Westland Seed

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Impact evaluation of localized nitrogen fertilization within potato rows

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4IEP - International Horticulture Management

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Assessing the localized fertilisation performance of nitrogen on potato production

AERES HOGESCHOOL

Preface

As a student of the European Engineer Degree, I had the opportunity during my studies to do an internship abroad in an American company: Westland Seed, a farm, and ranch supplier based in Ronan Montana. This company advice farmers and sell them seeds, fertilizer, and chemicals. The valley where they are doing business in, is led by seed productions (potato, weed, barley, oat).

This research thesis is the last step before obtaining my Dutch degree and therefore, the European Engineer Degree.

Before, I wish to acknowledge all the people that helped me during this internship that took place from July until October.

I want to thank Micah MCCLURE in the first place for allowing me to work with him on a daily base. Everybody from the agronomy department gave me a warm welcome and provided me with all the tools to be successful during this research. I have learned a lot and improved my methods of researching.

I wish to thank Forest JOHNSEN, who is the fertilizer expert in the company He advised me and provided me with all the resources necessary to be as efficient as possible during this internship.

Ultimately, I want to thank Paul RINGELBERG, my university coach and some of my teachers from last year for all the advice and curses that helped me a lot.

Content

Summary

The factors that can influence development, growth and agricultural production in quantity and quality are constantly being explored.
High-value crops such as potatoes (Solanum tuberosum L.) are good candidates for the adoption of precision agriculture due to their particularly high production costs.
The amount of fertilizer required fuels the permanent challenge of finding the specific fertilization optimization for each agroecosystem. Modeling provides a toolkit for decision support. Regarding to fertilization, yield is usually related to variable rates of fertilizer, which help predict the optimal rates of fertilizer required.
The producer can then see the consequences in terms of yield and income, of increasing or decreasing his inputs under different seasonal conditions.
Fertilizer recommendations are made according to the type of production, the bioavailability of nutrients in the soil and, for certain crops, the textural group of the soil surface layer.

For this experiment, 6 differents modalities were tested with 5 differents percentages of the recommended dose in localized application and 1 modality 100% of the recommended dose in generalized spraying.
The objective of the experiment is to evaluate the agronomic potential and the environmental interest of a fertilization 'at the line' during the plantation.
The environmental aspect concerns the possible reduction (or not) of fertilization with this optimal production goal. The analysis is carried out by measuring the nitrogenous residue in the soil at harvest.
Soil analyses on the 0-30cm / 30-60cm / 60-90cm horizons in March and the day of harvest, in order to evaluate the mineral nitrogen stock in the microplots.
The potatoes were weighed, calibrated; the underwater weight of each sample was measured, and the defects (cracks and deformities) were qualified and evaluated.

To summarize the results of this experiment, with localized nitrogen application, it is possible to reduce fertilization by 20 to 40% (compared to a generalized application) without a statistically significant loss of yield.
Such a reduction in fertilization lowers (on average, not significant) the nitrate nitrogen stock at harvest by 6 and 18 kg $N\text{-}NO^{-}3$/ha (respectively for 20 and 40% reduction in nitrogen fertilization),
By localizing the nitrogen application, the proportion of tubers with cracks or hollow cores decreased (non-significantly) compared to generalized fertilization.

Introduction

We live in a society where the word sustainability is at the heart of every topics, especially in the agricultural field because people are becoming more aware of what they are eating because healthcare is one of the priority for more and more people. Whether the use of pesticides, fertilization or tillage, these techniques will be modified in the future so that the agricultural world has a more sustainable footprint. Potatoes are an industrial crop with a very high agronomic value, representing about 19,000,000 ha on the planet.

In a world where the population keeps increasing, and agriculture that have higher and higher input costs, a good fertilization management plays a key role in a sustainable production and better efficiency(less evapotranspiration in the air or lixiviation in the soil).

The control of fertilization is important not to penalize the yield and to ensure a good quality of tubers. Erosion, lixiviation, and flushed nutrients are a major problem so every way to reduce those issues are welcome especially with potatoes, a demanding crop in terms of nitrogen, phosphorus, and potassium. The management of the inputs must integrate multiple constraints such as the needs of the crop, the history of the plot, the pedo-climatic conditions and the regulatory obligations. The potato creates its own roots system and leaf surface in about two months.
In its vegetative growth period, the potato mobilizes up to 4 kg of nitrogen (N) and 9 kg of potassium (K_2O) per day, which is a lot. That's why I did a research on how to improve nitrogen efficiency, and how to use less input on a crop for more sustainability.

Potato production in Montana represents around 4500ha, Montana is not among the major potato growing states. In the valley where Westland Seed is base, a lot of seed potato are produced, this is the reason why some trials has been done in this area, trials that I'm going to need for this research to support my words.
Westland seed is a farming retailer, that is advising farmers and selling them seeds, fertilizer, and chemicals. They did not set up the trials an extern company was in charge of it.

Fertilization practices greatly influence the yield and quality of the potato crop.
In this thesis I will focus on localized fertilization on potato, that is one of the major crops in the world, and as always been.

In a current situation where nitrogen is an expensive commodity that could become

scarce, the importance of its management is and will become more and more paramount.
In order to answer this problem, new means of fertilization are an answer to this problem, and among them : localized fertilization in potato ridges.

The concern of fertilizers is worldwide, and started to intensify 3 years ago when the price of nitrogen reached levels that has never been seen before. So the potato grower and all the farmer in general are concern about this fertilization problem, because first the prices are very variable and second they don't know if this resource will be limited or not in the future so they don't want to waste any of it as long as it is available.

There are some articles about potato fertilization but the topics and the results that are going to concern my research has never been published before, which make this thesis unique.

Theoretical framework:

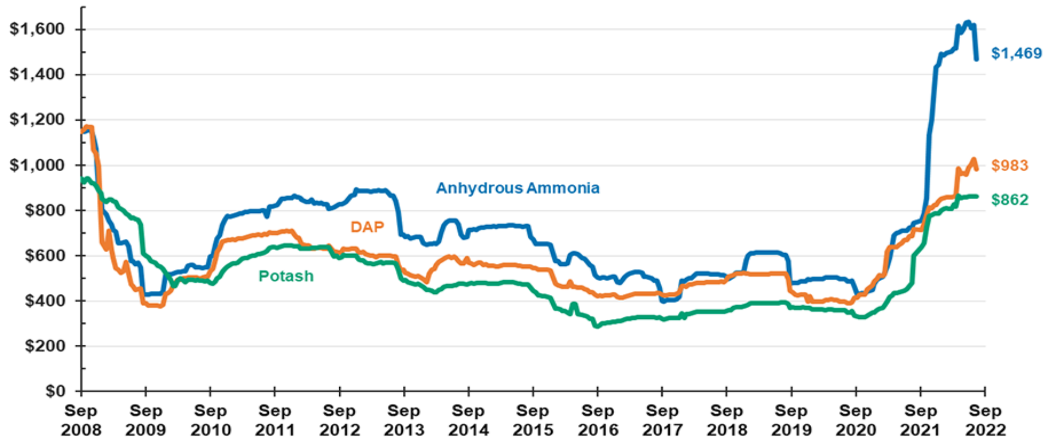
For the last two years the price of fertilizers have reached record levels, like the *figure 1* illustrate and this has made farmers aware of the extent of the problem. Since the mineral fertilizer market is international, everybody is impacted at the same scale. This makes this research even more interesting, research that will target mainly producers, mineral fertilizer's companies and farming retailer like Westland seed for example.

The reasoning behind nitrogen fertilization is based on two pillars: the estimation of plant needs and the calculation of inputs. The needs correspond to the effects of nitrogen on production, following the processes of absorption, accumulation and redistribution of nitrogen : *as mentioned in the article of Bio online (Bio en ligne, 2018) with the nitrogen balance*. Nitrogen supply concerns the forms of nitrogen available in the soil and exogenous inputs.
In this thesis I'm going to take in consideration the current nitrogen cost, so the result might be different if the nitrogen cost would be lower or higher.
The impact of nitrogen application and localized fertilization on potato yield is already known therefore i'm going to go deeper in this topic and include more parameters.
Localized fertilization consists of including a small quantity of fertilizer directly through the drill, only a few centimeters below the potato in the ridge, as explained by the article published by the *American university of Minnesota , (Rosen, 2021)* that is based on a scientific experience of the university on soil, water, and climate department
The research is going to be oriented on the efficiency of the nitrogen and more specifically the localized one.

The informations i am going to need, will be the datas from the trials that has been done in Montana in the past few years and the soil analysis before and after harvest.
I'm not going to focus on the variety of potato that was on the trials, or the different element that can influe the crop like disease or pest.
The potatoes calibers will be a major factor on my research, from 35mm to 50mm most of the diagram will be based on that.
The type of soil and the previous crop are going to set the nitrogen need of the potato crop and based on that need, different application rates will be applied to the different experimental plots.

The nutritional quality of potatoes or the leaching of potential excess nitrogen are themes associated to my topic that will not be addressed and answered.
In the fertilizing sector and in agriculture in general, as soon as we want to mix production and sustainability, some conflicts of interests are showing up. If the localized application is more efficient than the regular application, less nitrogen will be needed so the farming retailer are going to sell less fertilizer.

Figure n°1: Fertilizer prices per ton from 2008-2022
Source: USA department of agriculture, University of Illinois (Zulauf, 2021)



Knowledge gap :

There's a lot of bibliography on nitrogen efficiency on potato production. However, all these experiments concern general application not localized ones. Therefore, we don't know the behavioural differences between localized and spraying fertilization on the potato quality.
I am going to take in consideration the calibres of the potatoes because this has a consequence in the nitrogen absorption.

It is crucial to be focus on the potato's calibres; this is why the research is going to be oriented on the 35mm and 50mm calibres.
The quality (hallow heart and crack) is not something that has been researched before when we are talking about localized fertilization. None of research or thesis were oriented that way, this is going to be the first year of this research that I hope is going to be done over and over in the coming years in order to have a consistent result.

Main Question:

Does localized fertilization have a real benefit on the sustainability of potato production in Montana

Sub question:

- What is the benefit of localized nitrogen for potato yield?
- What is the impact of potato caliber on nitrogen efficiency?
- What is the impact of fertilization on the underwater weight of potato?
- What's the impact of fertilization on potato quality?
- What is the effect of fertilization on the amount of relics after harvest?

Objective of the experiment:

In potato, the production goals impacted by nitrogen nutrition are mainly total yield, size classes and quality oriented.
Currently, mineral fertilization is brought in major part before the works of plantation, as explained on an article of the Canadian website Yara (Hebert, 2021) that shows the efficiency of this fertilization on potatoes, for every single nutrient. That way the nitrogen is distributed in a homogeneous way to the ground; that is to say, in the mound but also in the inter-mound.

The objective of the experiment is to evaluate the agronomic potential and the environmental interest of a fertilization 'at the line' during the plantation within the mound.
The objective is also to measure the impact of a fluctuation of the recommended nitrogen dose according to the soil residues.
A sample of the relics could be explained in more details on the article that has been made by two French agronomist (Bruel & Darbin, 2021). It will also be taken during harvest in order to measure whether or not the quantity of nitrogen applied locally has an influence on the quantity of nitric nitrogen in the soil.
This will tell the efficiency of nitrogen by telling us how much the crop used.
The quality is a major factor in potato production, so we wanted to make sure that it was going to be taking in account.
In fact, we measure three different quality factors within this research.
First of all, the underwater weight that determine the rate of dry matter and the starch content has been analyze.
Then the number of potatoes with hollow heart, an irregularly shaped crater in the potato's heart.

And finally the potatoes with cracks, an external noninfectious physiological disorder of the potato tuber in which the tuber splits while growing.

The agronomic aspect concerns the achievement (or not) of an optimum production equivalent to a 'generalized' fertilization practice, which means an application with a sprayer.
The environmental aspect concerns the possible reduction (or not) of fertilization with this optimal production goal, that is well shown in a thesis written, by a student from a university in. Pakistan (Fiaz, 2022) by taking in consideration the impact of reactive nitrogen losses. This reduction could decrease the percentage of nutrient lixiviation or flushing away with water and erosion. The analysis is carried out by measuring the nitrogenous residues in the soil during harvest.
The goal was to see if the fertilization had an impact on it and if yes then how?
Secondly, the analyze of the percentage of the potato with hallow heart (a factor that could downgrade the crop) that each plot with different nitrogen rates had, has been done.
And to finish the numbers of potatoes with scab (a factor that could also damage the crop) that each plot had, had been count

So, i really analyze every main factor that could be related to the fertilization and that could affect the potato.

2/ Materials & Methods:

2.1/ Experimental protocol:

As mentioned before, six different types of fertilizer application are going to be apply on different experimental plots.
The localized one, differ from each other by their applications rates, with the recommended rate as a base (100%).

In order to have a baseline for comparing the results, an application of generalized spraying has been done to compare the efficiency with the localized one.
The field was irrigated, at the same rate to increase the chance of success of this trial, if you want to see why irrigation increase the efficiency of nitrogen, check the thesis of (N.Sah , 2022) where the Pakistani teacher talks about Coupling Effects of Nitrogen and Irrigation Levels on Growth Attributes.

A lack of water can interfere with the results, so the probability of success for the test are higher, as mentioned on the article published on Archive Ouverte, by (Turpin, 1997) with a lot of experimentations explanations.

The six objects tested are:

1. Localized

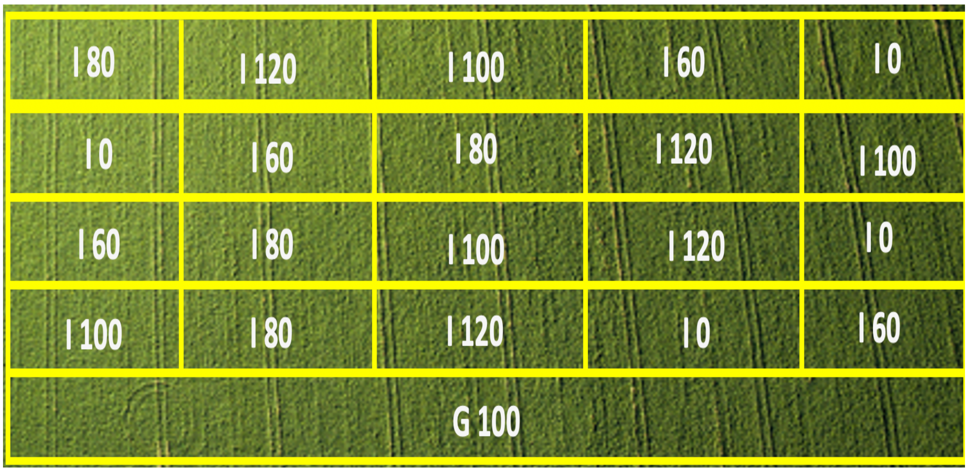
- 0% of the recommended dose
- 60% of the recommended dose
- 80% of the recommended dose
- 100% of the recommended dose
- 120% of the recommended dose

2. In generalized

- 100% of the advisory dose

The experiment was conducted in four replications, as shown on the figure n°2. In order to facilitate the implementation of the protocol, the four replicates were placed on four lines (of four mounds) of plantation. A protocol explanation has been done on the webpage on Cirad.fr, with an analysis (Letourmy, 1999) with all the experimentation issues.

Figure n°2: Map of the different modalities
Source : (Cloue,2022)



Legend:
I 0= 0% of the advisory rate
I 60= 60% of the advisory rate
I 80=80% of the advisory rate
I 100=100% of the advisory rate
I 120= 120% of the advisory rate
G100=100% of the advisory rate
I = Localized application
G = General application

This map represent the experimentation that has been use to elaborate this thesis. Four lines of 50 meters has been done, and each line are divided in five 5 meters sections.

The six objects were placed in each row but in a different order from row to row .
The length of an object was at least ten meters.
A buffer zone of a few meters was placed between each object so that the driver could modify the nitrogen flow rate setting without stopping the planting.
A staking (physical and RTK) was carried out simultaneously with the planting to delimit the 'object' and 'buffer' zones.

Every modality was repeated 4 times except the general application that had been applicated just in one line. They did that because it was harder to randomize some localized applications with spraying one, so the easiest way to do it was to set the whole 50 meters line.
The 'generalized' area was pre-supplied (between the tillage operation and the planting operation) with nitrogen in the form of N27 granules (27% nitrogen) by GRENeRA.
This zone, three meters wide and of a length equivalent to the length of the previous lines, was adjacent to the 'localized' experimental zone; both zones being located on a homogeneous part of the plot from a pedological point of view.

Planting:

Planting has been done on May 7th, 2022, the mounds were spaced laterally by 75 cm. The plants are placed at a depth of 20 cm with a spacing of 33 cm. Nitrogen has been applied threw the drill.

Soil sampling:

Several soil samples were taken before planting to determine the actual needs of the potatoes, and the residue from the previous crop.
Soil samples were also taken after harvest to see the residues left by the potatoes and to evaluate the efficiency of the nitrogen.
- 1st sample: March 17, 2022
- 2nd sample: October 17, 2022

Harvest:

In each test plot the harvest was done manually for technical reasons, four plants on the two central rows were pulled out.
The potatoes were putted into a bag that was weighed, sorted by caliber, quality checked and the weight under water of each sample was also done.

2.2/ Potatoes Caliber:

The calibers of the potatoes is a main factor to differ them, and at the end to sell them.

Nitrogen and phosphorus play a role in that because they guarantee a strong foliage and tuber growth, where potash improves water absorption and dry matter production.

We know that nitrogen plays a role in photosynthesis (sugar production that is stored in the tubers) which induces tuber size, but no research has really been done on the impact of localized fertilization on potato size.

After harvest, the tubers of each microplot were graded to see whether or not the nitrogen supply in the ridge plays a role on the potato.

We just kept the potato caliber above 35mm and 50mm and analyze them based on the localized nitrogen that has been applied to them.

Nitrogen, phosphorus, potash, magnesium... potato fertilization has consequences on the number of tubers at harvest and their size.

In potatoes, depending on the outlet targeted, the producer will try to increase, or not, the number of tubers (*explain by figure n°3*), and to obtain, or not, tubers of large size. In both cases, plant nutrition plays an essential role.

To obtain a large number of tubers, phosphorus fertilization is very important. When it is readily available at tuberization, phosphorus promotes the formation of a maximum number of tubers.

Roots development depends mainly on the conditions of the plant, the physical and chemical characteristics of the soil, such as texture, structure and water status. The nitrogen stays in the plant and his amount increase, as it's accumulating according to the organs and the growth period (*explanation on figure n°4*). As an example, the potential N exploitation rate is only about 20% for the 60-90 cm deep horizons of a loamy soil with degraded structure.

Figure n°3: Evolution of the number of tubercules based on nitrogen rate application and the stage of the crop
Source: university of Montana (Ryler, 2017)

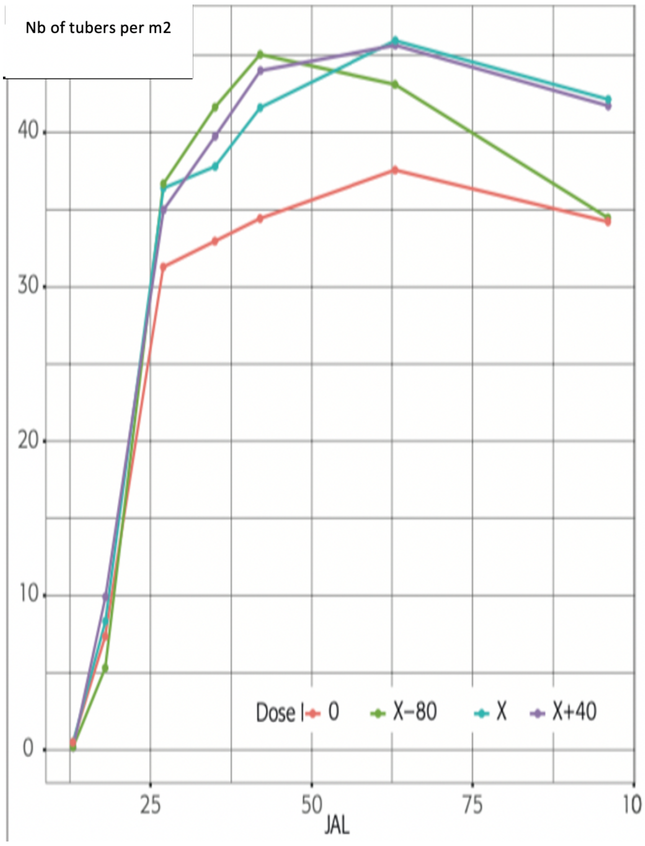
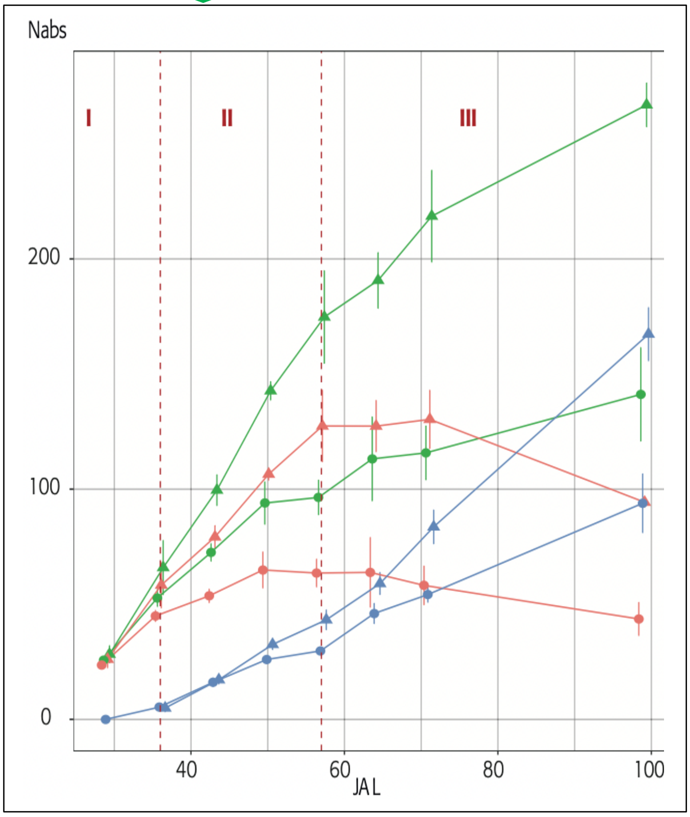


Figure n°4: Nitrogen accumulation according to the organs
Source: university of Montana (Ryler, 2017)
I = emergence / II =tuberization / III = senescence
AP = aerial parts / Plant ent = whole plant/ Tub = tubers



2.3 / Nitrogen for potatoes:

The plants use nitrogen for the growth of its aerial and underground vegetative apparatus. Therefore, the nitrogen requirement is proportional to the total biomass, depending on the length of the vegetative cycle and excluding other limiting factors (e.g. water, underground pests, ...).

The availability of nitrogen conditions, the foliar part for the indicators stem length and leaf area.

In case of nitrogen deficiency, the plants decreases their photosynthesis capacities and therefore their potential accumulations of underground biomass (roots and especially tubers). On the contrary, an excess of nitrogen availability has, as main effects, an increase of the cycle length, of the leaf surface and of the number of branches per stem.

Nitrogen also impacts root development and consequently the potential for soil exploration and this nitrogen uptake.
The dynamics of nitrogen uptake and accumulation in the plant is therefore a function of the biomass of the different organs during growth. This dynamic can be segmented into two phases:

- From emergence to initiation of tuberization: the nitrogen absorbed is directly correlated to the growth of the aerial parts,

- Tuberization: an increasing fraction of the biomass produced and therefore of the nitrogen absorbed is allocated to the tubers,

From the maximum level of biomass reached by the aerial parts until the removal of the weeds: the newly produced biomass and the absorbed nitrogen are allocated exclusively to the tubers.

2.4 Localized fertilization:

Farmers are leading a reflection on the way of reduction and optimization of the quantity used. It is not enough to reduce the doses and to bring the fertilizer as close as possible to the plant, the positioning must be rigorous to obtain all the benefits.

This improvement seems to allow to reach lower doses of nitrogen and total production levels equivalent to those obtained with a full application.
The optimal positioning of the fertilizer below the level of the seed (*shown on figure n°5*), for the potatoes is advised (in case of doubt about burning the sprouts), to shift about 5 cm to the line of sowing by burying 5 cm compared to the level of the seed. It also has a positive impact on the yield and on the using rate (*explain by figure n°6*). The degree of volatilization differs according to the form of mineral nitrogen used, from 1.9% for ammonitrate to 7.9% for nitrogen solution and 13% for urea.
Localizing the mineral fertilizers will reduce the volatilization loss from 65 to 85%.

Figure n°5: Diagram of localized fertilization
Source: (Cloue, 2022)

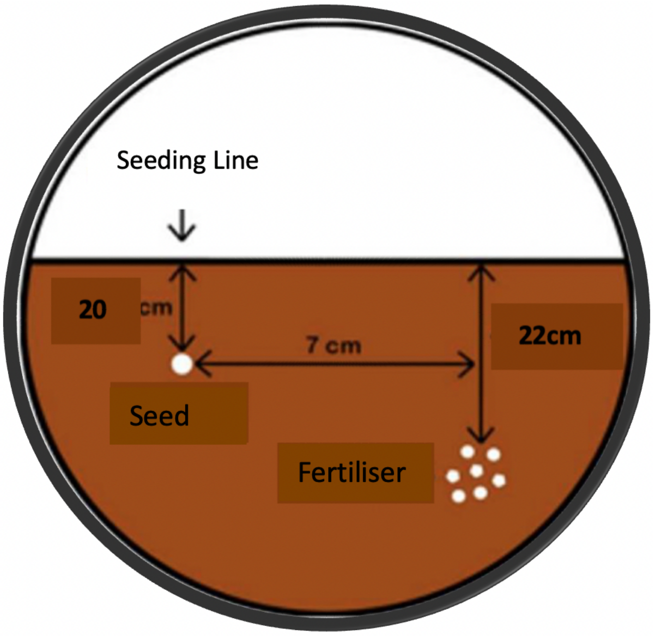
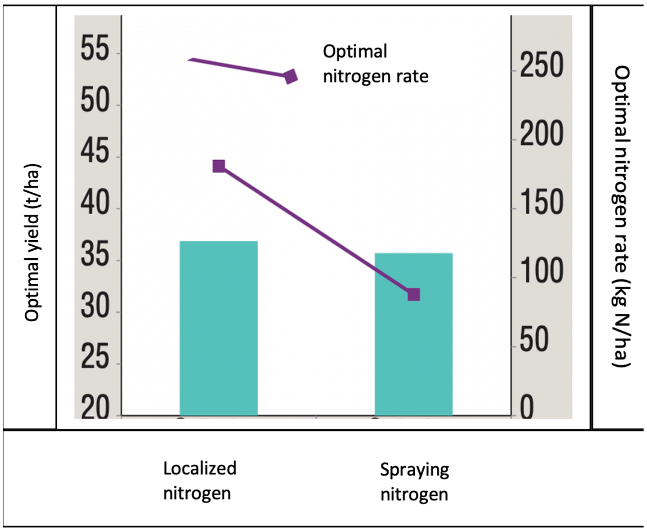


Figure n°6: Optimal yield and total nitrogen rate in relation to total production
Source: réussir, (Turio,2012)



2.5 Soil analysis:

Soil analysis is a decision support tool to conduct fertilization of agricultural soils. It will allow to evaluate the physical characteristics in order to know the capacity of the soil to mobilize and provide mineral elements for the development of the plant. The chemical composition of the exploited soil and the content of fertilizing mineral elements of the soil are also collected data.

The physical analysis represents the constitution of the soil as the content of the 4 major constituents of a soil aggregate, namely: clay, silt, sand, and organic matter.
An American article from the webpage JGK Consultant (Partner, 2017) will show you all the soil analysis instruments and clews.

The chemical analysis represents the capacity to retain fertilizing elements and the quantity of fertilizing mineral elements present (Ca^{2+}, Mg^{2+}, K^+, Na^+, pH, CEC etc).

Two samples both physical and chemical has been done before planting and after harvest.

- First analysis 17/03/2022
- Second analysis 17/10/2022

For the soil analysis, a soil probe was use, in order to have a homogeneous sample of the field, we tried to take samples from different area. In total, 10 samples had been taken for each field analysis.
Once the sample are in a bucket, we put them in a small 1-pound bag and send it to a laboratory in Idaho.
A week after, the lab sends the analysis back.

This analysis is a key factor for this thesis because first of all it's going to establish the optimal amount of fertilizer that the crop is going to need, and secondly, it's going to show how much nitrogen is still in the soil after the crop consumption.
It's the basement of the research because the optimal nitrogen rate is going to be a percentage of the recommendations that appear on the analysis.
This analysis wasn't done in the trial field only but in the field in general. On this part of the field a regular application was done with 100% of the recommended rate.

Figure n°7: Soil analysis of the field in march
Source: Stukenholtz laboratory (Sale, 2022)

SOIL TEST DATA	Amount	Units	Evaluation
PH	6.3		L
SALTS	0.2	mmhos/cm	VL
CHLORIDES	9.0	ppm	VL
SODIUM	0.1	meq/100g	VL
CEC	5.1	meq/100g	L
EXCESS LIME	0.0	%	VL
ORGANIC MATTER	3.49	%	M
ORGANIC N	80.0	lb/acre	M
AMMONIUM	3.1	ppm	VL
NITRATE	4.0	ppm	VL
PHOSPHORUS	28.0	ppm	H
POTASSIUM	118.0	ppm	L
CALCIUM	3.0	meq/100g	VL
MAGNESIUM	0.4	meq/100g	VL
SULFATE	4.0	ppm	VL
ZINC	1.6	ppm	M
IRON	36.5	ppm	H
MANGANESE	9.8	ppm	H
COPPER	0.6	ppm	L
BORON	0.22	ppm	VL

Recommendations	
Nitrogen	175
Phosphate	90
Potash	175
Calcium	0
Magnesium	10
Sulfate	65
Zinc	5
Iron	0
Manganese	0
Copper	1
Boron	3
Gypsum	500
Lime	2000

Loamy sand soil
Date : 17/03/2022
Prev Crop : Wheat
Crop Potato
Yield goal : 400 CWT

This table (*figure n°7*) is the first analysis that had been done, a week before the potatoes were planting.
The soil laboratory analysis has a detail on all the nutrients that the soil content, and a quick evaluation on the level of those nutrients.
This soil is not in the best shape, but with wheat as a previous crop this make sense.
The percentages of potash and nitrate are low, this could cause some damage for the tubercules.
The recommendations were made by the laboratory.
One of the agronomists of Westland Seed is in charge of making a fertilizer mix that is related to the soil analysis and to potato production.
Mixing fertilizer is better in order to complete every deficiency that the soil has.
The problem is: it takes more than one year to change the fertility of a soil.
All the nutrients are not absorbed the first year, some of them can be flush out by water, this is why it's important to do soil analysis every 4-5 years.

Figure n°8 : Soil analysis of the field in october
Source: Stukenholtz laboratory, (Sale,2022)

SOIL TEST DATA	Amount	Units	Evaluation
PH	6.3		L
SALTS	0.3	mmhos/cm	VL
CHLORIDES	17.0	ppm	VL
SODIUM	0.1	meq/100g	VL
CEC	5.1	meq/100g	L
EXCESS LIME	0.0	%	VL
ORGANIC MATTER	3.49	%	M
ORGANIC N	80.0	lb/acre	M
AMMONIUM	2.8	ppm	VL
NITRATE	83.0	ppm	M
PHOSPHORUS	14.0	ppm	H
POTASSIUM	148.0	ppm	L
CALCIUM	6.8	meq/100g	VL
MAGNESIUM	1.1	meq/100g	VL
SULFATE	16.0	ppm	VL
ZINC	2.3	ppm	M
IRON	44.4	ppm	H
MANGANESE	11.7	ppm	H
COPPER	1.0	ppm	L
BORON	0.32	ppm	VL

Recommendations	
Nitrogen	105
Phosphate	170
Potash	170
Calcium	0
Magnesium	10
Sulfate	40
Zinc	0
Iron	0
Manganese	0
Copper	1
Boron	3
Gypsum	0
Lime	2000

Loamy sand soil
Date : 17/10/2022
Prev Crop : Wheat
Crop Potato
Yield goal : 400 CWT

This table (*figure n°8)* is the second analysis that has been done.
It was made in order to see the consumption of the crop, and to evaluate the amount of nitrogen that are still in the mound after harvest.
The factor that was observed in the first place is nitrogen, and we can see that with the main application in general, the amount of nitrogen in the soil went up.
For the other part, same story as the first analysis. This soil analysis should've been done in every experimental plot to have data on every application rate, but it hasn't been done for some financial reasons.
This can be an improvement for the future in order to see if the concentration of nitrogen play a role with the other nutrients in the soil. Just a nitrogen relic was done within the mound because this was one of the research topic of this thesis.
The financial funds are limited and not everything can be done the first year.

Potatoes are really high nitrogen, potash, and phosphate consumers, so a fertilizing application is mandatory before and after planting to fulfill the need of this crop.
The yield goal is a part of the recommendation process and the higher it is, the higher the amount of fertilizer is.

2.6 Equipment:

For this trial, some equipment were necessary in order to achieve all experimental research.
For the planting, a 4-row potato planter was needed with a localized fertilization system.
For harvest, it was operated manually, so labor was needed and potato bags to collect them from each trial plot.

For weighting, a precise scale was useful to sort the big potato from the smaller one.
For the calibers, a potato sizer was necessary. Net bags were needed to put the potato in, and labels were used to recognize them.

2.7 Measurement:

Two types of measurements have been done, measurement of the soil and measurement on the potatoes.
The measurement of the soil has been realized in two times, before planting and after harvesting. The goal of this measurement is to collect data from the amount of nitrogen that is still in the soil after the potato production.

We wanted to check based on the amount of nitrogen applied, what percentage stay in the soil.

The measurement of the potato was divided in four parts: the caliber above 35mm, the caliber above 50mm, the water weight and the nitrogenous relics.

So those data are going to be collected and analyzed after harvest. All of our data are physical and not informatically, so all of them are going to be collected and analyzed manually by me. The nitrogenous relics is the only data for which we are going to need a soil analysis, so an extern help.
The fact that we can do most of our information collection and analyze by ourselves the chance factor that an error could be occurred is reduced.

The reliability of those data is higher and the validity of it fulfilled our validation criteria.

The collected data are going to be analyzed by a bunch of statistical tests. Descriptives researches are going to be done in order to classifies, describes, compares, and measures data. Meanwhile, the analytical research focusing more on the cause and effect are going to be more an explanation of the results part of this thesis.
The criteria that are important when you evaluate some data for research are their Credibility and authenticity.

A. **Calibers above 35mm :**

- Yield measurements on each plot
- Crack measurement
- Hallow heart measurement

B. **Calibers above 50 mm :**

- Yield measurements on each plot
- Crack measurement
- Hallow heart measurement

C. **Waterweight :**

- Yield measurement based on the fertilization rate

D. **Nitrogenous relics:**

- Impact of fertilization on nitrogen residues in the mound during harvest

2.8 Statistical analysis:

A variance analysis was needed to conclude the collected data and analyze them. The different calibers were compared between the different rates application and the type of application. The water weight was analyzed as well to see the impact of the fertilization.

We analyzed the difference between the nitrogen rates, the type of application and the potatoes calibers. An ANOVA test has been done to compare the potato caliber from the nitrogen applications.

2.9 Limits of the research:

Research in agriculture are complicated, the results and analysis of them are not accurate all the time because many factors play a role in each research. Those factors like the weather or the type of soil are specific to some area, so it makes the results works for a specific type of situation. This is one limit of the research, the factor that we can't control.

It is also complicated to find scientific references that were published less than ten years ago about potato localized fertilization. Most of the research are explaining some criterium that are not the same one that I really needed.

So, I had to collect and ad some information from many different thesis and reports to make something precise that makes sense.
Most of the localized fertilization research on potato are just measuring the yield but they don't take in consideration the calibers or the quality impact that the nitrogen have.

The fact that this was one of the first research on these specific topics, this research will have to be done again and again to make some accurate and precise results. This is the problem with science, it takes a lot of time and a relatively large amount of money to achieve a scientifical project.

3/ Results

3.1 Yield by calibers class?

We started the result part with the yield per caliber class.
The caliber will be important for the result; therefore, I chose to start with it.

Each tuber was classified according to its size:
- less than 35 mm
- between 35 and 50 mm
- between 50 and 60 mm
- between 60 and 70 mm
- above 70 mm

The tubers classified were then counted and weighed.
An average, a minimum and a maximum of each plot was made as you can see on the *table n°9*.
This allows us to see the impact of the amount of nitrogen applied and the relation with the size of the potatoes.
Generally, only calibers larger than 35 mm have a market value. Price bonuses are sometimes granted for sizes over 50 mm. The analysis of yields will therefore be carried out

Figure n°9 : Yield by calibers class

Calibers	Rates	N	Average	Std Dev	Min	Max
0-35 mm	000	4	3737	484	3182	4192
	060	4	2071	605	1263	2727
	080	4	2323	454	1869	2929
	100	4	2058	495	1566	2677
	101	2	1742	179	1616	1869
	120	4	2222	1113	1313	3737
35-50 mm	000	4	24508	6970	15657	31717
	060	4	22500	4130	18030	26162
	080	4	18472	3974	15152	24040
	100	4	18497	5084	12929	24899
	101	2	16919	4143	13990	19848
	120	4	16705	4095	11212	21061
50-60 mm	000	4	13232	3407	8283	15960
	060	4	23712	3981	21111	29646
	080	4	24710	1954	22879	27475
	100	4	24141	4321	20202	30101
	101	2	24268	4535	21061	27475
	120	4	25467	6360	17576	32929
60-70 mm	000	4	1944	2392	0	4899
	060	4	2386	1239	1313	3485
	080	4	7475	4282	1364	10707
	100	4	5455	5719	0	11970
	101	2	8965	3750	6313	11616
	120	4	7311	5287	2778	14646
> 35 mm	000	4	39684	6474	36263	49394
	060	4	49040	4245	43131	53081
	080	4	51679	6808	44040	60152
	100	4	48561	2569	45152	51111
	101	2	54747	1571	53636	55859
	120	4	49962	7110	42879	57273
> 50 mm	000	4	15177	5407	8283	20859
	060	4	26540	4452	23384	33131
	080	4	33207	5554	25505	38182
	100	4	30063	6158	23283	38182
	101	2	37828	5714	33788	41869
	120	4	33258	10425	21818	43535

Statistical analysis

In order to determine if the nitrogen rate and the caliber had any influence over the yield, an ANOVA test has been done on every calibers that has been harvested in the field. We are going to be focus on the potatoes above 35mm and above 50mm after this test.

Impact of the nitrogen rate and caliber on yield:
- Dependant variable: potato's yield
- Independents variables: potato's calibers and nitrogen rates

First, we need to see if the dependant of variable (potato's yield) is normally distributed on each category of the independent variable (potato's calibers and nitrogen rates).

For the first ANOVA test, i focused on every caliber that has been harvested.
I didn't take in consideration the rate into my analysis otherwise it would have been too long to analyze to whole table.
I would go more into the details further down the result part.

Calibers	*Average yield*
0-35	*2359*
35-50	*19600*
50-60	*22588*
60-70	*5589*

For this test, I took the average yield of each caliber class based on the table up above.
So, an addition of every yield of each size as been done in order to do a mean to simplify it and not having to do a table per caliber class.
We wanted to see if the results were representative and if the caliber had something to do with the yield.
To determine if the varieties are normally distributed in this table, we need to look at the Shapiro-Wilk Sig. If the value is of more than 0,05 they are normally distributed.

Here, at least one rate is not normally distributed which give us only one option : a non parametric test. A Mann-Whitney test has been run.

Mann-Whitney test:

H0: There are no differences on yield between nitrogen rates
H1: There are differences on yield between nitrogen rates

Pvalue = 0.05
Statistical test value Z = 0.956
Asymp. Sig = 0.467

The results of the Mann-Whitney test gives a pvalue of more than 0,05. Therefore we can not reject the null hypothesis and assume that we don't have any difference of yield between low, medium, high and general rates.

To make a quick conclusion of this first statistical analysis after this test, we can say that we have a difference on yield between nitrogen rates and potato caliber as well. This difference is not normally distributed (*figure n°10),* for every case, as we can see above with the result of the Shapiro wilk sig, that gives us half of the cases above 0.05.
So, we can't conclude with the fact that the yield, the caliber class and the nitrogen rate are directly related.

Figure n°10 : Test of normality of the average yield per caliber

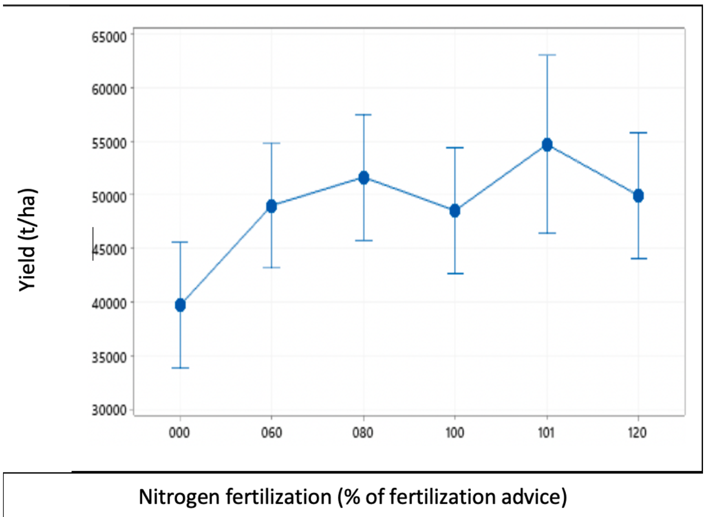
Calibers	Statistic test value	Shapiro-Wilk sig	Distribution
0-35	0.378	0.006	Not normally distributed
35-50	0.897	0.461	Normally distributed
50-60	0.174	0.041	Not normally distributed
60-70	0.069	0.651	Normally distributed

3.2 Impact of localized fertilization on the yield of the calibers above 35mm?

Figure 11 shows the impact of fertilization on the production of sizes larger than 35 mm. An analysis of variance reveals no significant difference in yield (pValue = 0.05).

Under spot fertilization, object 080 had the highest yield (51.7 t/ha).
Objects 100 and 101 differed in the application method (100 = 100% of the recommended dose for localized application; 101 = 100% of the recommended dose for generalized application).

Figure n°11 : Impact of fertilization on the yield of the caliber above 35mm



The localized application method seems to be detrimental to production, with two reservations: (1) the differences are not significant and (2) object 101 was tested in only two replications instead of four for the 'localized application' objects.

<u>Statistical analysis</u>

In order to determine if the nitrogen rate and the caliber had any influence over the yield, ANOVA tests have been done on every calibers that has been harvested in the field. We are going to be focus on the one above 35mm.

Impact of the nitrogen rate and caliber on yield:

- Dependant variable: potato's yield
- Independent variable: potato's calibers

Firstly, we need to see if the dependant of variable (potato's yield) is normally distributed on each category of the independent variable (potato's calibers).

For this ANOVA test, i focused on the calibers above 35mm.
To make the test simpler I divided the localized application rates in four different ones and skipped two rates (*Figure n°12).*

Low rate: 60 % of recommendation
Medium rate: 100% of recommendation
High rate: 120% of recommendation
General application: 100% of recommendation non localized

The results of the Mann-Whitney test gives a pvalue of more than 0,05. Therefore we can not reject the null hypothesis and assume that we don't have any difference of yield between low, medium, high and general rates.

Figure n°12 : Test of normality of the differences between calibers above 35mm on Yield

Nitrogen rates	Statistic test value	Shapiro-Wilk sig	Distribution
Low rate	0.678	0.002	Not normally distributed
Medium rate	0.962	0.341	Normally distributed
High rate	0.574	0.040	Not normally distributed
General application	0.869	0.451	Normally distributed

For this range of sizes, a reduction in fertilization of at least 20% compared to the fertilization advice is appropriate.

To make a quick conclusion of this second statistical analysis after this test, we can say that we have a difference on yield between nitrogen rates and potato with a caliber above 35mm.
This difference is not normally distributed for every case, as we can see above, with the result of the Shapiro wilk sig, that gives us half of the cases are above 0.05.

So we can't conclude with the fact that the localized nitrogen rates and the potatoes above 35mm are not directly related like we can see in the graph up above. The nitrogen application has an impact on the yield but it's not concerning every rate at the same level.

We can see that from 0 to 60 % of the recommended rate locally applied, there is a clear increase of the yield but then from 80 to 100% the yield is decreasing.
The highest yield will be with the general application, and then when we had 20 extra percent, the yield is barely changing.
This brings us to a point that the nitrogen rate doesn't have the same impact for the potatoes above 35mm.
To determine if the varieties are normally distributed in this table, we need to look at the Shapiro-Wilk Sig. If the value is of more than 0,05 they are normally distributed.

Here, at least one rate is not normally distributed which give us only one option : a non parametric test. A Mann-Whitney test has been run.

Mann-Whitney test :

H0: There are no differences on yield between nitrogen rates
H1: There are differences on yield between nitrogen rates

Pvalue = 0.05
Statistical test value Z = 0.956
Asymp. Sig = 0.467

3.3 Impact of localized fertilization on the yield of the calibers above 50 mm?

Figure n°13 Impact of fertilization on the calibers above 50mm

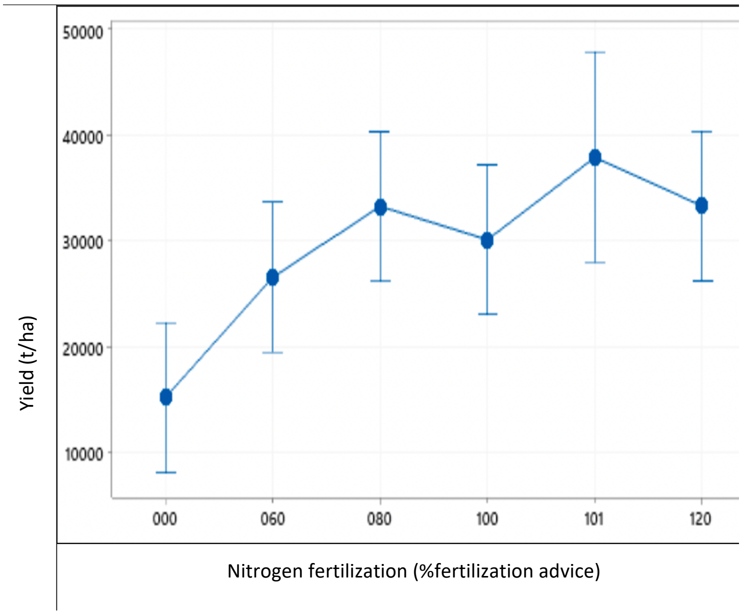


Figure n°13 illustrates the impact of fertilization on the production of sizes larger than 50 mm. An analysis of variance reveals significant differences in yield (pValue = 0.007).
Under localized fertilization, objects 080 and 120 had the highest yields (33.2 t/ha), but the general application is still a bit better than the localized one.
The localized fertilization method again appears to be detrimental to production (37.8 t/ha) with the same reservations as above (§ 3.5.1).

We are going to be focus on the potatoes above 50mm, because as said before 35mm and 50mm are the two references on potatoes.

Impact of the nitrogen rate and caliber on yield:

- Dependant variable: potato's yield
- Independent variable: potato's calibers

Firstly, we need to see if the dependant of variable (potato's yield) is normally distributed on each category of the independent variable (potato's calibers).

For this ANOVA test, i focused on the calibers above 50mm.
To make the test more simple, I divided the localized application rates in four different ones and skipped two rates.

Low rate: 60 % of recommendation
Medium rate: 100% of recommendation
High rate: 120% of recommendation
General application: 100% of recommendation non localized

For this range of sizes, a reduction in fertilization of at least 20% compared to the fertilization advice is appropriate.
Why am i saying that?
Because economically spoken, 80% of the recommended rate is almost as good as the yield that is using 120%. But the difference doesn't pay for 40% of extra nitrogen, especially at the moment where the nitrogen prices are rally high.

Statistical analysis

In order to determine if the nitrogen rate and the caliber had any influence over the yield, ANOVA tests have been done (figure n°14), on every calibers that has been harvested in the field

Figure n°14: Test of normality of the differences between calibers above 50mm on Yield

Nitrogen rates	Statistic test value	Shapiro-Wilk sig	Distribution
Low rate	0.478	0.012	Normally distributed
Medium rate	0.751	0.087	Normally distributed
High rate	0.187	0.344	Not normally distributed
General application	0.942	0.451	Not normally distributed

To determine if the varieties are normally distributed in this table, we need to look at the Shapiro-Wilk Sig. If the value is of more than 0,05 they are normally distributed.

Here, at least one rate is not normally distributed which give us only one option : a non parametric test. A Mann-Whitney test has been run.

Mann-Whitney test:

H0: There are no differences on yield between nitrogen rates
H1: There are differences on yield between nitrogen rates

Pvalue = 0.05
Statistical test value Z = 0.761
Asymp. Sig = 0.371

The results of the Mann-Whitney test gives a pvalue of more than 0,05. Therefore we can not reject the null hypothesis and assume that we don't have any difference of yield between low, medium, high and general rates.

To make a quick conclusion of this third statistical analysis after this test, we can say that we have a difference on yield between nitrogen rates and potato with a caliber above 50mm.
This difference is not normally distributed for every case, as we can see above with the result of the Shapiro wilk sig, that give us 3/4 of the cases are above 0.05.
So, we can't conclude with the fact that the localized nitrogen rates and the potatoes above 35mm are not directly related like we can see in the graph up above. The nitrogen application has an impact on the yield but it's not concerning every rate at the same level.

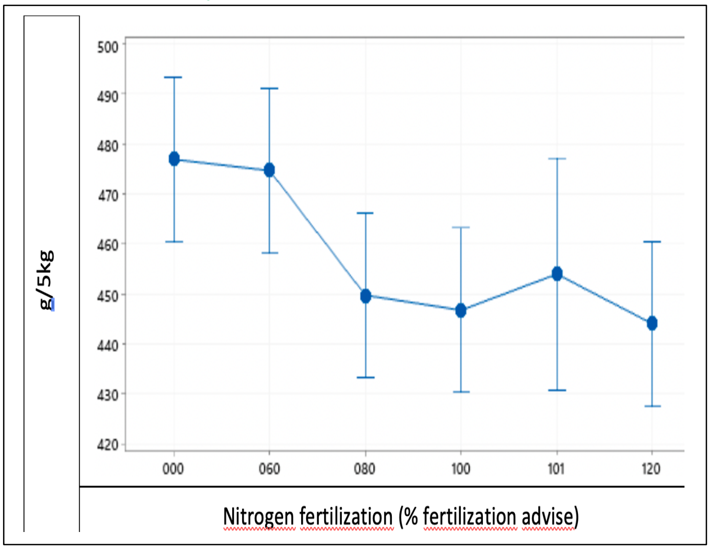
We can see that from 0 to 80 % of the recommended rate locally applied there is a clear augmentation of the yield but then from 80 to 100% the yield is decreasing.
The highest yield will be with the general application, and then when we had 20 extra percent, the yield is barely changing.

This brings us to a point that the nitrogen rate doesn't have the same impact for the potatoes above 50mm.

3.4 Impact of localized fertilization on the underwater weight of potatoes?

Figure n°15 shows the impact of nitrogen fertilization on the underwater weight of potatoes. The means calculated on objects 000 and 060 are higher than the other objects.

Figure n°15 Nitrogen fertilization impact on the potato waterweight



Impact of the nitrogen rate on underwater weight:

- Dependant variable: underwater weight
- Independent variable: nitrogen rate

Firstly, we need to see if the dependant of variable (underwater weight) is normally distributed on each category of the independent variable (nitrogen rate).

As an indication, a major Dutch potato processing plant (French fries) sets a minimum of 360 g/5 kg.

This threshold is reached regardless of the fertilization applied. However, it should be added that the higher the underwater weight, the more sensitive the tuber is to blows (uprooting and destocking).

<u>Statistical analysis</u>

In order to determine if the nitrogen rate had any influence over the dry matter and starch content of potatoes, ANOVA tests have been done on every calibers that has been harvested in the field.

For the ANOVA test, i focused on the nitrogen rate.
To make the test simpler I divided the localized application rates in four different ones and skipped two rates.

Low rate: 60 % of recommendation
Medium rate: 100% of recommendation
High rate: 120% of recommendation
General application: 100% of recommendation non localized

To determine if the varieties are normally distributed in this table, we need to look at the Shapiro-Wilk Sig. If the value is more than 0,05 they are normally distributed.

Here, every rates are normally distributed which give us only one option : a parametric test : An independent t-test has been run.

Independent T-test :

H0: There are no differences underwater weight between nitrogen rates
H1: There are differences on underwater weight between nitrogen rates

Pvalue = 0.05
Statistical test value Z = 0.956
Asymp. Sig = 0.467

Figure n°16 : Test of normality of the differences between nitrogen rates and underwater weight

Nitrogen rates	Statistic test value	Shapiro-Wilk sig	Distribution
Low rate	0.768	0.029	Normally distributed
Medium rate	0.501	0.031	Normally distributed
High rate	0.137	0.007	Normally distributed
General application	0.549	0.011	Normally distributed

The results of the Mann-Whitney test gives a pvalue of more than 0,05. Therefore we can not reject the null hypothesis and assume that we don't have any difference of yield between low, medium, high and general rates.

This test permits us to arrive to the following conclusion: nitrogen rate has a strong impact on the underwater weight of potato.

To make a quick conclusion of this third statistical analysis after this test, we can say that we have a difference on nitrogen rates and underwater weight.
This difference is normally distributed for every case, as we can see above with the result of the Shapiro wilk sig, that give us, all cases are under 0.05.
So, we can conclude with the fact that the localized nitrogen rates and underwater weight are directly related like we can see in the graph up above. The nitrogen application has an impact on the yield and it's concerning every rate at the same level.

We can see that from 0 to 100 % of the recommended rate locally applied the yield is constantly decreasing, not as much for some rates but it's decreasing so it doesn't really matter.
Then with the general application, the underwater weight is increasing, which make sense.
And then the 120% rates are as well below the 100%.
The highest underwater weight will be with the general application and the lowest will be the 120%.

This brings us to a point that the nitrogen rate has the approximately an impact on the underwater weight for potatoes.

3.5 To what extent does fertilization have an impact on potatoes scab?

Each sampled tuber was inspected to classify possible crevices:

- category 1: tubers with light cracks (angles >90°) = light
- category 2: tubers with 1 strong crack (angle <90°) = moderate
- category 3: tubers with several cracks = severe

We didn't took into consideration the category n°1 because we just wanted to see the potatoes that had scabs.
Categories 2 and 3 were counted (number of tubers) and weighed.
The results (Table n°1) immediately indicate that the generalized fertilization (object 101) has higher values (and always non-zero within a replication) than the objects fertilized in the mound. The objects fertilized in the mound present averages of about 3 t/ha while the object fertilized in generalized (object 101) shows an average of 8 t/ha, that is 15% of the production.
As an indication, an important Dutch potato processing plant (French fries) sets a ceiling of 30% of cracked tubers. This ceiling is never reached whatever the fertilization applied.

Figure n°17: Quantity of potato with scabs related with fertilization rates

Var	Obj.	N	Mean	Std dev	Min	Max
Cat. 2	000	4	4457	3844	657	9141
	060	4	1591	794	606	2374
	080	4	1717	924	758	2980
	100	4	934	299	657	1263
	101	2	3788	429	3485	4091
	120	4	1048	1550	0	3283
Cat. 3	000	4	1957	2386	0	5354
	060	4	896	1122	0	2323
	080	4	1818	2595	0	5505
	100	4	2727	4217	0	8889
	101	2	4167	2178	2626	5707
	120	4	1944	2564	0	5404
Cat. 2 & 3	000	4	6414	6111	1313	14495
	060	4	2487	876	1313	3333
	080	4	3535	2919	758	7071
	100	4	3662	3990	1111	9545
	101	2	7955	1750	6717	9192
	120	4	2992	4100	0	8687

Statistical analysis

In order to determine if the nitrogen rate had any influence over potential presence of scabs on potatoes, ANOVA tests have been done on every calibers that has been harvested in the field.

Impact of the nitrogen rate on potato scabs:

- Dependant variable: scabs
- Independent variable: nitrogen rate

Firstly, we need to see if the dependant of variable (potato scabs) is normally distributed on each category of the independent variable (nitrogen rate).

Given the standard deviations observed for these two criteria within each object, however, the analysis of variance reveals, but logically, no significant difference between objects (pValue of 0.101 and 0.813).

For the ANOVA test, i focused on the nitrogen rate.

To make the test simpler I divided the localized application rates in four different ones and skipped two rates.

Low rate: 60 % of recommendation
Medium rate: 100% of recommendation
High rate: 120% of recommendation
General application: 100% of recommendation non localized

To simplify the above table, I did another one that just take in consideration the essentials parts.

The column on the right shows the mean of potatoes with scab.

The worst case is always the one with the general application.

Cat.2	60%	1591
	100%	934
	100% (general appl)	3788
	120%	1048
Cat.3	60%	896
	100%	2727
	100% (general appl)	4167
	120%	1944
Cat.2&3	60%	2487
	100%	3662
	100% (general appl)	7955
	120%	2992

To determine if the varieties are normally distributed in this table, we need to look at the Shapiro-Wilk Sig. If the value is of more than 0,05 they are normally distributed.

Here, every rates are normally distributed which give us only one option : a parametric test : An independent t-test has been run.

Independent T-test :

H0: There are no differences underwater weight between nitrogen rates
H1: There are differences on underwater weight between nitrogen rates

Pvalue = 0.05
Statistical test value Z = 0.956
Asymp. Sig = 0.467

Figure N°18 : Test of normality of the differences between nitrogen rates and underwater weight

Nitrogen rates	Statistic test value	Shapiro-Wilk sig	Distribution
Low rate	0.768	0.029	Normally distributed
Medium rate	0.501	0.031	Normally distributed
High rate	0.137	0.007	Normally distributed
General application	0.549	0.011	Normally distributed

To make a quick conclusion of this fifth statistical analysis after this test, we can say that we have a difference on nitrogen rates and potato scab.
This difference is normally distributed for every case, as we can see above with the result of the Shapiro wilk sig, that give us every cases are under 0.05.
So, we can conclude with the fact that the localized nitrogen rates and potato scab are directly related like we can see in the graph up above. The nitrogen application has an impact on the yield and it's concerning every rate at the same level.

We can see on the table that the best result is usually with the less localized nitrogen possible.
The worst case is always with the general application.
This brings us to a point that the nitrogen rate and application has a strong impact on potato scab.

3.6 To what extent does fertilization have an impact on hollow heart?

Each sampled tuber was inspected for hollow hearts:

- category 1: no hollow heart
- category 2: barely visible hollow heart (<10 mm)
- category 3: moderate (>10 mm) to important but dry hollow heart
- category 4 : moderate (>10 mm) to important but wet hollow heart

Category didn't get take into consideration because we were just looking for the potato with a hollow heart.
Categories 2, 3 and 4 were counted (number of tubers) and weighed.
The results (Table 6) immediately indicate that generalized fertilization (object 101) has the highest values with an average of slightly more than 11 t/ha, i.e. 20% of the production.

As an indication, a major Dutch potato processing plant (French fries) sets a ceiling of 30% of tubers with hollow core. This ceiling is never reached, regardless of the fertilization applied.
The analysis of variance nevertheless revealed no significant difference between the objects (pValue = 0.643).

Figure n°19. Amount (kg/ha) of hollow-core potatoes (categories 2 to 3) as a function of fertilization

Var	Obj	N	Mean	Std dev	Min	Max
Cat. 2	000	4	1364	1193	0	2576
	060	4	2298	1214	859	3535
	080	4	3131	1491	1515	4949
	100	4	1982	2324	0	5202
	101	2	3535	1643	2374	4697
	120	4	2247	2088	0	5051
Cat. 3	000	4	5543	4163	0	10101
	060	4	3295	1607	1566	5455
	080	4	6061	5328	1061	12576
	100	4	5505	5274	1010	13131
	101	2	7727	5857	3586	11869
	120	4	3295	2828	606	7121
Cat. 4	000	4	694	1389	0	2778
	060	4	240	480	0	960
	080	4	1768	3535	0	7071
	100	4	0	0	0	0
	101	2	0	0	0	0
	120	4	720	887	0	1818
Cat. 2 à 4	000	4	7601	5642	0	12677
	060	4	5833	2438	2424	8182
	080	4	10960	6059	2576	16212
	100	4	7487	5295	1010	13737
	101	2	11263	7500	5960	16566
	120	4	6263	4170	2424	12172

Statistical analysis

In order to determine if the nitrogen rate had any influence over the hollow heart, ANOVA tests have been done on every calibers that has been harvested in the field. To simplify the above table, I did another one that just take in consideration the essentials parts.

The column on the right shows the mean of potatoes with hollow heart.

The worst case is most of the time the one with the general application.

Impact of the nitrogen rate on hollow heart

- Dependant variable: hollow heart
- Independent variable: nitrogen rate

Firstly, we need to see if the dependant of variable (hollow heart) is normally distributed on each category of the independent variable (nitrogen rate).

For the ANOVA test, i focused on the nitrogen rate.

To make the test simpler I divided the localized application rates in four different ones and skipped two rates.

Low rate: 60 % of recommendation

Medium rate: 100% of recommendation

High rate: 120% of recommendation

General application: 100% of recommendation non localized

To simplify the above table, I did another one that just take in consideration the essentials parts.

The column on the right shows the mean of potatoes with hollow heart.

The worst case is always the one with the general application.

Cat.2	60%	2298
	100%	1982
	100% (general appl)	3535
	120%	2247
Cat.3	60%	3295
	100%	5505
	100% (general appl)	7727
	120%	3295
Cat.4	60%	240
	100%	0
	100% (general appl)	0
	120%	720
Cat.2&4	60%	5833
	100%	7487
	100% (general appl)	11263
	120%	6263

To determine if the varieties are normally distributed in this table, we need to look at the Shapiro-Wilk Sig. If the value is of more than 0,05 they are normally distributed.

Here, every rates are normally distributed which give us only one option : a parametric test : An independent t-test has been run.

Independent T-test :

H0: There are no differences underwater weight between nitrogen rates
H1: There are differences on underwater weight between nitrogen rates

Pvalue = 0.05
Statistical test value Z = 0.956
Asymp. Sig = 0.467

Figure n°20 : Test of normality of the differences between nitrogen rates and underwater weight

Nitrogen rates	**Statistic test value**	**Shapiro-Wilk sig**	**Distribution**
Low rate	0.768	0.029	Normally distributed
Medium rate	0.501	0.031	Normally distributed
High rate	0.137	0.007	Normally distributed
General application	0.549	0.011	Normally distributed

The results of the Mann-Whitney test gives a pvalue of more than 0,05. Therefore we can not reject the null hypothesis and assume that we don't have any difference of yield between low, medium, high and general rates.

To make a quick conclusion of this sixth statistical analysis after this test, we can say that we have a difference on nitrogen rates and hollow heart.
This difference is normally distributed for every case, as we can see above with the result of the Shapiro wilk sig, that give us every cases are under 0.05.

So we can conclude with the fact that the localized nitrogen rates and hollow heart are directly related like we can see in the graph up above. The nitrogen application has an impact on the yield and it's concerning every rate at the same level.
We can see on the table that the best result is usually with the less localized nitrogen possible.
The worst case is always with the general application.
This brings us to a point that the nitrogen rate and application has a strong impact on hollow heart.

3.7 Effects of nitrogen fertilization on nitrogen residue in the ridges?

On July 1, 2021, soil sampling was conducted in each microplot to assess the mineral N stock during the period of high N uptake.
It is accepted that the period of high N uptake (80-90%) occurs over a two-month period following crop emergence; roughly during the months of June and July.

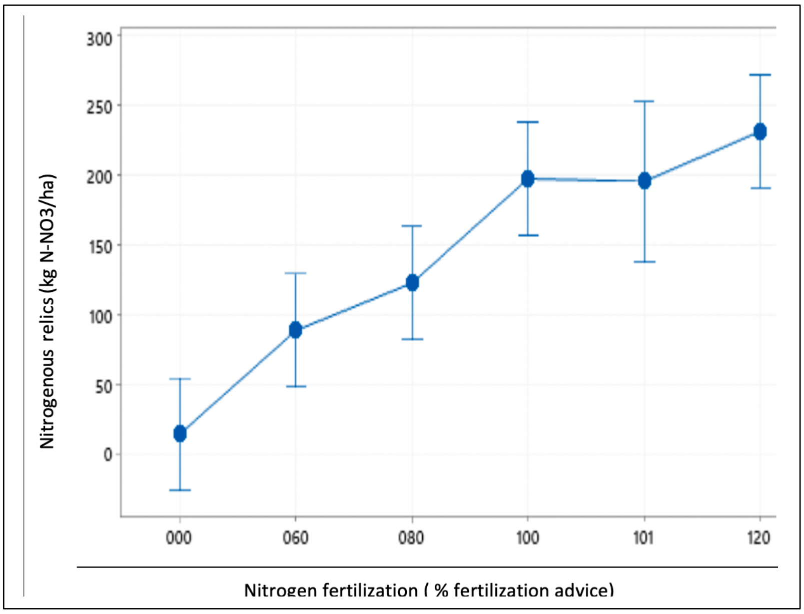
Figure n°22 illustrates the results of the analyses performed. Fertilization "101" corresponds to an application of 100% of the recommended dose in generalized application. The other objects correspond to applications (% of the fertilization advice) locally applied in the mound. Logically, the stock of nitric nitrogen increases with the applied fertilization.

Figure n°21: Nitrogen residue (kg N-NO$^-$3/ha) in the mound in July - Tukey

Ferti	N	Mean	Grouping			
120	4	231,0	A			
100	4	196,9	A	B		
101	2	194,9	A	B		
080	4	122,1		B	C	
060	4	88,1			C	D
000	4	13,5				D

A Tukey test informs statistically equivalent groupings

Figure n°22: Nitrogen residue in the mound in July.

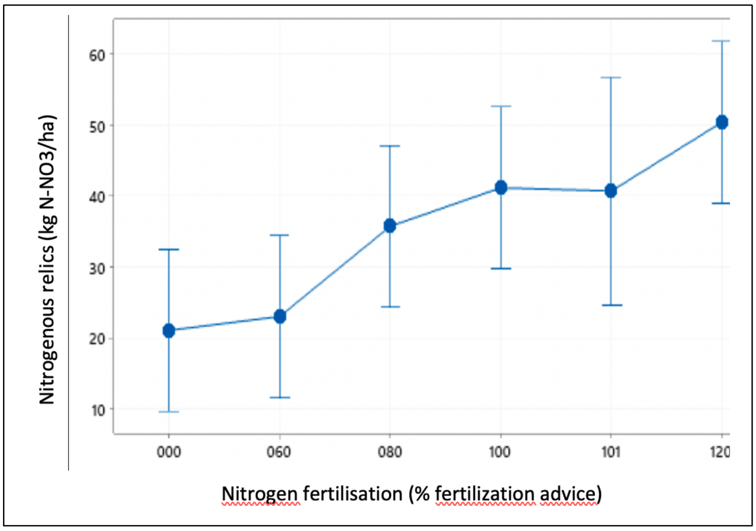


June 2021 was exceptionally rainy (172 mm at the CRAW weather station in Ronan instead of a normal 76 mm).

Soil sampling at harvest time

Soil samples were taken on harvest day (September 28), prior to the harvest operation in each replication.
Figure n°23 illustrates the impact of fertilization on soil nitrogen residue at harvest.

Figure n°23 : Nitrogen residue in the mound at harvest as a function of fertilization.



The Tukey test (Table n°24) shows two groups, one including the nitrogen relicts of the 120, 101, 100, and 80% modalities and the other including the 101, 100, 80, 60, and 0% modalities.

Figure n°24. Nitrogen residue (kg N-$NO^{-}3$/ha) in the mound at harvest - Tukey

Ferti	N	Mean	Grouping	
120	4	50,38	A	
100	4	41,16	A	B
101	2	40,71	A	B
080	4	35,72	A	B
060	4	23,01		B
000	4	21,05		B

Visually ignoring object '101', the nitrogenous residue increases from object '060' onwards in a constant way with the nitrogen input.

As an indication, the LPA measurements carried out around October 22 in the 36 'potato' reference plots of the Survey Surfaces show an average of 71 kg N-NO^-3/ha; i.e. about 30 units more than the objects '100' and '101' corresponding to the nitrogen fertilization advice.
This increase corresponds to the mineralization of soil nitrogen and potato haulm residues between the two observation periods.
To make a quick conclusion of this statistical analysis after this turkey test, we can say that we definitely have two main groups. The relics are increasing from the 60% recommendations.

So, we can conclude with the fact that the localized nitrogen rates have a positive impact on the nitrogen relics. The more you fertilize the more nitrogen stay in the soil for the following crops.

We can see on the table that the best result is usually with the highest localized nitrogen, which is 20% above the full recommendation

This brings us to a point that the nitrogen rate has a strong impact on the nitrogen relics.

Discussion

Discussion of the results

Just as a little reminder, this research aims to have an idea of how to optimize the fertilization of a potato crop by using a localized application at different rates and as well a general application. We know that with agronomy experimentation, that it would take way more than just one year to know the exact result, this is why it's just the first step. The goal is to fertilize with the less amount of input possible and to have the best result in term of yield and the minimum waste. Therefore it was needed to find possible differences on different elements such as hollow heart, potato scab or underwater weight between the same variety but with different calibers.

With all the measurements that have been done, this research confirmed that the caliber plays a role in the efficiency of the nitrogen (Yara, 2017). However, it didn't allow us to confirm that the potatoes from different calibers are wasting nitrogen if they are not consuming it.

Statistical tests did prove some difference for the hollow heart damage, or the potato scab and underwater weight between the calibers, the applications and the rates of nitrogen. It is important to note that the statements made in this report only concerns this particular experiment. Though, those three aspects of potato production are not the only parameters that needs to be compared concerning the yield and the nitrogen efficiency. It was planned to look out for diseases, and see if the localized nitrogen application had an impact on it, but none was observed this year due to the specific dry spring that Montana had. Since the data wouldn't be relevant for a statistic test, it was decided to leave it aside and focus on other aspects where enough data have been measured throughout the experiment.

However, it has been statistically observed that we have differences based on the calibers, the nitrogen rate and the type of application on the three following parameter : potato scab, hollow heart and underwater weight. Because no difference were detected for the yield above 35 and 50 mm and the yield by caliber class, we can say that fertilization rate and application are not directly related to the yield but they affects some other aspects of the production.

Following these results, it was interesting to know if this relations/difference took effect during the trial or not. ANOVA tests have been done on every single measurements throughout the experiment. It had been found that it did happen during the end of the conducted research, because the potato needed to be big enough to be affected. Those aspects happened at the end of the potato cycle.

Following the notations on the calibers and fertilization, it was decided to do a statistical test on both applications (localized and generalized). However, statistical tests did not prove that the fertilization rate and application had an impact on the yield in general, as shown by the first test that had been done on this thesis.

Critical reflection on the experiment

This research has confirmed that we have effectively some differences of scab, hollow heart and underwater weight in correlation with the fertilization. There are also differences between the calibers concerning their resistance or not to those aspects. The difference between general application and a localized one is very clear because the localized one is directly in contact with the roots and the plants in general so it's not as exposed to lixiviation and evaporation as the general one.

However, the results of this conducted research are not completely reliable, because as said before, it takes at least 5-10 years to have a precise result for an agronomy research like that. Indeed, for a quality and yield experiment, this trial lasted for the cycle of the crop which is not enough to analyze every single variable. And agriculture is a sector where the weather is a key factor, that can be with or against your experiment, so therefore it is mandatory to repeat these trials many times to conclude with a reliable result.

Also because of that short period, reliable measurements and notations couldn't be done on every factors such as diseases, or germination or the shelf life of the potatoes in the materials and methods. Nevertheless, the results are still providing interesting elements that can be reused for future research.

It was noticed that the soil and the climate in the experimental field were not similar as usual. And that because of the weather and the sandy soil that is not representative of the American type of soil.

It is important to keep doing experiments on these materials to adapt the fertilization methods so that the potatoes are in the best possible conditions to be sowed during spring. Localized or general application might differ later in the time, but it is interesting to keep them under the same setting during the next trials to observe the differences and adapt their future uses.

As a result of the methodology and the limits of this research, here are improvements that can be done for new research next year:

- This research could be done on different locations, using different conditions to measure extensive data on germination, density or diseases
- Being able to repeat this research for at least five years in a row
- Taking in consideration every caliber and not choosing only two
- Try out different variety to see if it has a link with our problematic
- Voluntarily inoculate some plots with diseases to observe the effect on the starting materials

With these improvements, we would be covering a lot more possibilities and answer many more question that we still don't know about. These improvements can give more reliable results and conclusions compared to this research.

Conclusion and recommendations

Conclusions

The evolution of mechanization has made the application of nitrogen while planting possible in recent years, directly into the potato ridge and therefore closer to the plant.
A first year of experimentation was carried out in order to evaluate the impact of this localized application of fertilizer on the potato harvest from a quantitative and qualitative point of view. This experiment was conducted in a silty region with a variety (Fontane) intended for consumption.

A measurement of the nitrogen content of the soil was carried out before planting in order to elaborate a fertilization advice (180 kg N/ha). Six objects (in four replications) were tested:

- a 0 N control ;
- four objects with localized fertilization (60, 80, 100 and 120% of the fertilization advice);
- one object with generalized fertilization (100% of the fertilization advice in two replications).

A few days before harvest, tubers were taken from each microplot to quantify and qualify the yield. During this operation, soil samples were also taken to estimate the nitric nitrogen content.
The analyses carried out reveal the following lessons:

- by localizing nitrogen application, it is possible to reduce fertilization by 20 to 40% (compared to a generalized application) without a statistically significant loss in yield;
- such a reduction in fertilization lowers (on average, not significant) the stock of nitric nitrogen at harvest by 6 and 18 kg $N\text{-}NO^{-}3$/ha (respectively for a 20 and 40% reduction in nitrogen fertilization) ;

- by localizing the nitrogen application, the proportion of tubers that are cracked or have a hollow heart decreases (not significantly) compared to generalized fertilization.
- it’s going forward a sustainable production, with less inputs and waste.

At a time of high nitrogen prices (~ 2 € /uN), a 40% reduction in the dose, i.e. 72 uN, would reduce the production cost by about 144 €, which corresponds roughly to the value of one ton of potatoes. In the context of this experiment, a gain in yield of about half a ton was observed for such a reduction in fertilization, i.e. an increase in economic yield of over 200 €/ha.

Measurements of the nitric nitrogen concentration in the mounds were carried out at the beginning of July, at the closing of the lines. They indicate that a stock of 100 to 150 kg N-NO^-3/ha in the 0-60 cm layer (observed for the objects "60% of the advisory dose" and "80% of the advisory dose") makes it possible to reach the expected yield. A stock of more than 200 kg N-NO^-3/ha (observed for the objects "100% of the advisory dose" (in localized or generalized) and "120% of the advisory dose") does not increase the yield at harvest.

This first experiment will have to be repeated in order to establish these lessons more comfortably. `

Recommendations

For the fertilization experiment it is interesting to reuse the data retrieved from this research to confirm the differences between the localized and the general application. With the extent of the experiment enhanced, it would be interesting to confirm if this is also the case for the localized fertilization.

Moreover, it is recommended to also focus on the sprouts measurements and diseases for future research to have an in-depth analysis of the differences between varieties, starting materials and soils.

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