant whereas the working capacity increase. This could be related to the quadratic relationship between the draft force and speed.
Increasing the width of plough reduces the fuel consumption and increases the work efficiency at the same time. This result illustrates the interest of the area fuel indicator, compared to the hourly fuel consumption: with a larger plough, the hourly fuel consumption increases. But the time need to cover a large area is smaller, leading to a decrease of the energy needs and a better working capacity. The rise is monotone, except for measurements for '3 meters' that show a lower field efficiency than for '2.4 meters': the "'3 meters"' is related to small areas where the accuracy of the measurement is always weak.
Regarding the depth, results are not as scattered as for other parameters and no monotone relation was found between increasing depth and both fuel and productivity response. This gives an indication that advisors should be very rigourous when testing depth effects because its impact is less sensitive than others.
About soils, firm soils clearly affect operation efficiency and lower the production with increasing fuel consumption. This is on the contrary to soft or tilled loam soils where productivity is higher for a lower fuel cost. It is to noticeable that the soil impact is in the same range as the width of plough.

3.3 Combine

The combine harvester, or simply combine, is a harvester for grain crops processing simultaneously four separate operations (harvesting,reaping, threshing and winnowing) into a single process. 67 operations were recorded for combine, corresponding to 6,040 hectares of harvest during 570 hours. It needs therefore 123,450 liter of fuel. The measurements are generally carried on for very large areas (30 ha) compared to other implements. This indeed explains the huge amount of hours for a small amount of records. Combine are in general highly powered (between 265 and 320 hp) and operates on large width (7-8 meters). But 8 measurements are related to small combines, with a power about 160 ch and a width of 3-4 meters. Only one value of speed (4 km/h) was reported and no soil details were given. Other parameters were also poorly reported, that'why only the width parameter is represented in the figure 3.3. Increasing the power of combine leads to a higher fuel consumption associated with higher field efficiency. There were only 2 values in Pick's report for combine: each of them matches with the actual averages for small and width combine. But there is not enough details in the report to ensure that the comparison is significant taking into account the power or the width. Like for plough, measures show a huge discrepancy: the median fuel consumption is at the same level as for ploughing whereas the field efficiency is some two times higher.

3.4 Beet harvesters

For agricultural equipment in general and beet harvesters in particular, the economic and environmental effectiveness of hyper-specialized and very powerful machines is often questioned. Harvesters are generally very powerful machines and the average engine powers of Efficient'20 harvesters are indeed between 350 and 480 hp. Harvesting is carried on at low forward speeds, between 3 and 5 km/h. During the project, 1260 ha were harvested during 2777 hours: the fuel needs therefore is about 56,040 litres. Like for ploughing, references were collected on operations roughly corresponding to 8 ha area, which represents about 6 hours per operations.

But in fact, only 3 harvesters were studied: soil properties, width and engine power are therefore divided into 3 classes matching exactly the harvester type. One harvester was dedicated to assess impact of eco-solution and it has therefore only 3 reference values. For one other, problem occurs with work duration reporting and measurements have therefore not considered, except one operation with a global duration above zero. At the end, the latest harvester is related to 7 'reference' operations: the related measurements give an idea of data scattering for one machine, one depth, one soil and 3 kinds of crops. External data were added to the efficient data represented on the figure 3.4. These are related to another harvester working only on sugar beet harvesting with 2 drivers on different fields under various climate conditions. Field efficiency and fuel consumption variances are so high that any significant trend is found when comparing subsamples. On this figure, the median values of harvester are also reported: these were computed according to the engine power classes and are correlated as well with soil properties or working depths. No significant trend appears clearly when measuring the vicinity of the average value and it illustrates the need of a larger amount of data to decorrelate the working parameter. For beet harvesters, the operations are too scarce to ensure a parametric study on operating parameters without en experiment design.

3.5 Cultivators

The cultivator prepares the soil for sowing, working on secondary tillage. They are generally not working in depth but designed to disrupt the weeds and sparing the crops plants. They are usually attached by means of a three-point hitch and are sometimes driven by the power take-off (PTO) for rotating cutlivators.

3.5.1 Heavy Cultivator

Within the 61 operations, most of works are carried on with 3 meter width cultivators (34) working between 10 and 16 cm depth. 4,846 litres of fuel were consommed to work 225 hours on 441 ha of field. The most frequent speed reported for heavy cultivator is between 8-9 km/h. Reference efficiencies for heavy cultivators are the median values of 1.63 ha/h needing 12.3 liter of fuel per hectare. Medians were chosen here because median and mean time efficencies differ due to extreme values observed for large implements. The data are organised into 2 groups: small area were cultivate with small tractor (138 hp) at depth below 10 cm and at speed equal or below 8 km/h. Others are dealing with larger implement (5 m) and higher depth (> 10 cm), more powerful tractors driven between 9 km/h up to 14 km/h. Fuel consumption is around 9. for the first group when it is at 12. l/ha for the second. Productivity also changes from 1.6 ha/h up to 2 ha/h for the second group. Here, the tractor power is correlated with an improvement of productivity (+ 20%) increasing fuel needs (+30%).

3.5.2 Light Cultivator

136 operations are recorded for light cultivators. 5,606 litres of fuel were used to cultivate the 800 ha during 330 hours. Hence, reference efficiencies for light cultivator are the median values of 2.32 ha/h needing 7.3 liter of fuel per hectare. Although the amount of operations is above those of heavy cultivator operations, database fields were poorly fulfilled. Widths are distributed equally between 4 and 5 m and the corresponding size of tractor is 140 hp (respectively 170 hp). In this subgroups, the productivities are quite equal whereas the fuel consumption slightly increases by less than 10 % for the high powered group. The unknown widths are the last third of the sample. Medians are useful here because of the extreme values: fuel consumptions were very high for operations related to very small area (above 0.5 ha).

3.5.3 Stubble disc cultivator

54 operations are related to stubble disc cultivators. It represents 277 ha of cultivating during 120 hours and needing 2,270 litres of fuels. Stubble disc cultivators are generally 3 meters width (25 answers) and the treatment is carried on at 11 km/h forward speed. The fuel consumption is around 6.5 l/ha for a high working efficiency of 3.22 ha/h due to the high speed of operating. The median working depth is about 10 cm and sample is too small for further analysis about depth.

3.5.4 Tine stubble cultivator

The database contains 48 operations for tine stubble cultivators, representing 280 ha of work during 278 hours. The fuel needed to operate is of 3,060 liters. As the forward speed is generally lower than for stubble disc cultivators, the median field efficiency remains lower at 1.70 ha/h and the fuel consumption is around 10.2 l/ha. Depth work is generally above ten whereas the implement width is frequently of 3 m. The median tractor power in this subsample is slightly lower than for the previous one (140 hp instead of 160 hp).

3.5.5 Cultivator sowing combination

222 operations are related to cultivator and sowing combine. This corresponds to a 2,050 ha area treated during 2400 hours. It needed therefore 26,600 litres of fuel. The implement width is of 3 meters for 129 operations: only one report is related to a 4 meter cultivator. Tractors were equipped with 110 hp engine for this treatment and the forward speed during work is between 6 and 8 km/h. The frequent depth is of 7 cm, but few records reported a depth varying from 4 up to 30 cm. The median efficiency indicators are a fuel consumption of 14.1 l/ha for 1.00 ha/h for time efficiency, as shown on the figure 3.6.

Soil effects were also represented although the Fisher test indicates that we shouldn't and the Student test that differences are unsignificant. Like for plough, the work efficiency is higher for soft soil and very low for clay. For these latest, tractor sizes are smaller than for other subsamples and that could have a cumulative impact, enhancing the gap with other soils. The soil texture slightly affects the fuel consumption.

3.6 Loading activity

Tractors are often used for loading goods inside the farm or outside. Smaller tractors are generally dedicated to this kind of work: the mean tractor size used for loading is around 60 hp. This activity is not related to fields and the area consumption isn't therefore a pertinent indicator. 28 records are dedicated to loading but some of these seems related to unreliable duration: some errors may occured during fullfilling the database and it leads to very small hourly fuel consumptions (above 1 l/h). The 7 remaining values fluctuates between 4 and 11 liter of fuel per hour.

3.7 Forestry activities

Forestry machines were also monitored during the project: work is divided in 2 types: the first one is related to soil preparation and the second to harvesting.

3.7.1 Forestry preparation

Five operations are concerning forestry preparation. These are realized with forwarders with traction winch, powered with 140 kW engines. There were followed on long time period: it corresponds to 326 hours of observations during 3575 liters of fuel were consumed. Nothing is given about the area and there is therefore just the hourly consumption to give: it varies between 9.1 and 13.1 litres per hour.

3.7.2 Harvesting

321 operations are related to forestry harvesting. Here, the work output is expressed using harvest quantities expressed in cubic meters. This was used instead of area to establish efficiency indicators. 2 kinds of vehicle were surveyed during the harvest: first, forwarders are the vehicles used to carries big felled logs. These are divided into classes according their transport capacity. The others are harvesters, used in cutting operations for felling, delimbing and bucking trees. Forestry harvesters are subdivided into 3 power classes: 15 records concerns small harvesters (engine power: 125 KW), 37 are related to intermediate harvesters (140 KW) and 35 values are for 193 harvesters. The engine power is unknown for other machines. The records represent 3485 hours of works during them 79,560 m^3 of woods were collected and 59,936 liter of fuel were consumed. For this activity, a clearer correlation between time and fuel efficiencies appears and the most rapid operations are generally the less fuel consuming (see figure 3.7).

Some of these differences are clearly related to the machine power: in fact, the subsample containing the harvesters above 140 kW presents significant difference for time efficiency. The p-value doesn't allow to the same result for the fuel efficiency. This group differs from the other that all present insignificant changes for both time and fuel efficiency. The p value is found more discriminant if subsamples are built on "‘power"’ classes rather than on "‘implement"’ classes. Surprisingly, no difference appears between forwarder groups and small harvesters.

The working time is generally about 4 and 5 hours per operations and their global duration is between 7 and 8 hours. For transport, 152 operations contains a travel part between 1 and 2 hours: then, the travel duration is known but not the corresponding fuel part. When the transport increase inside an operation, the global duration is the same but the working duration (see table 3.7.2). As the efficiency is computed from the global duration and global fuel, operations with transport inside is lower efficient (20 %) less whereas the fuel efficencies are near. The hourly consumption during transport may be the same as during work, which could explain that efficiencoes are similar whatever the transport part (see figure 3.8). Fuel consumption

transport duration (hours)	0	1	2
working duration (hours)	4.7	4.2	4.5
operation duration (hours)	8.6	6.4	7.1
cubic meters	139	73	96
fuel (l)	92.2	62.8	69.4

Table 3.2: Median values for forestry harvesting operations according to the transport part

and cubic quantities were found in the medium of values for this subsample, whereas work durations are in the lower part of the distribution: this indicates that the work duration tends to be lower if there is displacement. Fuel consumptions were not corrected for transport operations: results are then slightly less fuel efficient for operation having a big part of transport. For soil properties, many operations are carried on with a unknow or "‘sand and firm"’ soil. Few records are related to other soil properties that were found insignificant on both fuel and work efficiencies (see figure 3.7.2).

3.8 Transport

The transport operation consists either in moving the tractor from its garage to the field or in displacing goods. The common unit for dealing with fuel is, for transport, either the fuel quantity per kilometer. Sometimes, the fuel economy, ie, the km/l of fuel is also used. A first element about transport is related to the travel distance within operations: 140 values are given about the trip between field and farms. But some of these values seem out of a normal range, being above 100 km and even up to 45,000 km. This may be related to a mistake on the unit for travel distances. When removing these data, the median value of the travel distance is 10 km. This seems extremely high and this is perhaps because only high values were reported whereas smaller trip were neglected in the daily reports.
159 transport related operations were stored in the database. They correspond to nearly 50 hours of transport: 850 km were travelled using therefore 620 liters of fuels. Although some parameters allow to take into account the mass of good during transport, very few details were recorded: for example, only 24 values are related to a trip with a trailed or semi-trailed implement. No detail is given about the measurement method for 58% of records. Excluding values where either duration or distance are null, 44 operations remains. Transport is mainly done by tractors, whose power is in the medium range of data: the mean power is around 150 hp. A huge discrepancy is observed for the travel having speed under 10 km/h. In these cases, the fuel consumption is often above 1.0 l/km: the mass is often given for these trips but it was impossible to distinguish if the fuel consumption is high because of the low speed or the mass. The median give common fuel consumption around 0.5 l/km and the median speed of travel is of 27 km/h. Looking for power impact, we found that operations were very similar for class 1 (100-130 ch) and class 2 (130-160 ch): the global duration (1 h) and vehicle speed (27 km/h) are in the same range for both classes. The fuel consumption increases of about 10% from 0.44 up to 0.54 when the engine power is increased.

3.9 Logistic analysis

Fuel reduction may also come from a eco management of agricultural practices: reduced tillage, use combine for tillage and sowing, reduce transport part... The 2 following applications are presenting the way to use the reference values. The first one is dedicated to sugar beet cultivation. The second focuses on the impact of transport in fuel and time budget for one operation.

3.9.1 Fuel and time budget for cultivation

Agricultural scenarios were provided to study ecosolution related to logistic management. The number of operations during the whole cultivating process are taken from [1] and corresponds to sugar beet cultivation. Some details are directly coming out from the project. The field is supposed to cover 5 ha, the most common area in operations. The transport distance between farm and fields is taken by averaging the trip distances stored in the database: the leads to 2 km per trip, ie 4 km per operation. Cultivation process is given in the table 3.9.1 where fuel and time need are computed according the field size and related transport according to the following equations:

$$F_{op} = \sum_{impl} n_{op,impl} \left(C_{50,impl} * S_{field} + 2.d_{ff} * C_{50,transp} \right) \tag{3.1}$$

$$T_{op} = \sum_{impl} n_{op,impl} \left(S_{field} / EF_{50,impl} * + 2.d_{ff} * C_{50,transp} \right) \tag{3.2}$$

The balance is presented in figure 3.10 and shows that the main part of the fuel budget is devoted to

Operation	Amount	$C_{50,impl}$ (l/ha)	$EF_{50,impl}$ (ha/h)	total fuel(l)	total time (h)
Harrowing	2	12.3	1.69	123	5.92
Plough	1	17	1	85	5.00
Sowing	1	7.2	1.12	36	4.46
Spraying	4	2	3.86	40	5.18
Fertilizers	1	7.2	1.66	36	3.01
Rollers	1	1.8	3.18	9	1.57
Harvesting	1	14.7	0.64	73.5	7.81
Transport	44	0.5 (l/km)	27 (km/h)	22	8.15
Total	11			503	42

Table 3.3: Example of a cultivation scenario for sugar beet over $S_{field} = 5$ ha field at $d_{ff} = 2$ km from farm

soil tillage (plough and harrowing) whereas an important time is related to crops harvesting and transport. In this example, the transport contribution is twice higher than the common estimated of 10% time for transport.

3.9.2 Lower travel part

In this example, we considered different operations having contrasted fuel consumptions and productivities. For each, we add a transport contribution using the same equations as in the previous section. But the d_{ff} distance varies from 2 up to 8 kilometers. Results are presented in the figure 3.11. It shows that the lower the fuel reference is, the more sensitive it is to the transport contribution: at 8 km, the fuel needs increase of 80% for fertilizing and only 5% for seed bed combine. The productivity decreases when the transport part increases: at 8 km, the productivity of fertilizing is decreased by 30 % compared to the reference value and only by 8% for seed bed combine. The impact of transport is as important as the productivity is high. The impact of transport was found significant, especially for operations presenting low fuel consumption and high productivity. It appears from this analysis that the huge variance of the EFFICIENT20 dataset may lie in the difficulty we had to obtain data about the transport part.

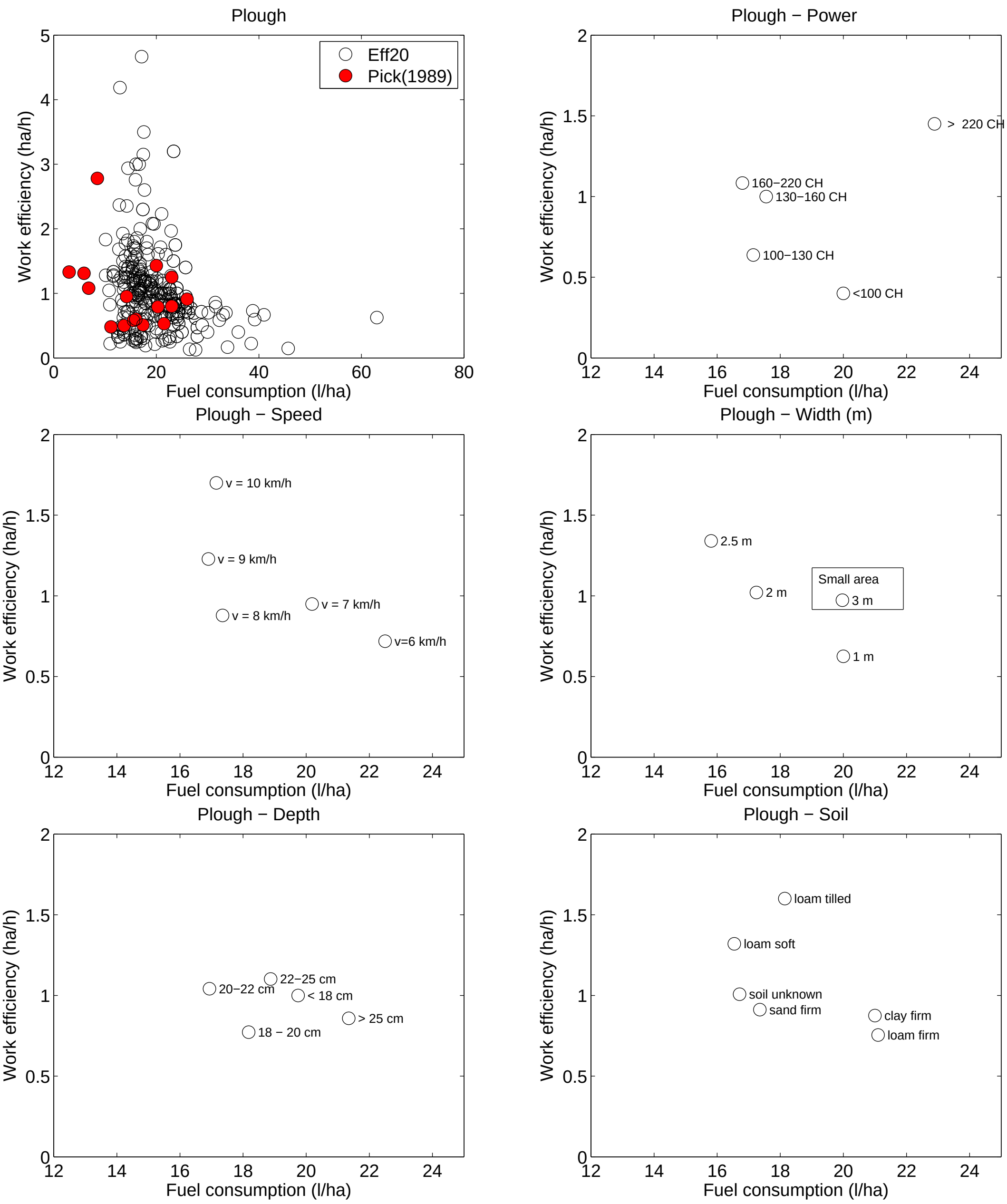

Figure 3.2: Fuel and field efficiency for ploughing operations - impact of settings on fuel consumption - subsamples have at least 7 operations - see text for explanations of bordered values

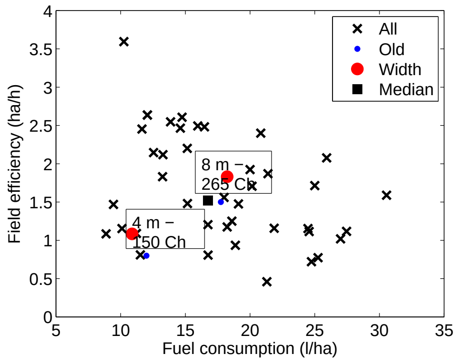

Figure 3.3: Measurements of fuel efficiency versus work efficiency - Combine

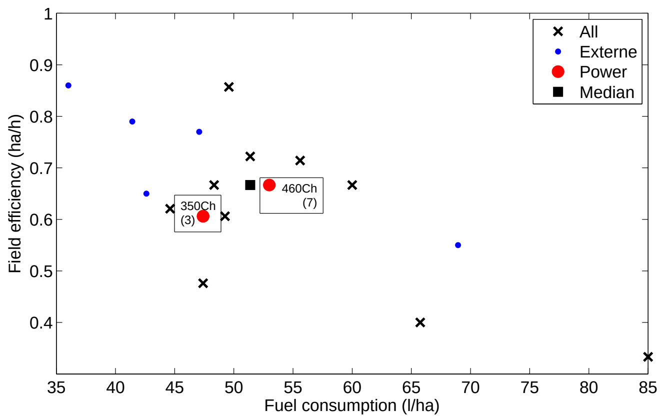

Figure 3.4: Measurements of fuel efficiency versus work efficiency - Sugar beet harvester

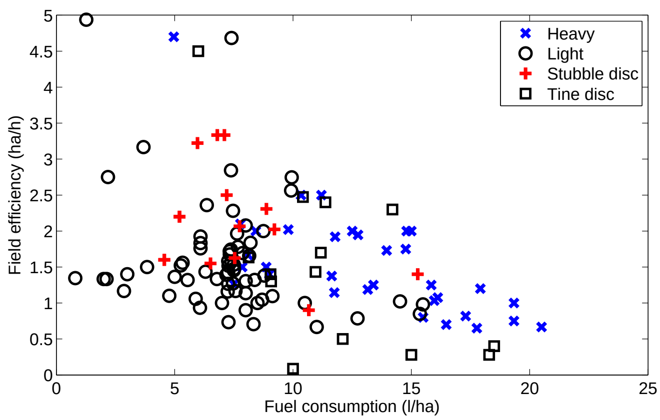

Figure 3.5: Measurements of fuel efficiency versus work efficiency - Cultivator

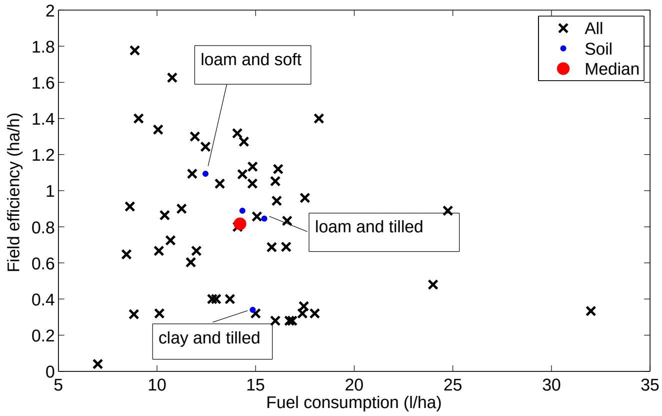

Figure 3.6: Measurements of fuel efficiency versus work efficiency - Combine cultivator * sowing

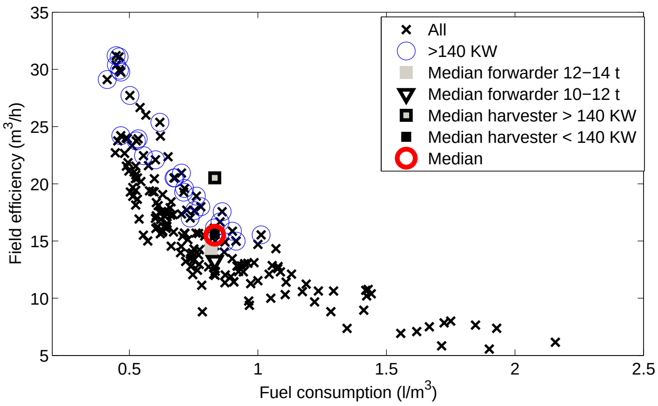

Figure 3.7: Measurements of fuel efficiency versus work efficiency - Forest Harvesting

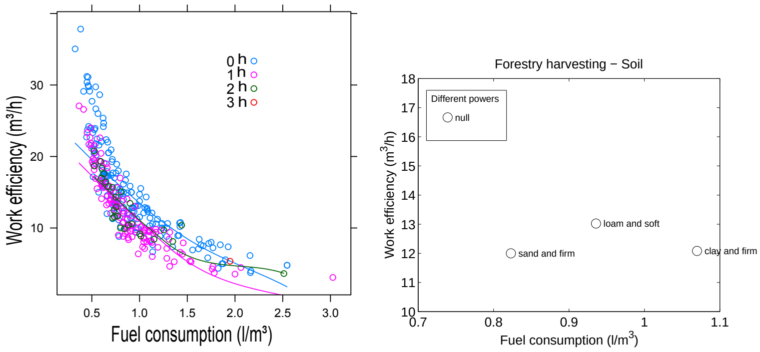

Figure 3.8: Impact of transport part and soil state on Forest Harvesting

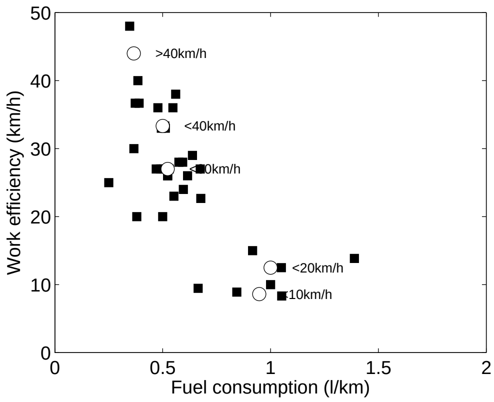

Figure 3.9: Measurements of fuel efficiency versus work efficiency - Transport

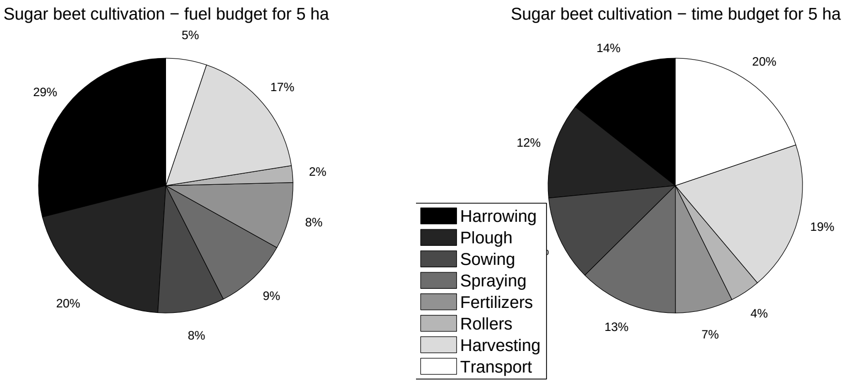

Figure 3.10: Fuel and time budget for tractor use during sugar beet cultivation

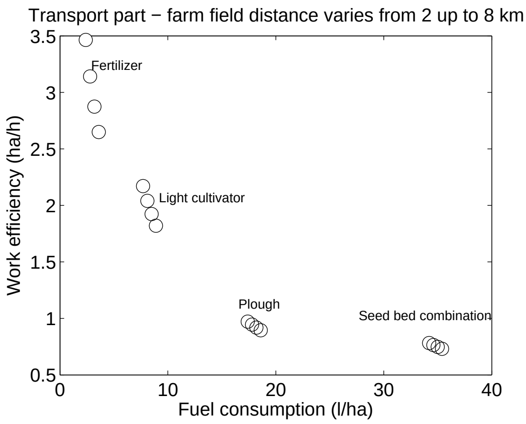

Figure 3.11: Transport contribution on fuel consumptions and field efficiencies for different implements

Conclusion

Area fuel consumption and productivity are the indicators proposed here to establish fuel needs and mechanization use describing the tractor's activities. They are used to produce reference values about tractor's fuel consumption needed in environmental impact studies, like life cycle analyses of agricultural productions. The database built in this project gives an picture of european farms and their heterogeneities. If the median european farm spends about 15,000 liters of fuel per year, agriculture needs between 100 and 170 l/ha/year. Data also show a general trend of higher fuel consumption for high powered tractor. Then, multivariate methods are used to appreciate the data structure. Sampling data by implements is found the best way to study more deeply fuel needs. But this analysis also hgihlights about a size effect in data: indicators are sensitive to the operation duration and differences, maybe related to a lack of accuracy in measurement method, is observed for small operations. Engine power also presents a negative correlation with duration indicating that powerful tractors work quicker than the small ones. This enhances the choice of our 2 efficiency indicators. The eco-solutions are presented and the analysis of the so-called logistic solutions were rejected. But the eco-solutions for other settings is also very difficult using the statistical approach and examples detail the difficulties in doing comparisons with the reference values. That's why ecosolution cases were gathered with reference measurements. For field activities, fuel consumption and productivities were computed for all the tested implements. A figure shows the distinction between light operations, having low fuel consumptions and high productivities and on the opposite, heavy works with low time efficiencies and high fuel demands. Then, details are given for the most documented implements. With 17 l/ha and 1. ha/h for plough, results show a slight increase in fuel consumption compared to the 1990's data. Engine power is correlated with the width of implements, leading to reduced fuel consumptions and higher productivities for larger ploughs. Speed and soil have an impact as great as width on fuel and time needs: for plough and cultivation/sowing combine, clay soils lead to higher consumptions and reduced productivities compared to lighter soils. The depth has less effect on the results. For other implements, fuel and time needs are presented and the most common operational parameters are given. In general, the time efficiency is higher for high powered machines but the fuel consumption also increases. Forestry activities are an exception because high powered harvesters were found more rapid without any additional fuel costs. The quantified fuel and time need give an idea of the fuel costs for higher productivity. The high rate of missing parameters does not allow the modeling of operational parameter impacts on efficiency indicators. At the end, an application presents the method for doing fuel and time budgets giving an annual cultivation scenario: this method allows studying the so-called logistics eco-driving solutions. A sensitivity analysis is carried on to study how the transport part affects fuel and time need assessments. This highlights how the lack about transport information may have contributed to the huge discrepancies in the data.

Acknowledgements

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Annexes

Name	Amount	$\sum Area$ (ha)	$\sum fuel$ (l)	$C_{50,fuel}$ $\left(\frac{l}{ha}\right)$	$s_{C,fuel}$ $\left(\frac{l}{ha}\right)$	$EF_{50,time}$ $\left(\frac{ha}{h}\right)$	$s_{EF,time}$ $\left(\frac{h}{ha}\right)$	Power (hp)
Baler	40	511	3840	4.9	0.51	1.97	0.19	115
Choppers / Feeders	3	5	43	8.5	0.60		0.01	35
Combine	67	6040	123450	18.0	0.77	1.51	0.09	317
Complete beet harvester	147	1257	55897	45.4	0.57	0.90	0.02	353
Cult./sow. Combin.	213	2046	26503	14.1	0.35	1.00	0.05	117
Cult. combination	1	3	49	16.3	NA	1.07	NA	175
Disc harrows	20	230	2421	12.7	0.95	1.54	0.15	135
Drill-direct sowing	6	46	475	11.5	0.69	0.47	0.14	100
Fertilizer spreader	37	1004	1022	2.0	0.34	3.86	1.18	75
Forage harvester	59	1573	52341	35.9	1.81	1.72	0.12	476
Hay tedder	7	226	311	2.0	0.52	2.83	0.92	51
Heavy cultivator	61	489	5729	12.3	0.53	1.69	0.19	165
Lifter/sugar beet harvester	15	39	558	14.7	0.66	0.64	0.03	100
Light cultivator	136	918	6398	7.3	0.30	2.32	0.12	170
Meadow aerator	5	75	172	2.4	0.39	1.73	0.28	51
Mounted gyrotedder	2	13	66	8.3	5.28	1.01	0.63	75
Moving harrow	57	325	5201	15.8	1.13	1.00	0.07	135
Mower	112	897	4862	5.7	0.25	2.20	0.17	120
Muck spreader	41	209	2290	11.7	0.74	0.33	0.09	110
Plough	300	1753	29983	17.0	0.38	1.00	0.02	150
Potato harvester	2	9	191	27.1	9.06	0.26	0.03	80.5
Potatoes planter	1	11	145	13.2	NA	0.46	NA	90
Potatoes ridger	2	46	906	19.9	0.62	0.63	0.00	101
Rollers	7	87	164	1.8	0.33	3.18	0.39	78
Seed bed combin.	18	114	3028	33.8	3.99	0.80	0.16	220
Seed drill	22	262	1441	5.6	0.73	1.87	0.11	100
Semi-mounted gyrotedder	13	216	656	2.9	0.33	1.79	0.16	59
Shredder	6	28	263	11.7	1.74	0.92	0.20	101
Silage trailer	2	14	131	8.5	2.25	0.72	0.03	106
Slurry spreader	143	734	5629	7.0	0.58	1.66	0.20	97
Slurry tanker	5	49	379	7.8	3.19	1.25	0.24	160
Soil loosener	14	71	1451	25.0	2.74	1.22	0.12	220
Spacing drill	16	173	1155	7.2	1.49	1.12	0.07	160
Stubble discs cultivator	51	274	2259	6.5	0.42	3.20	0.14	145
Tine stubble cultivator	48	284	3058	10.2	0.42	1.70	0.14	140
Tined weeder	1	35	112	3.2	NA	1.36	NA	59
Wrappers	1	10	17	1.7	NA	2.00	NA	51
Forwarder	10	178	4865	24.2	3.77	2.10	0.23	428
Silage Tamping	16	182	1095	7.4	0.85	1.77	0.21	125

Table 3.4: detailed of measurements sorted by implement type

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