Czech University of Life Sciences Prague

Faculty of Economics and Management

Department of Economics

Bachelor Thesis

Economic Evaluation of Precision Agriculture Application on Spring Barley Cultivation

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Declaration

I declare that I have worked on my bachelor thesis titled "Economic Evaluation of Precision Agriculture Application on Spring Barley Cultivation" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the bachelor thesis, I declare that the thesis does not break copyrights of any other person.

In Prague on 15. 3. 2018 ____________________________

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Economic Evaluation of Precision Agriculture Application Spring Barley Cultivation

Summary

The focus of this thesis is to compare two different trajectory paths of agriculture machinery in terms of costs used on example of Spring Barley farm. Hypothesis of this work is to prove positive impact of optimized trajectory focused on overall costs of Spring Barley cultivation. By a trajectory path is assumed the shortest path to a target point on the boundary of an agricultural working area given a current position and heading of a ground vehicle within the area. The representative measurement of the shortest path will be based on two variables; Distance driven, and time spent and recalculated afterwards in terms of fixed and variable costs (the computerized solution needs an investment; the resume stands as evaluation of overall costs). The calculation will get us an overview of total spent work hours, fuel costs and cultivation related savings described on one-year cultivation and assumption of impacts on agricultural business management.

Keywords: GPS, RTK, CTF, Shortest path, Ground Vehicles, Spring Barley, Costs, Economics of Farm, Agriculture Management, Optitrail, Trimble, Organized Movement on Field

Ekonomické zhodnocení precizního zemědělství na kultivaci sladovnického ječmene

Souhrn

Cílem této práce je zhodnocení vynaložených nákladů dvou způsobů směřování zemědělské mechanizace po poli na příkladu pěstování sladovnického ječmene. Hypotéza se zaměřuje na zjištění přínosu použití optimalizované trasy vypočítané počítačovým algoritmem v porovnání s původním směrem, jenž byl používán v předešlých letech na zkoumaném poli. Srovnání vychází z údajů o ujeté vzdálenosti zemědělských strojů, z toho vycházející hodinové náročnosti a následný přepočet na variabilní a fixní náklady. Výsledné zhodnocení se zaměřuje na posouzení vlivu optimalizované trasy během ročního pěstování a zjištění, zdali přináší pozitivní důsledek pro podnikohospodářskou ekonomiku provozu.

Klíčová slova: GPS, RTK, CTF, Využití systémů GPS u techniky pro pěstování rostlin, Pozemní vozidla, Sladovnický ječmen, Ekonomika farmy, Kultivace sladovnického ječmene, Optitrail, Trimble, Organizovaný pohyb po poli

Table of content

1 Introduction

The dawn of personal computers started new Information era with almost unlimited possibilities. We are using computers in almost every aspect of our life. They are used in every industry to save time, materials and workforce. They maximize the effectivity of every process. Adopting of this technology in agriculture is the next logical step to achieve higher yields, less consumption of materials and consumables, less workforce, less environmental damage and better overall management (traceability of every step) which all results in much more effective system.

Afterwards the Navstar GPS was firstly introduced into civil and commercial sphere, the new and unexplored market has arisen. The first step was adaptation into airplanes navigation, few years after into car navigation and then straight into all kinds of consumers devices. The potential of using this technology in agriculture was expected but the process of adoption was not straight-forward. Shortly after start of using navigation in Agriculture machinery the problem was on sight. Not adequate accuracy for use in agriculture. At the time a solution called DGPS, Differential Global Position System exists, but only for privileged users such as U.S. Army and adjacent public services. That changes with turnout into new century and with opening into new commercial segment (companies renting radio stations transmitting differential signal for other companies) and the technology started to expand into agriculture.

Due to the fast development of other IT systems (in sense machines can process a lot of different data and use them in a meaningful manner) the initial expenses lower to such level that adopting this technology is reasonable and even inevitable for further development.

The power of whole system lies in sharing of data collected by sensors to better allocate resources, compiled by a computer and transmitted via signal to an end user, for example tractor with variable rate of application which can precisely adapt to unique attributes of specific location in soil.

Picture 1 – Collective gathering of data across platforms,
source: http://www.farmmanagement.pro

Objective

The purpose of this thesis is the evaluation of Precision Agriculture benefits on farm economics. Due to the complexity of this topic the first part will be summary of current technology, methods and basic information from available written and internet literature. The second part will focus on comparison of two same fields with different way of path. The first path is presumed be a traditional way used before without optimization, and the second is optimized for shortest path within agriculture field. The task of finding shortest path is itself complex operation where can be used different approaches of mathematical methods. This include dynamic programming and label correcting Algorithms such as Dijkstra's method (Bemporad, 2016). For purpose of this work we are using automated algorithm developed by a company Leading Farmer with commercial name Optitrail.

The goal is to compare two fields preserving constraints and deduct appropriate results and for our purpose is this approach convenient. Issue which arisen shortly afterward research is that current accepted normatives in the Czech Republic are mostly calculated in sense of extent (tonne per hectare). Because this fact we use two different methods. One method is deducting efficiency of agriculture machinery by recalculating performance per hour and yield where is time variable present in terms of yield performance and second method, where is used usual hour consumption rate during workforce which implies lower confident interval, but still maintaining meaningful results.

1.1 Introduction of Spring Barley

Barley is one of the most widely cultivated cereal over the world with higher profitability than others. It has an advantage thanks to relatively low requirements on soil and wide usability, it could be used as animal fodder, source of making a beer, certain distilled beverages and bread.

1.1.1 History

Barley has been known to people for at least 8000 years situated mainly in area of Eurasia. It's one of the first cultivated and domesticated grains known to humans. Cultivation of Barley was extended to Europe in Middle Age (5^{th} to 15^{th} Century) where its relatively low requirements for soil, convenient temperate climate and wide usability, makes Barley significant source of proteins not only for humans but also animals. Domestication of Barley in the Czech Republic can be traced down till 9^{th} Century. Barley was through the time modified to achieve more yields in terms of quantity and stability of outcome and more immune to different diseases and better cultivation on lower quality soils.

1.1.2 Spring Barley nowadays

Cultivation of Barley in the Czech Republic is second most profitable cereal (in term of gross profit) and outperforms even a rapeseed. Barley's convenient properties – high market price, low volatility, relative low expenses on cultivation, lower requirements of soil and not necessary high demand for predecessor cultivator in terms of soil fertility makes it one of the most profitability grains (Černý, 2007).

Nowadays the cultivation of Spring Barley is one of the most profitable cereals in the world and the demand is rising. World production of year 2013 was in general (this means accumulated winter and spring varieties) 144,755,038 tonnes which is higher than 139 million tonnes in year 2007 so we clearly see demand rise (Černý, 2007).

To better analyse current production, we need to differ Barley into two categories:

- Malt Barley (Spring Barley, Feed Barley, Two-Row Barley, Six-row Barley that are afterward processed by a food industry mainly in manufacturing alcoholic beverages)
- Feed Barley (used as feed for cattle) less quality kernels

From whole amount of 139 million tonnes only 30% are Malt Barley (usable as Feed Barley) and 20% of all production is used to malt alcoholic beverages (Beer, Whisky).
In 2007 the biggest producer of Barley was a European union (EU_{27} with 42% respectively) followed by a Russian Federation (13%), Canada (8,2%), Australia (6,5%), Turkey (5,3%), Ukraine (4,5%).

The biggest producer of Melt Barley is European union (EU_{27}) with 47% share which means 4,2 million tons per year. The Czech Republic produced 1,3 million tonnes of Spring Barley in year 2007. (Černý, 2007)

The biggest importer of Barley in 2017 is Saudi Arabia followed by China, Iran, Libya and Japan.

Interesting fact, the Czech Republic was in 60s of 20th Century biggest producer and exporter of Barley in the world. (Černý, 2007)

Vývoj produkce a spotřeby ječmene ve světě. Dle USDA.			
Rok	Produkce (mil. tun)	Konečné zásoby (% na celkové spotřebě)	Podíl krmné spotřeby z produkce (%)
1978/79	176	14	71
1987/88	175	19	74
1997/98	154	22	67
2002/03	135	20	70
2006/07	137	15	73
2007/08	137	13	71

Table 1 – Production and consumption of Barley in world, source: Černý (2007)

From Table 1 we can deduct that the supply falls while demand rises, keeping same portion used as feed for animals. (Year/ Production/ Supplies in %/ portion of Feed Barley in %) (Černý, 2007)

Harvest estimates in the Czech Republic for selected crops as at 15 August 2017

Plodina	Osevní plocha v hektarech *Sowing area (ha)*	Výnos v t/ha *Yield (t/ha)*	Sklizeň v tunách *Harvest (t)*	*Crop*
A	1	2	3	b
Základní plodiny	**1 262 318**	**5,34**	**6 741 762**	*Basic cereals, total*
Ječmen celkem	**327 707**	**5,13**	**1 680 056**	*Barley, total*
Ječmen ozimý	97 178	5,69	552 836	*Winter barley*
Ječmen jarní	230 529	4,89	1 127 220	*Spring barley*

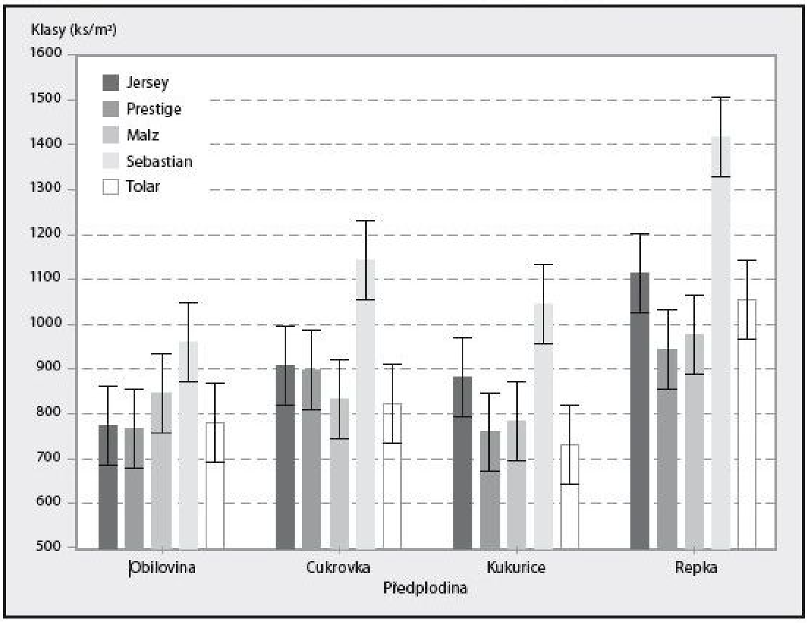
Table 2, Source: CZSO (2017)

1.1.3 **Spring Barley Varieties**

Barley has a wide variety of different varieties. For simplify we talk about 5 most used variates in Czech Republic. The differences between varieties are in their protein content and tolerance for the predecessor cultivar.

- Jersey – mostly used in brewery, not effective after the corn and sugar beet
- Prestige – preferred by breweries producing Czech beer.
- Malz – universal, balanced properties
- Sebastian – most effective variate in terms of density
- Tolar – not effective after root plants

On Picture 2 we see density of growth each variety of Barley dependable on predecessor cultivar (x axis is predecessor cultivar accordingly; root vegetables, sugar beet, corn, rapeseed; y axis is density of ears in units/m^3).



Picture 2 – Density of Barley ears depending on predecessor cultivar, source: Černý (2007)

1.1.4 **Spring Barley Cultivation**

Even the cultivation of Barley is widespread there are few rules to achieve high quality of yield.
Maintain cultivation between 400 m - 500 m to prevent most limiting factor – low precipitation. Its relatively resistance to cold places but the dry season is quickly lowering the quality (in that case the N-substances portion is rising to 15% - 16% which is not considered as usable for further processing) (Černý, 2007)

Spring Barley has roots long 30 cm, this implicates lower dependability on warmer temperature climate and relatively lower dependence on underground water management, but it needs for achieving quality yield fertile soil (for example Black soil, Brown soil, Clay soils) which prevents water leakage down into underground.

Soil acidity - expressed by pH should be between values 5,8 - 7,2 dependent on predecessor cultivator.

There is possibility to cultivate Spring Barley on field after not very convenient predecessor cultivate (other cereals) but to achieve stabile and high yield is required to use sufficient cultivators with regenerative effect and/or corresponding fertilization. That could be for example sugar beet, rapeseed which contributes to more fertile, cultivated and more acidity stabilized soil and exceeding to lower need for fertilizers, herbicides and pesticides. In terms of exact data cultivation of predecessor Winter Rapeseed and successor Spring Barley requires less usage of N fertilizer, from 90 $N.ha^{-1}$ used if different predecessor is cultivated to 60 $N.ha^{-1}$ (Černý, 2007)

Unique feature of Spring Barley is its monoculture in terms of one-year cultivating. Usually every cereal after few years occurs “decline” effect, when the yield outcome declines in next years. The Spring Barley is most tolerable if this happens from every other cereal.
But this property has got drawback for usage of Spring Barley as the predecessor cultivate when the successor cultivate is sugar beet, winter barley, triticale, potatoes so it’s not often used this way.

Even when is recommended to use predecessor cultivate sugar beet there is problem with high water consumption, so the soil is drier than should be and this could be considered. (Černý, 2007)

We are dividing cultivation process into three categories

- Minimizing processing
- Standard processing
- Intensive processing

Each process has advantages and disadvantages dependent mainly on type of soil, soil moisture, precipitation and period of the season. Academic audience recommends not using minimizing processing because ploughing on Autumn get soil fluffy on Spring sowing which results in better water allocation and lower fertilization and higher yield.

> "The best seedbed is that which got firm bed and fluffy blanket" (Černý, 2007)

1.1.5 **Spring Barley Diseases**

Protection of crop is also very important stage. Spring Barley, as every other cereal is vulnerable to fungus diseases which could happen by bad agrotechnical method, or disfavour weather.

Most frequent disease is Barley powdery mildew. We can recognize it as barley patches turn gray and small dark black or brown cleistothecia form in the mycelium mass. Symptoms progress from lower to upper leaves. Symptoms of powdery mildew are chlorotic areas surrounding the infected areas. The lower leaf surface corresponding to the mycelial mat will also show chlorosis. Lower leaves are commonly the most infected because of higher humidity around them. (Christensen, 1997)

In economic sense it can lower the yield by 25% (usually 10%). Every variation of Barley behaves differently so there is wide range of different fungicides on market now.
Protection of weeds in Spring Barley crop is easier due the ability of Spring Barley to suppress one-year two-sided weeds. But on the other side even small amount of affected area could lower the yield by 10%. (Černý, 2007)
Awareness of pests in Spring Barley crop isn't so significant as it happens mainly during invasive spread. Mostly pest spread involve aphids or greenflies.

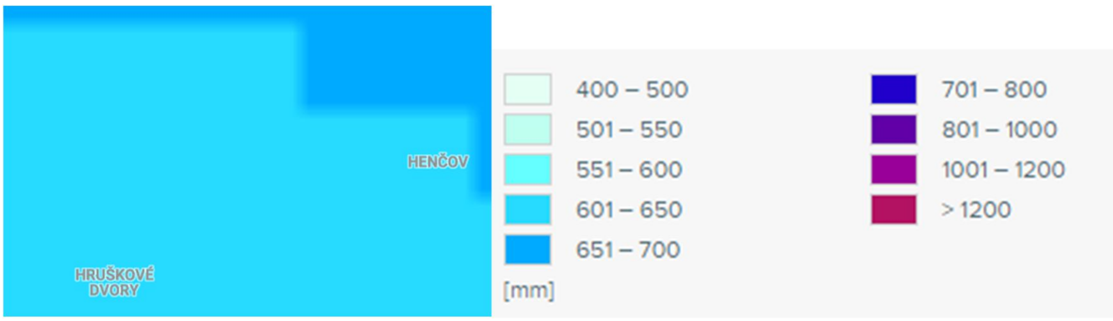
1.2 Selected Field

1.2.1 Description

Four our purpose was chosen field in district Jihlava, between Hruškové Dvory and Henčov villages. Field covers area of about 67,97 hectares. Predecessor cultivate was maize. Average precipitation is about 600mm of water column per year.

Map 1 – calculation of covering area, source: https://www.daftlogic.com

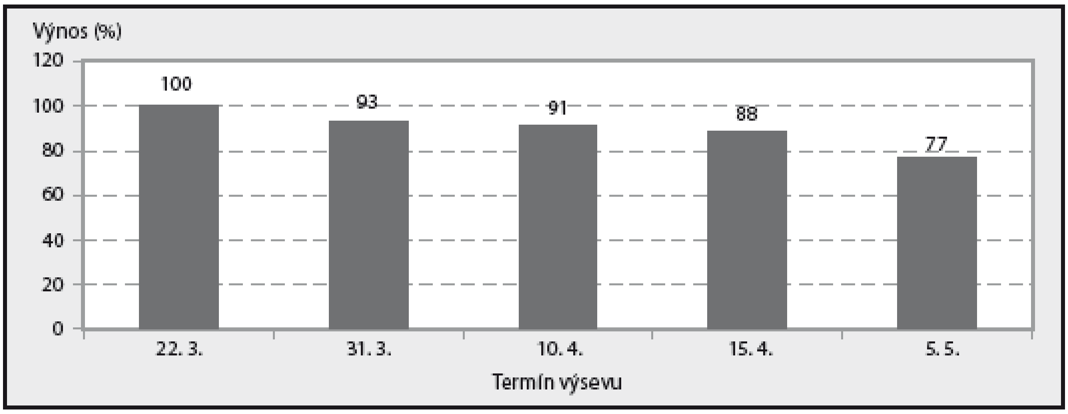
Map 2 – Field of research, source: https://www.optitrail.cz



Map 3 – Average precipitation of area, units in millimetres of water column per year, source: http://www.klimatickazmena.cz/cs/

1.2.2 **Spring Barley General Application**

Spring Barley sowing is 30mm-50mm deep dependent on soil rigidity. Pre-sowing preparation makes firm subsoil and appropriate structured soil to get best condition for grow. Important feature of Spring Barley is its propensity in early sowing (due the short root system) which affect yields more than delayed sowing. (Černý, 2007). This fact emphasizes on right agrotechnical methods as sowing seeds horizontally and vertically, using same distance and same width of cutting. Spring Barley instead of prolonged grow when sewed is growing faster with a lower protein volume which decreases yields.



Picture 3 - The effect of delayed sowing, source: Černý (2007)

In Picture 3 we see decreasing yield dependable on time of sow. This case study was done by ZVÚ Kroměříž between years 1993-2000 and average decrease due to late sow was in range of 40-130 $kg.ha^{-1}$ Which represents 0,6%-2% loss of every day after. (On y axis we see relative yield and on x axis date of sowing) (Černý, 2007)

Spring Barley cuttings depends mainly on specific variation soil moisture, quality of seeds and soil nutrition. There is eventuality of stronger “rowing” which could affect homogeneity of growth and maturity this could be minimized by larger volume on seed sowing.
In the Czech Republic condition is amount of sewn seeds in range from 3 to 5 million per hectare. When is soil drier than usual or we sow after the 15^{th} March we add 10% - 15% more seeds. Width of cuttings is normally 12,5 cm wide but in last years it is more common to use cutting 6,25 cm wide. In terms of effectivity there is a slight benefit of higher yield when new method is used.

1.2.3 **Nutrition of Spring Barley**

As we mentioned earlier in the text the Spring Barley benefits from low depth roots so it gathers nutrition from upper soil and using manure from animal breeding. Nowadays due to the decreasing cattle breeding on field this must be adjusted by using extra manure and more precise approach to fertilizers.

The first thing to perceive is what kind of predecessor cultivar we had.

- Organically fertilized root crops
- Crop leaving soil in trim with enough nutrition – Rapeseed
- Soil exhausting crop as Corn, Winter Barley

This mainly affect usage of N fertilizer which amount differs almost 2x times between groups. When we expect yield 5 tonnes and up we assume to use 100-125kg of N per hectare in two stages, at the sowing (under the seedbed) and in process of growing. Afterwards we use liquid fertilizers to support good leave grow.

1.2.4 **Harvest of Spring Barley**

Harvest is crucial moment in Spring Barley life. This is mostly by high demanded standards of companies which are using Malt Barley for products which are dependable on right amount of protein and other ingredients used for example in brewery and associated industry.

To sustain best sensorics properties of Barley the harvest must be done as quick as possible and the kernel must be mature. To found out if the kernel is sufficient mature we follow rules

- Kernel is not flexible but firm
- Rest of plant is dead
- Moisture of kernel beneath 16%

Also, the kernels are vulnerable to mechanical damage, so the combine harvester has to adjust speed of drum to sustain form and avoid breaking down. The losses could be as high as 15,3% of whole harvest (Černý, 2007)

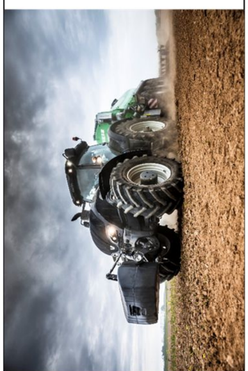
To storage Barley we need to assure silo with stabilized moisture conditions. If we don't do this, the Barley could get wet which results in fungi diseases and total loss of our crop.

1.3 Technical Equipment and Machinery

1.3.1 Overview of Machinery

For successful growth of Spring Barley, we assume these agriculture machines:

List of used Machinery

Tractor		Self-propelled sprayer	
Tractor Valtra S354 350HP		**John Deer 5430i**	
Seeding machine		**Spreader of Fertilizers**	
Horsch Terrano 10FG		**Amazone ZA-M 1501**	
Combine Harvester			
Claas Lexion 570M		**Orion 120 trailer**	

List of used Width

Tractor		Self-propelled sprayer	
Tractor Valtra S354 350HP	based on trailer	John Deer 5430i	36 m
Seeding machine		**Spreader of Fertilizers**	
Horsch Terrano 10FG	9 m	Amazone ZA-M 1501	36 m
Combine Harvester			
Claas Lexion 570M	9 m	Orion 120 trailer	9 m

Table 3 – List of used machinery, own work

1.4 Global Positioning System and Global Navigation Satellite System

We usually refer Global Positioning System as a method of localization of different subjects on the Earth by using measuring distance from satellites, but the term Global Positioning System is name of specific system invented and provided by the USAF in 70s of 20th century. To be right when we want to describe meaning mentioned earlier we use term Global Navigation Satellite System or GNSS (it merges GPS, GLONASS and Galileo altogether) At the moment (2017) there are three main providers of such a system.

- **Navstar GPS**
    - Original GPS system provided by USAF in 70s. Primary made for Army purpose but when the costs of maintenance started to escalate quickly up the army released it to civil utilization.
    - 32 satellites total
- **Galileo**
    - European Union developed system on behalf of 20th and 21st century, same principle. Independent in case of war accident.
    - 5 settings of accuracy and security
    - 10 satellites total
    - Not widely adopted, less devices, worse real-world application than GLONASS and GPS
- **GLONASS**
    - Russian parallel system as Galileo and Navstar GPS except with added two different accuracy settings.
    - 24 satellites on the three different trajectories

1.4.1 **Description of Navstar GPS Technology**

Current technology which is widely used as navigation element of agriculture machines is Navstar GPS (project by USAF form 60s 20th century which made into civil utilization in 80s). Due to the quick rise of mobile GPS locators and relatively open licensing system (more description ahead) the Navstar GPS or abbreviated GPS is now mostly used positioning system.

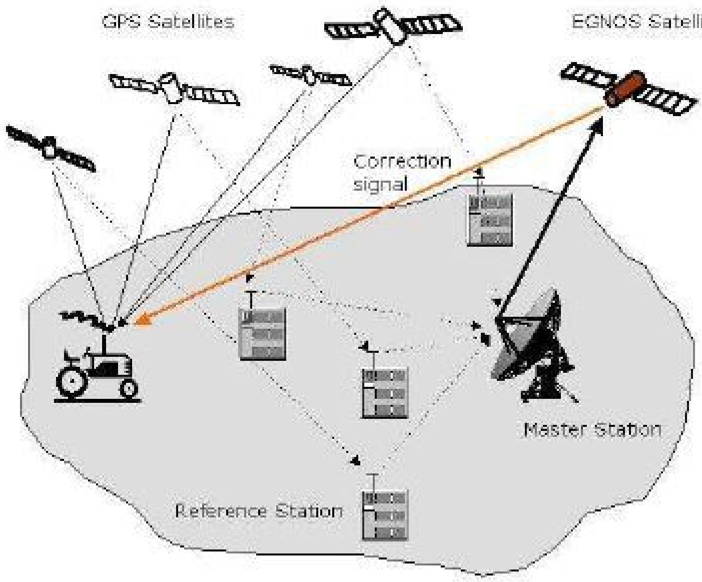
The Navstar GPS is divided into three categories

- **Cosmic segment**
  - At every moment and every place there should be visible at least 4 satellites. The more satellites visible the better
  - 5 different signals for different purposes

- **Guiding segment**
  - As there are atmosphere anomalies and irregularities there is grid of control stations which corrects signal values, synchronize time and correct satellites trajectories
  - 4 ground transmitter and main station

- **User segment (navigation box)**
  - This is mostly our first encounter to this technology. It consists of receiver of signals which are calculated by the device and then extracted as a position information in form of coordinates. It could be the mobile phone with GPS, camera or navigation console in agriculture machinery
  - Minimum 4 visible satellites to estimate the location
  - Receiver is just passive component
  - Most time its sufficient accurate (sufficient in car navigation)
  - Information about latitude and longitude and geographic height
  - Error rate with CI 95% less than 0,7 m (gps.gov, 2017)

The benefit of this technology is 24/7 availability, real-time information and no limitation for users. Even the GPS technology is quite sophisticated it got one major drawback and that's a passivity of the receiver device and in agricultural standards consequential inaccuracy (<0,7 m). Among other drawbacks is a lower accuracy nearby and in forests and in tunnels.



Picture 4 – GPS with Differencing signal system, source: www.environmental-studies.de

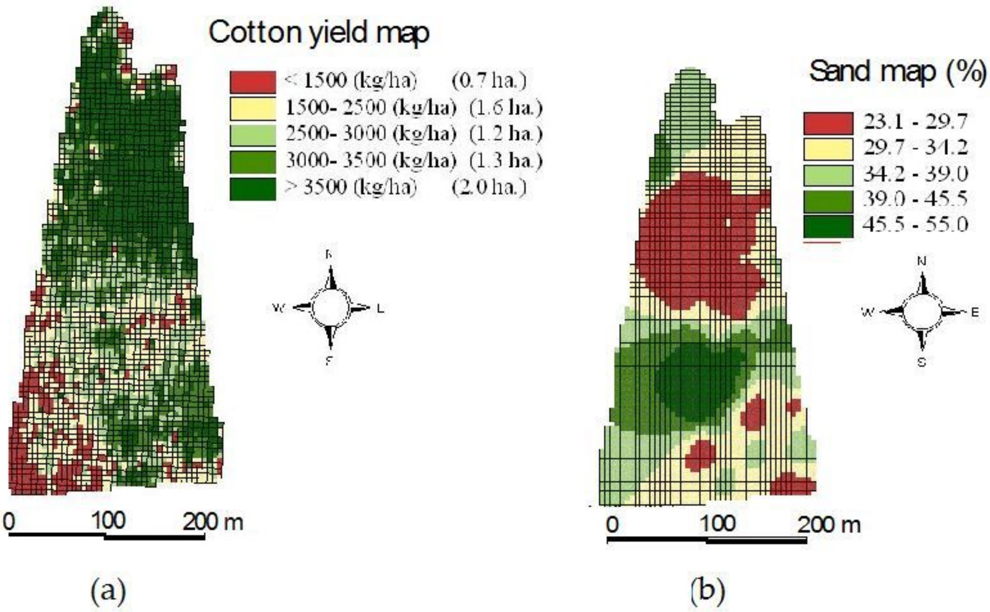
We compensate this drawback by introducing differencing signal. Differencing signal is signal which is transmitted by a local/or nearby station/satellite which refine our coordinates and give them better accuracy. There are lot of theory of different frequencies, multi-band receivers, transmitters but for our purposes I will use only the commercial solutions. (Picture 4)

1.4.2 **Methods of utilizing GPS in Precision Agriculture**

Due to the mass expansion of GPS locators literally in every device, the purchase price of this technology lowers at level when it's cost-effective even despite need a differentiating signal.

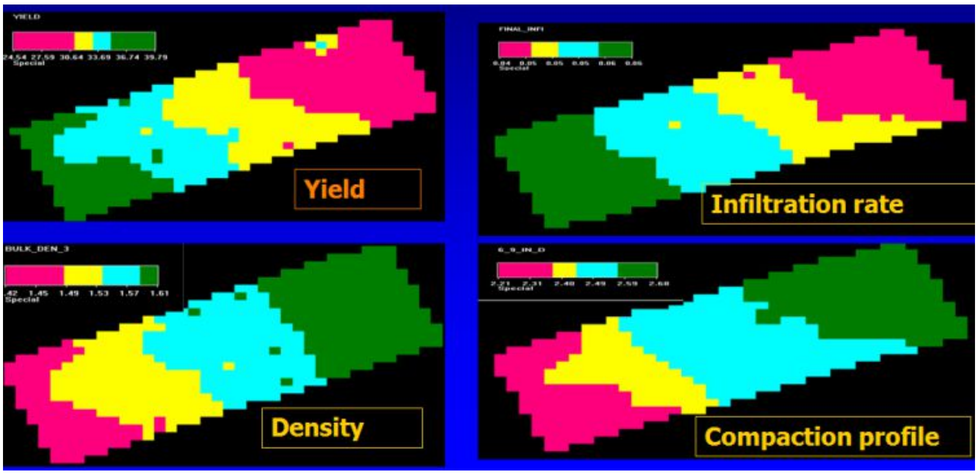
When we compare traditional field, we see that every process in previous century was taken in general, widely and universally. We used the same amount of fertilizers, herbicides, fungicides, pesticides per hectare and based on individual experiences we adjust the volume locally. This was big problem then because not every field is the same. It differs by the shape, type of soil, it can have nature irregularities, different slopes, trees etc. Nor soil is same over the whole field.

The GPS and adjected positioning technologies give us a powerful tool that we can accurately locate every point on field and use this information to get better understanding and better decision making. It's called sampling and it can help us generating a Yield maps (created by drones with special cameras and by on-field sensors of moisture and other soil parameters) which shows us precisely located under or over nutrition points. And from this information we can better arrange our next steps. (Picture 5 and 6)



Picture 5 – sampled yield map, source: Upadhayaya (2012)

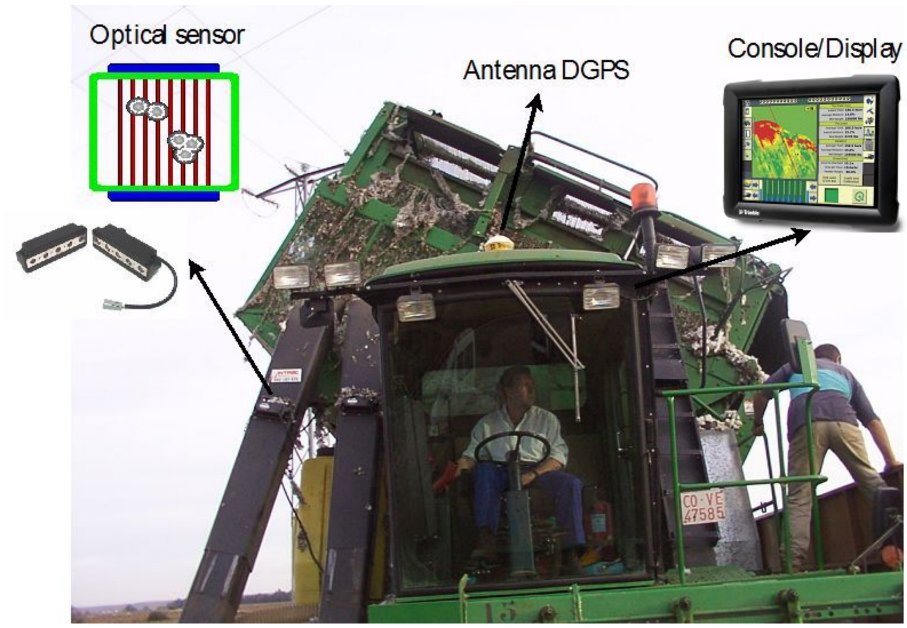
Next utilization which is main part of this thesis is using GPS and adjected positioning in controlled traffic farming or abbreviated CTF. The capability of this technology is enormous. Due to the usage of wider spans (up to 36m) during cultivation the self-navigation is harder and there is risk of blank spots which aren't managed so we risk less yield. This could be solved by using GPS guidelines which helps us better navigate and even it can self-navigate during whole process with greater efficiency.



Picture 6 – sampled maps, source Upadhyaya (2012)

1.4.3 **Differential Global Positioning System**

DGPS uses a grid of referential stations located over the world which transmits signals to GPS locator. Due to the fixed position of references stations the signal is compared with position of other satellites and in conclusion its accuracy could achieve <0,3 m. The problem of this technology is that the transmitters (DGPS radio beacons) are fixed and the signal must travel long distance which inevitably results in worse accuracy and greater delays. The greater distance, the worse signal. The signal is usually paid, and the most known providers are Omnistar, StarFire, Beacon, Egnos. (BAUER, 2006) (Picture 7)



Picture 7 – System of navigation using DGPS, source: Upadhyaya (2012)

DGPS despite these technical limitations have found numerous application in agriculture. It is used in field sampling (yield mapping, soil and nutrition mapping and other specific crop mapping situations) and in Variable Rate applications of fertilizers, herbicides, pesticides, fungicides. On the other precise planting in rows or autonomous navigation requires much more accuracy which can't be delivered by this method. The method enabling these capabilities is called Real Time Kinematic

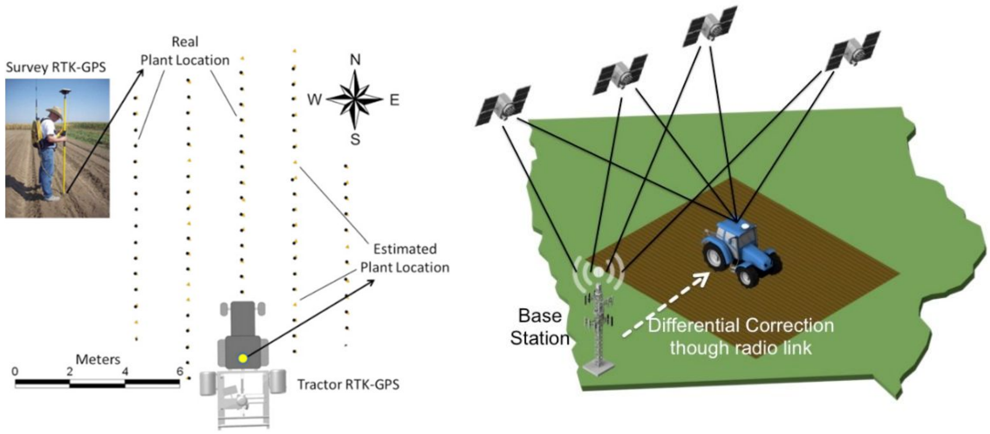
1.4.4 **Real Time Kinematic, RTK-GPS**

Real-time kinesis is a new solution to improve GPS signal accuracy. It’s closely based on technology Differential Global Positioning System abbreviated DGPS but it much more accurate.

Main reason why is this method more accurate is in the shorter distance between radio stations, which transmits radio signals and receiver, usually situated inside agriculture machine. Radio station must be located nearby field, be visible to other receivers of signal and precisely geo-localized. Radius of this radio beacon is between 3-10 km depending on radiated power. (Picture 8)

Also, instead of just one differentiated signal the beacon is emitting another control signal which assures right signal values in different magneto-atmospheric conditions. This has results in accuracy of 2-5 cm dependent on conditions.

This value of accuracy is perfect for using inter-row sowing when is crucial to sustain good tracking stability, respecting constant tillage depth, avoiding drifts on skid angles of field and other imbalances.



Picture 8 – Real Time Kinesis with GPS, source Trimble

1.4.5 **Real time Kinematic Virtual Reference Station**

Even if the method with near-field radio beacon is the best way how to solve issues with accuracy there is newly arisen problem with high initial expenses to technology and need of expenses on maintenance. This situation solves RTK VRS or Real Time Kinematics Virtual Reference Station.

RTK VRS is preserving advantages of signal accuracy but for less expenses. This is achieved by as the name suggest making virtual reference station which necessarily does not have to be built nearby field. Instead of it's a local grid of radio beacons which shares between them all kind of data's which all results in very accurate signal even if they are far apart. The corrective is using GPRS carrier straight into modem located on machinery (tractor, combine harvester)

Pioneer of providing this technology in the Czech Republic is company Leading Farmers which offer own RTK VRS grid. Other providers are John Deere and others. (Table 4)

1.4.6 **RTK Extend**

This technology approach different path. It is provided by John Deer company and solves issues with short-term downtimes when tractor is passing by obstacle and the visibility between receiver and transmitter couldn't be reached. The downside is that it couldn't be used when overall strength of signal is weak.

1.4.7 **List of actual RTK-GPS providers (2017)**

Differenciating signal	accuracy during ride < 15 min	absolute accuracy	source of corective signal	carrier of signal	compatible GNSS systems
no (autonomous GNSS)	**0,5 to 2 m**	2 to 5 m	no	no	GPS/GLONASS
EGNOS	**25 cm**	1,3 m	3 sats	sattelite	GPS
OmniSTAR VBS	**25 cm**	<1 m	sat ESAT	sattelite	GPS/GLONASS
RangePoint RTX	**15 cm**	50 cm	Sat RTX EA	sattelite	GPS/GLONASS
OmniSTAR XP+	**10 cm**	20 cm	sat ESAT	sattelite	GPS
OmniSTAR G2	**10 cm**	20 cm	sat ESAT	sattelite	GPS/GLONASS
OmniSTAR HP	**7,5 cm**	20 cm	sat ESAT	sattelite	GPS
RTK single base station	**2,5 cm**	2,5 cm	one beacon	satellite/GSM/walkie	GPS/GLONASS
RTK single base station xFIll	**2,5 to 4 cm**	2,5 to 4 cm	grid of beacons and sat RTX EA	satellite/GSM/walkie	GPS/GLONASS
RTK VRS	**3 cm**	3 cm	grid of beacons	satellite/GSM/walkie	GPS/GLONASS
RTK VRS xFill	**3 to 4 cm**	3 - 4 cm	grid of beacons and sat RTX EA	satellite/GSM/walkie	GPS/GLONASS

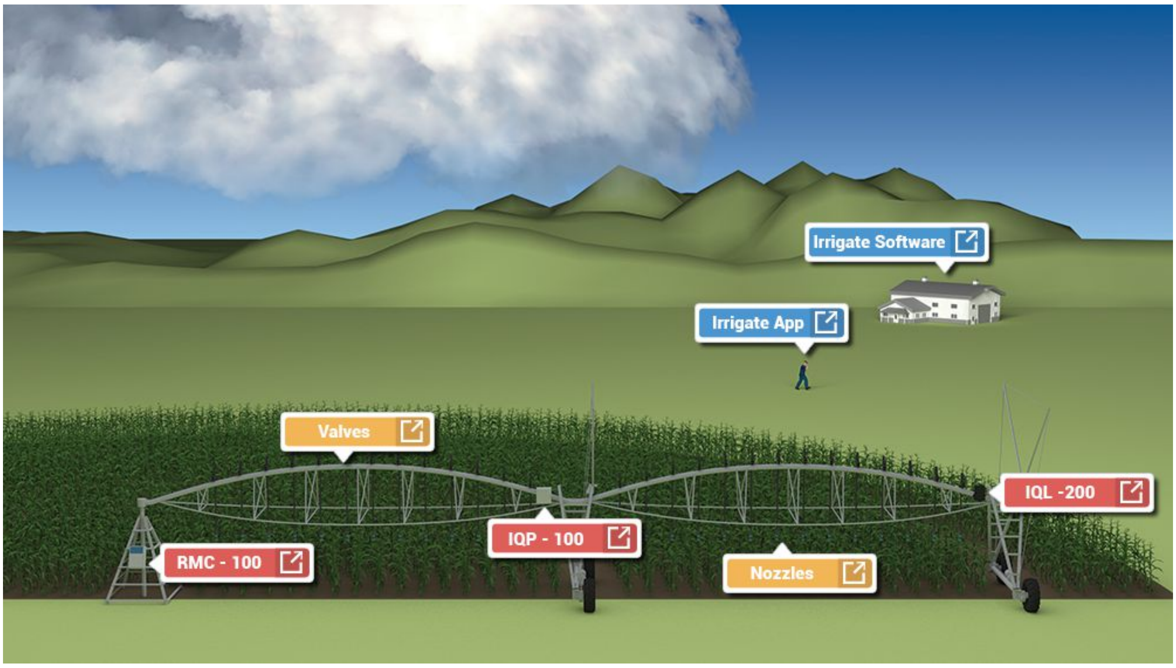
Table 4 – List of all available RTK signal providers with comparison, source: Leading Farmers edited

2 Controlled Traffic Farming

After briefly summarization of available signal navigation technology the next chapter is called Controlled Traffic Farming.

When the signals are abbreviated into one and with no more concerns of offline connection we could use it for overall control of traffic over the field. There are three categories based on level of automatization – on level of machine control. Each has advantages and disadvantages dependent on specific usage and higher level also means higher expenses on technology. Higher level of automatization means presumably expectation of lower fuel consumption, higher yields, lower overall turns on field, shorter distance, low overall emissions and low field erosion during turning on hillside.

CTF is more alike platform that associates all assistants. Basis lies in permanent traffic lanes. Due the future unification of wide of chassis could be minimized soil compaction. Better field traffic, less headlands, faster sowing and harvesting. This technology also accumulates all kinds of automatization systems such as Variable Rate Control, Irrigation systems (Picture 9), On field radars situated on tractor roof for locating weeds etc.



Picture 9 – Irrigation solution by Trimble, source: TRIMBLE

2.1 Manual navigation

Solution that usually uses light emitting bar or display show direction and diversion from predicted pathway to aware driver keeping the lane to assure right and optimized trajectory. (Picture 10)

- Advantage: Tolerable initial expense, easy installation across different machinery, interchangeable
- Disadvantage: Only basic ride assists showing diversion of generated pathway

Picture 10 – John Deere Lightbar, source John Deere

2.2 Assisted Navigation

Next level of control. The driving column is equipped with electric servo motor (or complete steering wheel) which means capability of active assist drive. It used with LCD display showing directions.

- Advantages: Interchangeability between machines, semi-automated driving helps actively maintain pathway. Expense costs could be redistributed among different machines
- Disadvantages: Technology of transferring torque from electromotor to servo integrated into steering column isn't so precise so it can feel loose at demanding pathways, disturbing way of direction.

Picture 11 – EZ Steer, semi automated steering wheel by John Deere, source: John Deere

2.3 Autopilot – Automatized Navigation

Most sophisticated level of automatization. Steering is fully automated. The steering rod has automated valves which assures right angles during turning and precise navigation through pathways. On steering wheel is button which enables or disables Autopilot function. This technology has biggest benefit on lowering expenses. But with highest initial expenses and no interchangeability among different machinery.

- Advantage: Most sophisticated solution fully automatized. Self-driving through turns, minimizing terrain erosion. Dependent on Optimized trails – pathways to achieve better economics
- Disadvantage: Higher initiative invest costs. No interchangeability. Investment return convenient for large agro-enterprises with large fields and high profits.

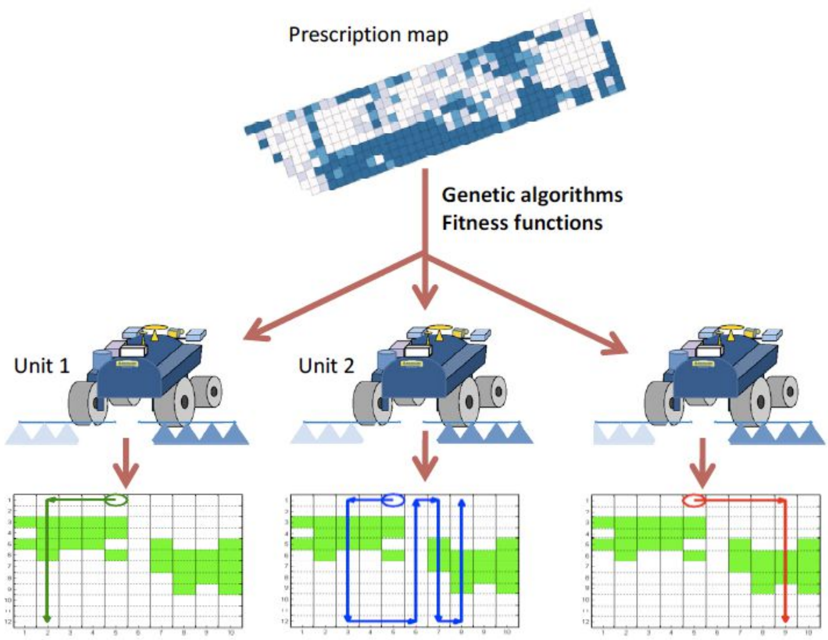
Picture 12 – Emmetts John Deere iTec Pro demonstration, source: Youtube.com

Picture 13 – John Deere iTec Pro, source: John Deere

2.4 Variable Rate Application – Trimble

Variable Rate Application is method of application specified amount of material to precise location. In agriculture it is a technology which can precisely dose exact amount of seeds, chemicals and fertilizers into precise location thus saving costs and reducing environmental damage. Its connected with automatic section control avoiding already processed spot of field. As we can see on Picture 14, into technological ready sprayer is imported special prescription map with exact amounts of chemicals and thanks to computer-controlled nozzles the field is sprayed as prescription map tells. Fertilizing only sport where it's needed. This can be done independently by more than one vehicle at once.

The pioneer of this technology is company Trimble.



Picture 14 – Application of maps into sprayer, source: Trimble

2.5 **Optitrail**

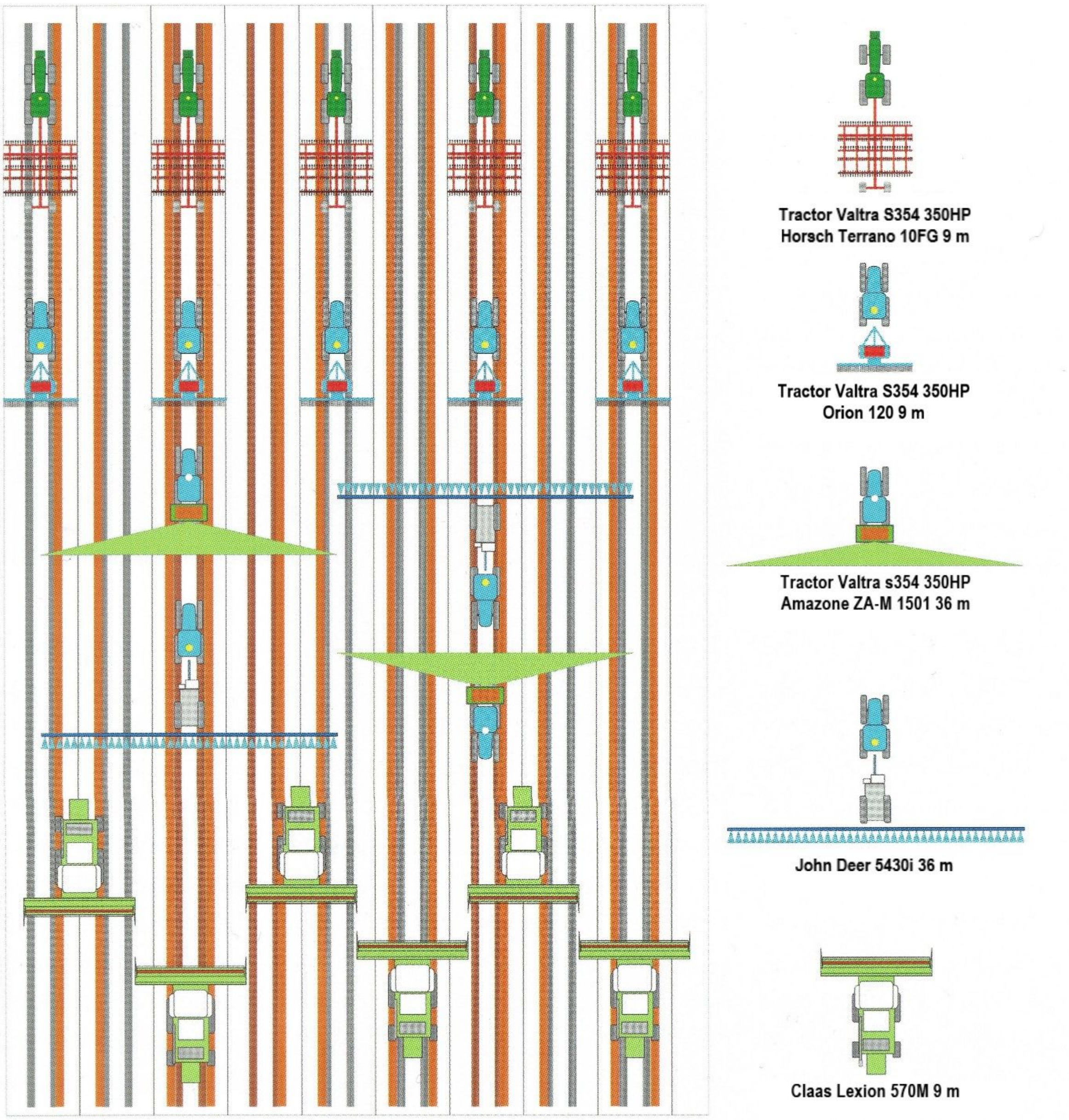
Is commercial platform developed by LeadingFarmers CZ a.s. company. It’s a Farm Vehicles Trajectory Optimization software which uses specialized algorithm to optimize number of headlands (turns) and minimize length and time to necessary to plough field. It’s simple and user-friendly.
Benefits of this application are wide options of export maps. It can be exported in same format as is used by database LPIS (public register of land) and it supports exporting maps straight to Trimble navigation system.

2.5.1 **Leading Farmers**

It is company founded in 2000 and majority share is held by Norway company named Leading Farmers AS. Main business activities is to provide business, counselling, communication and informational system for agriculture needs with developing new technologies connected mainly to Precision Agriculture.
Leading Farmers are also distributors for different agriculture devices namely moisture meters, Meteorological stations, anemometers, pH meters, sprayers, navigation systems and the list go on.

3 Practical Part

Practical part contains calculation of distance, time and consumption of every field machinery respecting every process of successful cultivation of Spring Barley guided by normative of cultivation Spring Barley (Černý, 2007) and Technical and Agriculture Normatives (Juřica, 2007). Next step is using these data to calculate expenses and profits and make a balance sheet.



Picture 15 – Schematic picture of our field machinery, source: modified picture from SPU Nitra

The method of comparison is based on normatives of Spring Barley cultivation.

ATL	Machine
20.09.	**Amazone ZA-M 1501 SPECIAL on tractor**
12.10.	**Amazone ZA-M 1501 SPECIAL on tractor**
13.10.	**Orion 120 trailer + tractor**
15.10.	**Horsch Terrano 10FG 9 m**
28.03.	**Amazone ZA-M 1501 SPECIAL on tractor**
02.04.	**Sewer Pronto 9 m DC**
01.05.	**Amazone ZA-M 1501 SPECIAL on tractor**
07.05.	**John Deer 5430i 36 m**
02.06.	**John Deer 5430i 36 m**
10.06.	**John Deer 5430i 36 m**
25.07.	**Claas Lexion 570M 9 m**

Table 5 – Listed processes, own work

Table 5 contains timeline of intensive cultivation steps of Spring Barley and each specific machine used. In next table 6 we see material which is needed.

Procedure	Material
Transport and spread of limestone	Limestone grinded
Transport and spread of solid mineral fertilizers (up to 0,2 t/ha)	Amofos + Potassium
Transport and spread of Manure (30 t/ha)	Manure
Middle depth plow with soil treatment	Preparation of soil
Transport and spread of solid mineral fertilizers (up to 0,2 t/ha)	LAV
Cultivation with sowing - Sowing combination	Spring Barley seeds
Transport and spread of solid mineral fertilizers (up to 0,2 t/ha)	LAV
Widespread up to 300 l/ha	Sekator
Widespread up to 300 l/ha	Bumper 25 EC
Widespread up to 300 l/ha	Nurelle D
Harvest of cereals	Harvest of Spring Barley

Table 6– separately procedures, own work

Amofos = Ammonium phosphate
LAV = Ammonium saltpeter with limestone
Sekator = Iodosulfuron-methyl Na herbicid
Bumper 25c = Propiconazol Fungicid
Nurelle D = Pesticid

Table 7 – Legend for material

Material	General Repetition	Used Units	Our Field TOTAL [q/used units]	Values per ha
Limestone grinded	0,1	t	13,594	2
Amofos + Potassium	1	t	13,594	0,2
Manure	0,15	t	305,865	30
Preparation of soil	1	-	0	0
LAV	1	t	6,797	0,1
Spring Barley seeds	1	t	12,9143	0,19
LAV	1	t	6,797	0,1
Sekator	1	kg	15,2933	0,225
Bumper 25 EC	1	l	33,985	0,5
Nurelle D	1	l	40,782	0,6
Spring Barley	1	t	339,85	**5**

Table 8 – List of material and calculation of compulsory expenses Spring Barley cultivation, own work

Values are calculated for adequate field area; General repetition means how often is specific process performed (0,25 means 1x per 4 years). Green material means normative yield just for completeness.

Material expenses are calculated for both fields, because normatives for materials are based on extent and not on time so to assure same conditions for calculations we do it generally for both.

Material Expenses:

Type	price [CZK]per unit	Unit	Price of Quantity in Respective Unit
Limestone grinded	2500	t	33 985
Amofos + Potassium	10550	t	143 417
Manure	200	t	61 173
LAV	4850	t	32 965
Spring Barley seeds	9900	t	127 852
Sekator	3415	kg	52 226
Bumper 25 EC	1100	l	37 384
Nurelle D	900	l	36 704
TOTAL EXPENSES			**525 705**

Table 9 – Material expenses setup by normatives

Normative expenses on material per our field are 525 705,00 CZK.

Expenses of Agriculture Machinery in General:

Machine	Efficiency	Fuel Consumption	Expenses ($CZK.h^{-1}$)			Normative fuel consumption per hour
	($ha.h^{-1}$)	($l.ha^{-1}$)	Fixed	Variable	Total	
Amazone ZA-M 1501 SPECIAL on tractor	1,5	5,1	403	506	909	7,65
Amazone ZA-M 1501 SPECIAL on tractor	2,1	5,5	596	779	1375	11,55
Orion 120 trailer + tractor	20	0,8	1120	1360	2480	16
Horsch Terrano 10FG 9 m	2	20,5	710	2128	2838	41
Amazone ZA-M 1501 SPECIAL on tractor	2,1	5,5	596	779	1375	11,55
Sewer Pronto 9 m DC	4,8	6,5	1719	2038	3757	31,2
Amazone ZA-M 1501 SPECIAL on tractor	2,1	5,5	596	779	1375	11,55
John Deer 5430i 36 m	7,1	1,8	1021	857	1879	12,78
John Deer 5430i 36 m	7,1	1,8	1021	857	1879	12,78
John Deer 5430i 36 m	7,1	1,8	1021	857	1879	12,78
Claas Lexion 570M 9 m	2,5	17	2245	2360	4605	42,5

Table 10 - Expenses of Agriculture Machinery in General, own work

Table 10 describes normative expenses of agriculture machinery which are used for comparison on effect of optimized pathway.

Total area of proposed field	67,97	ha
Price of diesel (without VAT and wholesale) 2007	22,2	CZK
Market price of Spring Barley normative tables	5172	CZK
Average Speed	14	Km/h
Manual workforce	150	1 person
Mechanized workforce	500	average

Table 11 – Standard values for computing, all prices without VAT and in CZK, own work

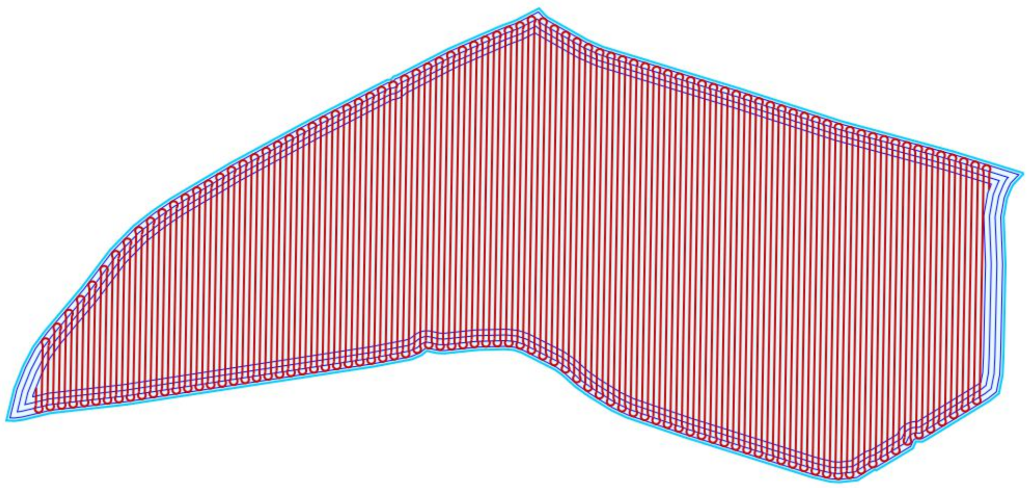
SPRING BARLEY	Index	Units	Normative of one hectar	Normative of whole field
Expenses	TOTAL MATERIAL COST	CZK.ha-1	9319	633 412,43
	Mechanized workforce	CZK.ha-1	7438	505 560,86
	Fuel Consumption	$l.ha^{-1}$	79,5	5 403,62
	Manual workforce	$h.ha^{-1}$	4,3	292,27
	VARIABLE COSTS	CZK.ha-1	16757	1 138 973,29
	FIXED COSTS	CZK.ha-1	3500	237 895,00
	TOTAL COSTS	CZK.ha-1	20257	1 376 868,29
Production	SPRING BARLEY			
	PER YIELD	$t.ha^{-1}$	5	339,85
	PER CURRENCY	$CZK.t^{-1}$	5172	351 540,84
	TOTAL VALUE OF SPRING BARLEY	CZK.ha-1	25860	1 757 704,20
Economy with unsubsidized production	Gross income	CZK.ha-1	9643	655 434,71
	PROFIT/LOSS	CZK.ha-1	6143	**417 539,71**
	PROFIT coefficient	%	30,33	30,33
	BREAK EVEN POINT	$t.ha^{-1}$	3,84	3,84
Economy with subsidized production	Subsidy 2009 (SAPS + TOP UP)	CZK.ha-1	5878	399 527,66
	Gross income	CZK.ha-1	15521	1 054 962,37
	PROFIT/LOSS	CZK.ha-1	12021	**817 067,37**
	PROFIT coefficient	%	59,34	59,34
	BREAK EVEN POINT	$t.ha^{-1}$	2,72	2,72

Table 12 – Normative values of Spring Barley Cultivation corrected for own field, source: VUZT (Juřica, 2007)

3.1 Field with Traditionally Directed Pathway

3.1.1 Overview

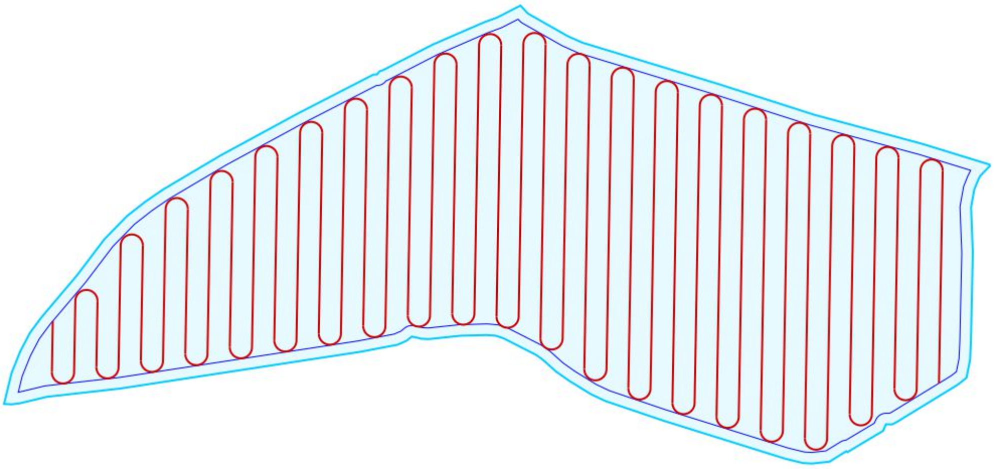
As we can see from map at the beginning of thesis, on the field are visible old pathways from previous cultivation. We will use this pathway for our comparison with the optimized pathway on the same field.
Traditional pathways were chosen many times without any higher meaning, usually it respected habits of farmers, traffic situation or obstacles. In small areas and in regular shapes of fields the difference between angles does not appear so visibly on first sight, but thanks to aerial maps and computers we can now these nuances see by our eyes.



Map 4 – Generated by Optitrail algorithm, source: optitrail.cz

On map number 4 we are defining old pathways as an 1° angle.
Total driven distance if we follow this path is 83 555 m.
There are 166x turns.
Distance when the machine is on field doing job is 63 317 m
Distance spent in headland (of the field turns) is 15 095 m
Calculated for wide bar 9 m
With determined minimum 6 m turning radius

On map 5 is shown pathway which is used by 36m wide spreading. We see that the distance is much shorter than 9 m.



Map 5 – Generated by Optitrail algorithm, source: optitrail.cz

Total driven distance is 23 075 m

Only 40 turns in total.

Distance spent in headland is 3 773 m

On field distance

Calculated for wide bar 36 m.

With determined minimum 5m turning radius

To maintain as much real behaviour as it can get so we use real turning radius from used machinery and applied it to the algorithm.

Map 6 – aerial view, source: Google Earth

3.1.2 **Calculations**

On Table 13 is shown every step which is held by machinery. For better understanding each process is done separately and explained at the beginning of this chapter.

	Travelled distance [km]	width of lane - bar [m]
Tractor Valtra S354 350HP + Amazone	23,075	36
Tractor Valtra S354 350HP + Amazone	23,075	36
Tractor Valtra S354 350HP + Orion 120 trailer	83,555	9
Tractor Valtra S354 350HP + Horsch Terrano 10FG 9 m	83,555	9
Tractor Valtra S354 350HP + Amazone	23,075	36
Tractor Valtra S354 350HP + Sewer Pronto 9m DC	83,555	9
Tractor Valtra S354 350HP + Amazone	23,075	36
John Deer 5430i 36 m	23,075	36
John Deer 5430i 36 m	23,075	36
John Deer 5430i 36 m	23,075	36
Combine Harvester Claas Lexion 570M 9 m	83,555	9

	Travelled time [h]	width of lane - bar [m]
Tractor Valtra S354 350HP + Amazone	1,648214286	36
Tractor Valtra S354 350HP + Amazone	1,648214286	36
Tractor Valtra S354 350HP + Orion 120 trailer	5,968214286	9
Tractor Valtra S354 350HP + Horsch Terrano 10FG 9 m	5,968214286	9
Tractor Valtra S354 350HP + Amazone	1,648214286	36
Tractor Valtra S354 350HP + Sewer Pronto 9m DC	5,968214286	9
Tractor Valtra S354 350HP + Amazone	1,648214286	36
John Deer 5430i 36 m	1,648214286	36
John Deer 5430i 36 m	1,648214286	36
John Deer 5430i 36 m	1,648214286	36
Combine Harvester Claas Lexion 570M 9 m	5,968214286	9

Table 13 – Traditional path with every agrotechnical ride process
Upper - distance, bottom - hours, own work

We are assuming average speed as 14 $km.h^{-1}$

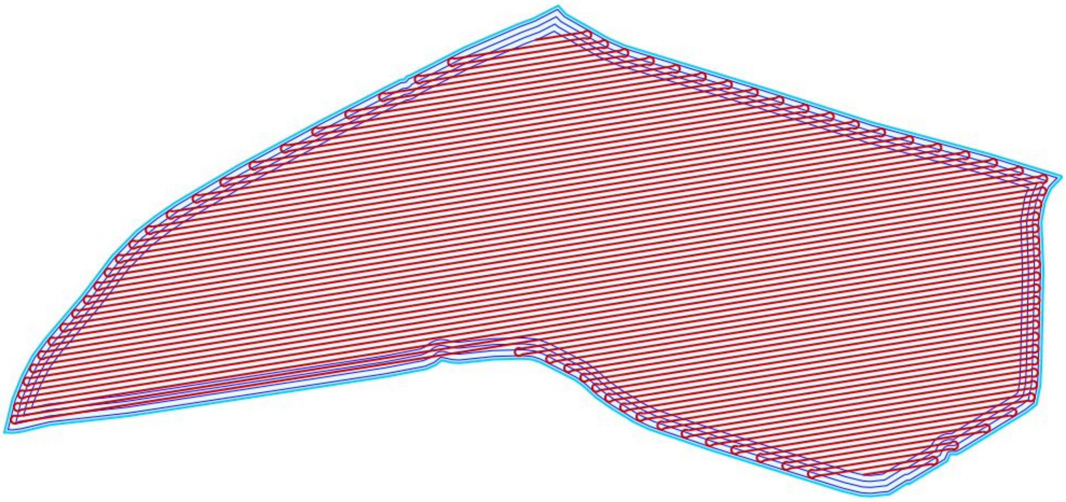
ATL	Machine	Normalized category	Procedure	Fuel Consumption	Efficiency	Fuel Consump	Expenses (Kč.h^{-1})			Total Distance driven [km]	Total Hours Spent [h]	Total Litres Spent [l]	EXPENSES ON FUEL [CZK]	Normative fuel consumption per hour	Normative TOTAL fuel consumption
				($l.h^{-1}$)	($ha.h^{-1}$)	($l.ha^{-1}$)	Fixed	Variable	Total						
20.09.	**Amazone ZA-M 1501 SPECIAL on tractor**	Sprea	Transpo	40	1,5	5,1	403	506	909	23,075	1,648	65,93	1463,614	7,65	12,6088
12.10.	**Amazone ZA-M 1501 SPECIAL on tractor**	Sprea	Transpo	40	5,6	1,5	683	706	1389	23,075	1,648	65,93	1463,614	8,4	13,845
13.10.	**Orion 120 trailer + tractor**	Manu	Transpo	40	20	0,8	1120	1360	2480	83,555	5,968	238,7	5299,774	16	95,4914
15.10.	**Horsch Terrano 10FG 9m**	Plow	Middle	40	2	20,5	710	2128	2838	83,555	5,968	238,7	5299,774	41	244,697
28.03.	**Amazone ZA-M 1501 SPECIAL on tractor**	Sprea	Transpo	40	5,6	1,5	683	706	1389	23,075	1,648	65,93	1463,614	8,4	13,845
02.04.	**Sewer Pronto 9m DC**	Sowi	Cultivat	40	4,8	6,5	1719	2038	3757	83,555	5,968	238,7	5299,774	31,2	186,208
01.05.	**Amazone ZA-M 1501 SPECIAL on tractor**	Sprea	Transpo	40	5,6	1,5	683	706	1389	23,075	1,648	65,93	1463,614	8,4	13,845
07.05.	**John Deer 5430i 36m**	Sprea	Widesp	11	7,1	1,8	1021	857	1879	23,075	1,648	18,13	402,4939	12,78	21,0642
02.06.	**John Deer 5430i 36m**	Sprea	Widesp	11	7,1	1,8	1021	857	1879	23,075	1,648	18,13	402,4939	12,78	21,0642
10.06.	**John Deer 5430i 36m**	Sprea	Widesp	11	7,1	1,8	1021	857	1879	23,075	1,648	18,13	402,4939	12,78	21,0642
25.07.	**Claas Lexion 570M 9m**	Comb	Harvest	65	2,5	17	2245	2360	4605	83,555	5,968	387,9	8612,133	42,5	253,649

Table 14 – Cost expenses recalculated per standard field, calculations of distance, consumption and time, own source

3.2 Field with recalculated Direction of Drive-lane

3.2.1 Overview

New direction of pathway optimized by Optitrail is using 81° angle to minimize number of headlands – turns and maximize time spent on field.



Map 6 – Generated by Optitrail algorithm, source: optitrail.cz

On map number 6 we are defining old pathways as an 81° angle.

Total driven distance if we follow this path is 83 555 m.

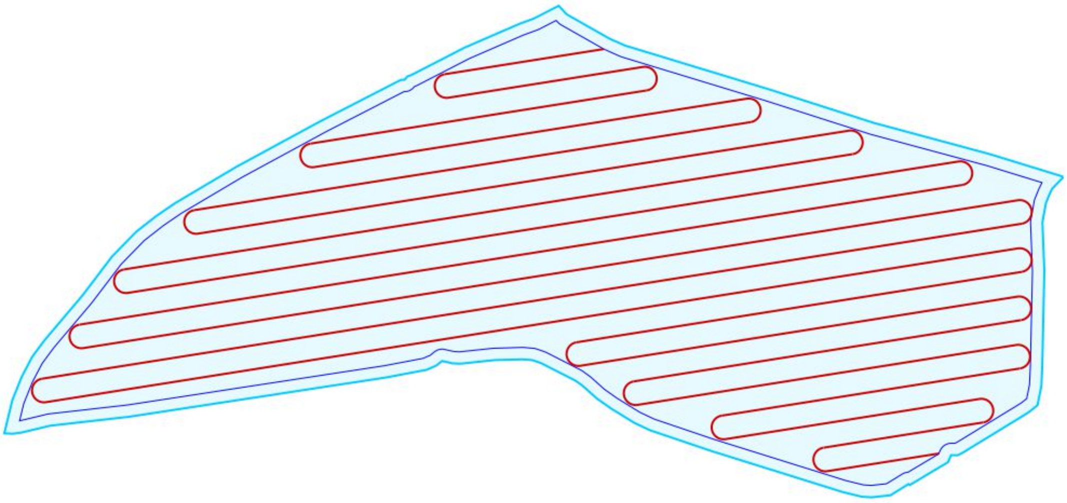
There are 166 turns.

On field distance is 63 317 m

Distance spent in headland is 15 095 m

Calculated for wide bar 9 m

With determined minimum 6 m turning radius



Map 7 – Generated by Optitrail algorithm, source: optitrail.cz

On map number 7 we define pathways as an 81° angle

Total driven distance is 21 348 m

Only 21 turns in total.

On field distance 16 388 m

Distance spent in headland is 3 773 m

Calculated for wide bar 36 m.

With determined minimum 5 m turning radius

3.2.2 Calculations

	Travelled distance [km]	width of lane – bar [m]
Tractor Valtra S354 350HP + Amazone	21,851	36
Tractor Valtra S354 350HP + Amazone	21,851	36
Tractor Valtra S354 350HP + Orion 120 trailer	81,027	9
Tractor Valtra S354 350HP + Horsch Terrano 10FG 9 m	81,027	9
Tractor Valtra S354 350HP + Amazone	21,851	36
Tractor Valtra S354 350HP + Sewer Pronto 9 m DC	81,027	9
Tractor Valtra S354 350HP + Amazone	21,851	36
John Deer 5430i 36 m	21,851	36
John Deer 5430i 36 m	21,851	36
John Deer 5430i 36 m	21,851	36
Combine Harvester Claas Lexion 570M 9 m	81,027	9

	Travelled time [h]	width of lane – bar [m]
Tractor Valtra S354 350HP + Amazone	1,560785714	36
Tractor Valtra S354 350HP + Amazone	1,560785714	36
Tractor Valtra S354 350HP + Orion 120 trailer	5,787642857	9
Tractor Valtra S354 350HP + Horsch Terrano 10FG 9 m	5,787642857	9
Tractor Valtra S354 350HP + Amazone	1,560785714	36
Tractor Valtra S354 350HP + Sewer Pronto 9 m DC	5,787642857	9
Tractor Valtra S354 350HP + Amazone	1,560785714	36
John Deer 5430i 36 m	1,560785714	36
John Deer 5430i 36 m	1,560785714	36
John Deer 5430i 36 m	1,560785714	36
Combine Harvester Claas Lexion 570M 9 m	5,787642857	9

Table 15 – Cost expenses recalculated per standard field, calculations of distance, consumption and time, own source

ATL	Machine	Normalized category	Procedure	Fuel Consumption	Efficiency	Fuel Consump	Expenses (Kč.h^{-1})			Total Distance driven [km]	Total Hours Spent [h]	Total Litres Spent [l]	EXPENSES ON FUEL [CZK]	Normative fuel consumption per hour	Normative TOTAL fuel consumption
				($l.h^{-1}$)	($ha.h^{-1}$)	($l.ha^{-1}$)	Fixed	Variable	Total						
20.09.	**Amazone ZA-M 1501 SPECIAL on tractor**	Sprea	Transpo	40	1,5	5,1	403	506	909	21,851	1,561	62,43	1385,978	7,65	11,94
12.10.	**Amazone ZA-M 1501 SPECIAL on tractor**	Sprea	Transpo	40	5,6	1,5	683	706	1389	21,851	1,561	62,43	1385,978	8,4	13,1106
13.10.	**Orion 120 trailer + tractor**	Manu	Transpo	40	20	0,8	1120	1360	2480	81,027	5,788	231,5	5139,427	16	92,6023
15.10.	**Horsch Terrano 10FG 9m**	Plow	Middle	40	2	20,5	710	2128	2838	81,027	5,788	231,5	5139,427	41	237,293
28.03.	**Amazone ZA-M 1501 SPECIAL on tractor**	Sprea	Transpo	40	5,6	1,5	683	706	1389	21,851	1,561	62,43	1385,978	8,4	13,1106
02.04.	**Sewer Pronto 9m DC**	Sowi	Cultivat	40	4,8	6,5	1719	2038	3757	81,027	5,788	231,5	5139,427	31,2	180,574
01.05.	**Amazone ZA-M 1501 SPECIAL on tractor**	Sprea	Transpo	40	5,6	1,5	683	706	1389	21,851	1,561	62,43	1385,978	8,4	13,1106
07.05.	**John Deer 5430i 36m**	Sprea	Widesp	11	7,1	1,8	1021	857	1879	21,851	1,561	17,17	381,1439	12,78	19,9468
02.06.	**John Deer 5430i 36m**	Sprea	Widesp	11	7,1	1,8	1021	857	1879	21,851	1,561	17,17	381,1439	12,78	19,9468
10.06.	**John Deer 5430i 36m**	Sprea	Widesp	11	7,1	1,8	1021	857	1879	21,851	1,561	17,17	381,1439	12,78	19,9468
25.07.	**Claas Lexion 570M 9m**	Comb	Harvest	65	2,5	17	2245	2360	4605	81,027	5,788	376,2	8351,569	42,5	245,975

Table 16 – Cost expenses recalculated per optimized field, Calculations of distance, consumption and time, own source

4 Results and Discussion

4.1 Results

	Total Distance driven [km]	Total Hours Spent [h]	Total Litres Spent [l]	TOTAL EXPENSES ON FUEL [CZK]	Normative TOTAL FUEL Consumption
STANDARD FIELD	495,745	35,4103571	1422,225	31573,395	897,3819821
OPTIMIZED FIELD	477,065	34,0760714	1371,945571	30457,19169	867,5572564
DIFFERENCES [%]	**0,037680662**	**0,0376807**	**0,03535265**	**0,03535265**	**0,033235262**
SUMMARY	**3,768 %**	**3,768 %**	**3,535 %**	**3,535 %**	**3,324 %**

Table 17 – Final results of comparison, own work

Finally, in Table 17 are shown results of our conducted research. We sum up values of every process need for cultivation process during cultivation year of each field and calculated it into categories.

- Total distance driven in km
- Total hours spent in hours
- Total litres spent (based on normative of fuel consumption of each process and sum up
- Total normative litres spent (based on different normative; standardized fuel consumption per different type of vehicle per hour multiplicated by number of spent hours and then sum up) (Juřica, 2007)
- Total expenses on fuel in CZK are calculated total spent litres multiplied 22,2 CZK per unit price of diesel.

4.2 CO_2 savings

Calculation of CO2 emissions

Fuel type	Kg of CO2 per unit of consumption
Grid electricity	43 per kWh
Natural gas	3142 per tonne
Diesel fuel	2.68 per litre
Petrol	2.31 per litre
Coal	2419 per tonne
LPG	1.51 per litre

Transport conversion table

Vehicle type	Kg CO2 per litre
Small petrol car 1.4 litre engine	0.17/km
Medium car (1.4 – 2.1 litres)	0.22/km
Large car	0.27/km
Average petrol car	0.20/km
Small diesel car (>2 litres)	0.12/km
Large car	0.14/km
Average diesel car	0.12/km
Articulated lorry, diesel engine	2.68/km (0.35litres fuel per km)
Rail	0.06 per person per km
Air, short haul (500km)	0.18 per person per km
Air, long haul	0.11
Shipping	0.01 per tonne per km

Table 18 and 19 – conversional table for co_2 computing, source: https://people.exeter.ac.uk

For our purpose is most convenient to use standard for an articulated diesel car. We need to compensate higher load due the cultivation process, so this approach could be more precise than recalculating general values mainly used for automotive industry. (Table 18)

Due the two methods of used normatives we have two results:

2,68 is value for computation

Normative per process		Normative per hours rate
3811,563	**Standard field**	2404,983712
3676,814131	**Optimized field**	2325,053447
134,7488686	Kilograms of CO_2	**79,93026491**

Table 20 – calculated table of saved quantity of CO_2 in Kilograms, own work

5 Conclusion

SUMMARY	3,768 %	3,768 %	3,535 %	3,535 %	3,324 %

134,7488686	Kilograms of CO_2	79,93026491

Our hypothesis has been proven right. There is a benefit of optimized pathway in theoretical sense. In terms of numbers we see almost 4 % shorter total distance and 3,5 % less fuel consumed which implicates 3,5 % savings on fuel expenses.

Calculations of CO_2 show us results from two methods suggesting one as an optimistic and second as pessimistic prediction. In best manner the amount of CO_2 saved due of better optimized trajectory path could be high as 135 kilograms per year process of cultivation. In worse scenario the saves are about 80 kilograms of saved CO_2.

On first sight these savings are not huge improvement, but we need to keep in mind that to achieve these values we just simply change the angle of vehicles pathway without any significant expenses into new technology. In long term saving of about 4 % per year on large scale could make huge improvement on economy of agriculture enterprise.

With higher budget for adopting complete CTF technology the savings would be much higher. The true potential of Technology could be achieved when using full automatization with connected Variable Rate Technology. In that combination with prescription maps and sensor sampled unique soil characteristics, with specified amount of chemical to specified spots of field, can save a lot of chemicals and therefore lower the expenses to minimum, with benefit of less damage to environment, and maximize profitability of farm.

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6.3 List of used pictures and tables: (till date 11.3.2018)

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Map 6 source: Google Earth
Map 7 source: Generated by Optitrail algorithm, source: optitrail.cz

7 Appendix