Developing selection criteria for breeding organic nitrogen-efficient potato (*Solanum tuberosum*) varieties:

Root Characteristics of Potato Crops under Different Levels of Organic Nitrogen Treatments

By Yazhen Qiao

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Summary

This study is to study the Root Characteristics of Potato Crops under Different Levels of Organic Nitrogen Treatments which was embedded into a three-year project (2008-2011) during 2008 growing season, as an MSc thesis research.

Comparably root system of potato crop penetrate the soil slower than those of cereal crops (wheat, barley, rye…), as they have smaller root length densities and grow shallower than other crops (van Delden, 2002). Thus, potato crop is expected to be in general more sensitive to (early) nitrogen limitations than other crops.

The tubers of the potato variety 'Spirit' were planted under three different levels of nitrogen application (90, 150, 300kg N/ha), in three replications, in sandy soil at Droevendaal organic farm in Wageningen. Root samples were taken by core sampler (auger) from root horizone of Spirit crop, at different depths and positions, after one week of second harvest i.e. 85 days after planting (DAP).

Root characteristics such as root length, root diameter, and root density of Spirit were analyzed under the three levels of organic nitrogen treatments. Preliminary results were found in this pilot study are the following:

- The mean root length in general reach the maximum value in the soil layer r30-40;
- Increased amount of nitrogen applying does not give significant effects on root thickness;
- The root branches of potato crop have quite fine/average thickness through all the root horizons, at least within the upper 50cm of the root system;
- Both of the root density and root length showed higher peaks under N2 conditions rather than N3 at the most concentrated soil layer r30-40;
- Root growth could be enhanced by increasing nitrogen supply at the early stage of growth; but a too high nitrogen level seems does not stimulate further root development i.e. root growth and nitrogen supply level is not in a liner relation.

As a final mark, all of the preliminary results from this study were based on one year trial, with one variety (Spirit), and one measurement. Thus, further experiments need to be done to confirm these first indications from this pilot study.

Table of contents

Acknowledgements....3
Summary....4
Table of contents....5
1 Introduction....6
1.1 General background....6
1.2 LBI project....9
1.3 Root study....10
2 Materials and Method....11
2.1 Plant material....11
2.2 Experiment design....11
2.3 Location and Nitrogen inputs....11
2.4 Root sampling....12
2.5 Data analysis....14
2.6 Climate status....14
3 Results....15
3.1 Root length....15
3.2 Root diameters....17
3.3 Root density....19
3.4 Tuber yield....22
4 Discussions and Conclusion....23
Recommendation....25
Appendix....26
References....29

1 Introduction

1.1 General background

Organic agriculture is growing rapidly worldwide but crop yields are generally lower than in conventional agriculture. To a large extent, this may be caused by the use of cultivars that are not adapted to organic growing conditions (Biological Farming System, WUR). The most yield reducing factors in organic potato growing are late blight infestation and nitrogen deficiency. Therefore, new varieties that are resistant to late blight and nitrogen efficient are required by organic potato growers. Breeders and organic farmers experience large genotypic variation in the response to low levels of nitrogen. But the physiological mechanisms explaining these differences and the genetic background are unknown yet (Tiemens-Hulscher et. al, 2007).

Potato is one of the top five crops feed the world. On the world scene, 293 million tons of potatoes were produced on 18 million hectares (i.e. averagely 16.28 tons per hectare) worldwide in 1998 (FAOSTAT, 1998). According to South Central New York Agriculture Team, in New York 20,000-40,000 pounds per acre, i.e. 22.5- 45 tons per hectare, was the usual range of organic potato yields in year of 1999; NYS conventional growers, often on muck soils, average around 27,000 pounds/acre (South Central New York Agriculture Team, 1999). This argument illustrated if the organic management suits potato growth requirement, the yield of organic potato would not be too much lower than the conventional yield.

The average potato yields in Dutch organic farming systems vary from 15 to 29 metric tons per hectare (Lammerts van Bueren, 2008). According to Lammerts van Buren, 20%-50% less nitrogen being used in organic farming compared with conventional situation. In order to reach a optimal tuber yields under low N input farming, we could think from two different points of view: organic farmer could improve practical management to optimize field conditions which suit the ordinary cultivars; nevertheless, on the other hand, organic breeders could breed new cultivars which adapt more to the organic farming conditions.

In organic production system, the lack of adequate and stable nitrogen supply leads to agronomic uncertainties. Through the long term of intensive agriculture selection, the modern varieties have a poor plasticity in response to variation in nitrogen availability, having small root systems, and require large quantities of nitrogen to maintain vegetative growth and productivity throughout the growing seasons. Such varieties are not adapted to organic cultivation conditions. The organic growers prefer varieties with good yield stability, good adaptation to low nitrogen input and a good recovery capacity after a period of nitrogen shortage.

Problem Statement

The growing season for organic potatoes is relatively short compared to conventionally produced potatoes. Two main restrictions lead to this are late blight (*Phytophthora infestans*) infestation and a low nitrogen supply. Generally speaking, In the Netherlands the canopy of the potato crop has to be destroyed at an infestation level of 7% to avoid spread of inoculums to surrounding fields (HPA regulation, 2003). In the years with little disease pressure, nitrogen availability is probably the most import yield limiting factor. In

Germany, nitrogen availability is the most important factor limiting yields in organic potato crops (Moller et al. 2007). They developed a model and found almost half of the variation (48%) in yield could be explained by differences in nitrogen availability, especially in spring and early summer.

As well known, the nutrient management in organic farming system is based on crop rotations, solid and liquid animal manures, green manures and compost (Finckh et al., 2006). The release of nitrogen from most of these fertilizers is slow and highly dependent on soil moisture and soil temperature affecting mineralization processes (van Delden, 2001). Therefore, nitrogen management in organic farming system is very complex (Figure1.1). The supply of nitrogen from organic resources is difficult to synchronize with crop demand (Pang and Letey, 2000).

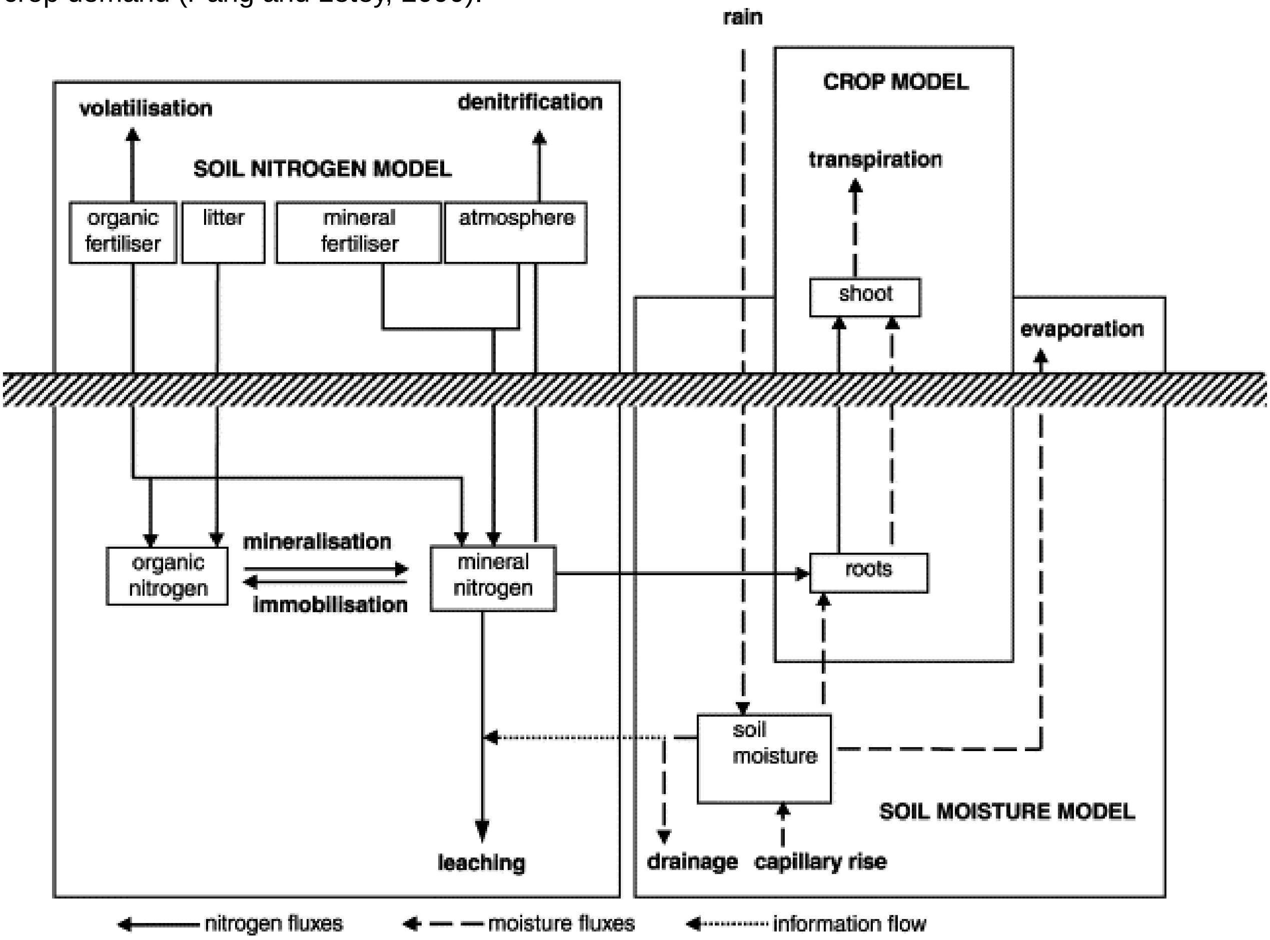


Figure 1.1 Schematic representation of the LINTUL-NPOTATO model structure (Van Delden et al. 2003). The model consists of three sub-models: one for soil moisture dynamics, one for soil N dynamics, and one for crop growth and N uptake.

Nitrogen availability can affects both of physiological processes and morphological traits of potato crop including a. the rate of canopy development, b. the rate of leaf appearance, the rate of individual leaf growth, final leaf size, and the life span of individual leaf, c. the integral of light interception by the crop over time, d. the rate of photosynthesis, e. the number of lower and sympodial branches, and f. the onset of tuberization , final tuber yield and final yield and final harvest index (Tiemens-Hulscher et. al, 2007). Nitrogen supply may also affect quality aspects such as tuber size distribution, tuber dry matter content, protein content, nitrate content and processing quality (van Kempen et al., 1996).

Based on much research which has been done to assess the yield response of varieties to nitrogen supply under high levels of input and analyze how to optimize nitrogen supply, Tiemens-Hulscher put the research question in an opposite way: “Given a low nitrogen input, what kind of variety will be able to perform well? “(Tiemens-Hulscher et. al, 2007). To answer this question we have to understand the physiological mechanisms behind nitrogen use efficiency of potatoes under low nitrogen conditions.

1.2 LBI project

Much empirical research has been done on the question of how can farming conditions meet the requirement of potato tuber growth. Little research on the question of the reverse way i.e. how potato variety can adapt the certain farming conditions and what could be the morphological selected criteria for breeders.

The project “Developing selection criteria for breeding organic nitrogen-efficient potato (*Solanum tuberosum*) varieties” launched by Louis Bolk Institute (LBI), corporate with Crop and Weed Ecology, Plant Sciences Group of Wageningen University, is focusing on the latter point, aims to design selection criteria for high nitrogen use efficiency under low nitrogen conditions to support breeding programs for organic potato varieties. It is a three-year project started in 2008, began with the identification of morphological plant traits that are correlated with nitrogen use efficiency (NUE). We expect to find some parameters (amongst rate of soil cover, time to reach maximum soil cover, length of period with maximum soil cover, time from maximum soil cover to haulm death; see Figure 1.2) that are correlated with NUE. The next step for later years is to translate the most promising traits into simple and easily applicable selection criteria.

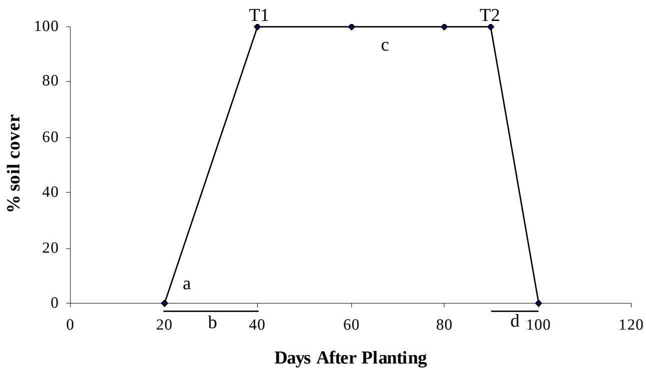


Figure 1.2 Soil cover curve with the parameters a, b, c and d (Vos & MacKerron, 2000).
a = rate of soil cover (%/day); b = time to reach maximum soil cover (days); c = length of period with maximum soil cover (T2-T1) (days); d = time from maximum soil cover to complete haulm death (days).

1.3 Root study

A study on Root Characteristics of Potato Crops under Different Levels of Nitrogen Treatments was associated into the LBI project during 2008 growing season, as an MSc thesis research. Thus, this report will mainly focus on the root experiment.

Comparably root system of potato crop penetrate the soil slower than those of cereal crops (wheat, barley, rye…), as they have smaller root length densities and grow shallower than other crops (van Delden et. al, 2003). Thus, potato crop is expected to be in general more sensitive to (early) nitrogen limitations than other crops.

Root system characteristics of potatoes are important for a better understanding of the uptake of water and minerals by the crop and in aiding decisions on soil amendments and fertilizer application.

As well known, for root characteristics or tuber study a hydroponic system has several advantages over field or pot experiment (Li, 1985):

- Plants can be supplied with defined amounts and concentrations of nutrients;
- Nitrogen uptake can be monitored;
- Growth of stolon and tubers can be observed easily;
- Manipulations like tuber pruning and application of hormones are possible;

However, the representativeness of hydroponic study compared with the field production situation was doubted; the difference of soil and water as growth media and the interaction mechanisms with root system are both significant. And furthermore, in organic farming system live soil based production is one of the key points of its philosophy principles. That is probably why the root research as a whole still remains challenging and costly. The root characteristics study only focus on one variety Spirit was due to the time and labour limitation.

This study is a preliminary experiment by taking the potato variety Spirit as plant material, analyzing root characteristics like root length, root diameter, and root density under a range of nitrogen supply conditions, to test this **hypothesis**: The more intensity the root system is, the higher nitrogen uptake efficiency the potato cultivar has.

The uptake of nitrogen by root system is ideally expected being transferred as much as possible into tubers which finally result as tuber yields. To see the relation between root growth (by using root density as parameter) and tuberization (by using tuber yields), i.e. how and on what extend root system could stimulate tuber yield, the Spirit tuber yields will be discussed regarding to its root density.

2 Materials and Method

2.1 Plant material

Nine varieties of potatoes known by experience differ in nitrogen requirement: Agata (A), Leoni (B), Biogold (C), Sante (D), Bionica (E), Fontane (F), Terragold (G), Agria (H) and Spirit (I) were used in the LBI study; variety Spirit (I) was selected for the root system experiment. The general information about those varieties including parentage, breeder, release year, and the maturity type are list in Table 2.1.

Table 2.1 The brief information of potato varieties[1]

Varieties\Infor.	**Parentage**	**Breeder**	**Release year**	**Maturity type**
Agata (A)	--	--	--	very early
Leoni (B)	ADORA x LIDO	IJSSELMEERPOLDERS BV	2003	very early
Biogold (C)	NOVITA x HZ 87 P 200	HANDELMAATSCHAPPIJ VAN RIJN BV	2004	early
Sante (D)	Y 66-13-636 x AM 66-42	J. VEGTER	1983	mid-early
Bionica (E)	PENTLAND IVORY x CMK 88-169-005	VOS 97-062-016	2008	mid-early
Fontane (F)	AGRIA x AR 76-34-3	SVALOF WEIBULL BV	1999	mid-early
Terragold (G)	--	--	--	mid-late
Agria (H)	--	--	--	mid-late
Spirit (I)	HAA 82-807-34 x REMARKA	HANDELMAATSCHAPPIJ VAN RIJN BV	2006	mid-late

2.2 Experiment design

The root system experiment is a split-plot design only focused on organic farming conditions and with one variety Spirit (I) with different factors: the three nitrogen levels (low (90 kg N/ha); medium (150 kg N/ha); and high (300 kg N/ha)) were considered as being main plots; seven different depths/ dig-points: five from the top of the ridge (r0-10cm, r10-20cm, r20-30cm, r30-40cm, and 40-50cm, the top of the ridge is considered as zero level; and two from the side of the ridge: s0-10cm and s10-20cm, the one third height of the ridge was considered as zero level) of root system were considered as being subplots; three replicates were considered as blocks. Three plants were randomly chosen for taking root samples in each nitrogen treatment (main plot).

2.3 Location and Nitrogen inputs

The organic field was in Droevendaal farm with sandy soil in Wageningen; the former crop in 2007 was Barley from April till August; afterwards clover was followed as winter green manure. The expected nitrogen release of trial field was estimated at 90 kg N/ha and this level was considered as zero level (N1). 60 and 210 kg N/ha were added to

[1] Information resource: Hutten RCB & Berloo, R van (2001) An online potato pedigree database.
URL: http://www.plantbreeding.wur.nl/potatopedigree/

create level N2 (150 kgN/ha) and N3 (300 kg/ha). On the organic field feather meal were used as fertilizer. Feather meal contains 11% N and was expected to release during potato growing period. Each nitrogen treatment were divided into nine sub plots of four ridges raised 30cm from ground surface and 9.6m long. Potato tubers were planted in each planting spot with plant to plant distance of 30cm. The details about how the fields divided into three mainplots of different nitrogen levels and nine subplots of varieties are attached in appendix1. Potato was planted on 22nd April, 2008 in Droevendaal organic field; fertilizers were applied just after planting before closing the ridges.

2.4 Root sampling

In crops with spaced plants, bore holes should not be made at random. Instead, it is necessary to identify the smallest land area containing all the possible systematic variation in root distribution caused by the planting pattern. The methodology of root sampling is according to Smit et. al, this area must be sampled in a systematic fashion; all the bore holes from such an area together forming one replication (Smit et. al, 2000).

Effect of different doses of organic nitrogen on root parameter of potato variety Spirit was evaluated after one week after the second intermediate harvest (of course, root samples were taken from the un-harvested plants), 85 days after planting (DAP) (Figure 2.1).

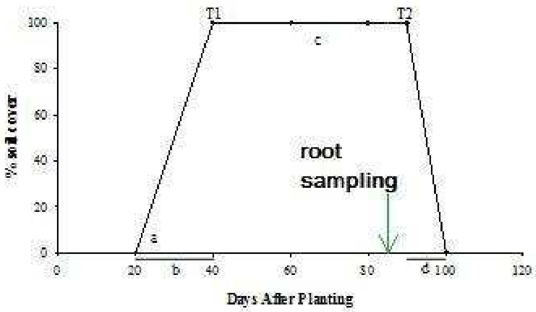


Figure 2.1 The time of root sampling (85 DAP) in the soil cover curve, with the parameters a, b, c and d (Vos & MacKerron, 2000).
a = rate of soil cover (%/day); b = time to reach maximum soil cover (days); c = length of period with maximum soil cover (T2-T1) (days); d = time from maximum soil cover to complete haulm death (days).

Root samples were collected from five consecutive root depths up to 50 cm form top of the ridge (i.e. r0-10cm, r10-20cm, r20-30cm, r30-40cm, and r40-50cm) and up to 20 cm from side of the ridge (s0-10cm and s10-20cm) in Droevendaal farm. In Figure 2.2 this area is indicated by the rectangle, we took root samples randomly from three plants in each nitrogen treatment (7*3), and again determined the values of the root parameters in three replications (7*3*3); Figure 2.3 shows the locations of seven root samples were taken from one potato plant, five from the top of the ridge (labeled as r0-10, r10-20, r20-30, r30-40, and r40-50), two from the one third height of the ridge (labeled as s0-10 and s10-20). We assumed that there were no systematic differences between the three replications.

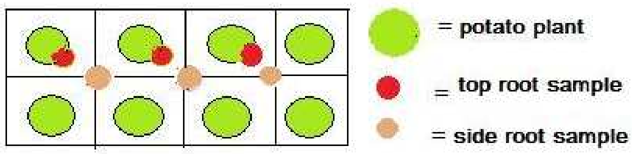


Figure 2.2 Schematic representation of the pattern of root sampling, showing the number of bore holes and their positions relative to the plants (top view).

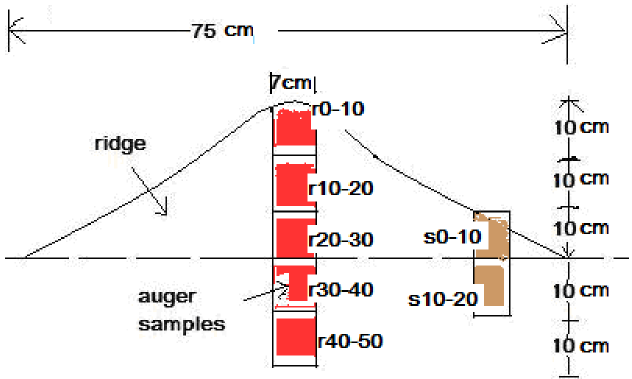


Figure 2.3 Schematic, vertical cross-section showing the pattern of sampling of five soil samples from top of the ridge (r0-10, r10-20, r20-30, r30-40, and r40-50); and two from side of ridge (s0-10 and s10-20) (cm). The mother tuber was located in the area of soil layer r10-20.

Root samples were taken by use of a cylinder-shaped core sampler (auger) with a diameter of 7cm, and a height of 10cm in three replications. In total, (3N-treatments* 3plants* 7samples* 3replications = 189) there were 189 root fraction samples were taken from the variety Spirit at 85DAP in organic field.

The samples were put into coded plastic bags and stored at 7 ◦C until be rinsed, cleaned, scanned. Root density per unit volume of soil was determined by winRhizo program (V-2005b).

2.5 Data analysis

The data were analyzed by carrying out a split plot analysis in GenStat as the design of the experiment corresponds to a split-plot design. The three replicates were considered as being three blocks; the three nitrogen input levels in each replicate were considered as being three main plots. Subsequently, the seven depths/dig-points were considered as being seven sub-plots.

ANOVAs were realized to determine whether there were significant differences between nitrogen levels, depths/ positions for the different traits but also to determine whether there were interactions between those different factors.

All statistical procedures were performed with GenStat Discovery 3rd Edition (Payne et. al, 2008).

2.6 Climate status

The growing season for organic potatoes at Droevendaal in 2008 was conventional Dutch climate without considerable extreme conditions.

According to the weather record from Haarweg weather station, 2008, there were two peaks of rainfall in March and July, with respectively 120mm and 122mm; It was quite dry during April, May, and June with an average of rainfall around 60mm. In term of temperature, April it varied from 3-17◦C; May 9-21◦C; June 12-23◦C; and July 13-24◦C (see appendix 3, 4).

3 Results

3.1 Root length

Mean root length were calculated for separate soil layers in table3.1 and Figure 3.1.Root length varied in a huge range between 131cm and 2858cm; For Nitrogen level factor the F pr. of F-test was 0.02; for Depth/position factor F pr. was <0.001; both of the F pr. < 0.05. The interaction of these two factors with an F pr. of 0.219.

Table3.1 Mean root length (cm) of different root fractions under a range of organic N treatments

Depth\N_level	N1	N2	N3
R0-10	1708	789	2195
R10-20	612	617	1300
R20-30	832	875	808
R30-40	1010	1385	1116
R40-50	216	352	505
S0-10	785	666	1245
S10-20	392	573	684

For nitrogen level1 and 2, the mean root length were similar, respectively were 794cm and 751cm; but for nitrogen level3, it suddenly increased to 1122cm averagely.

The mean root length had peaks at the soil layer R0-10 (1564cm) and R30-40 (1170cm); reached the lowest value at layer R40-50 (358cm). Below 40cm of the ridge top, mean root length hardly ever exceeded 500cm. The root length under N3, averagely higher than those under N1 and N2.

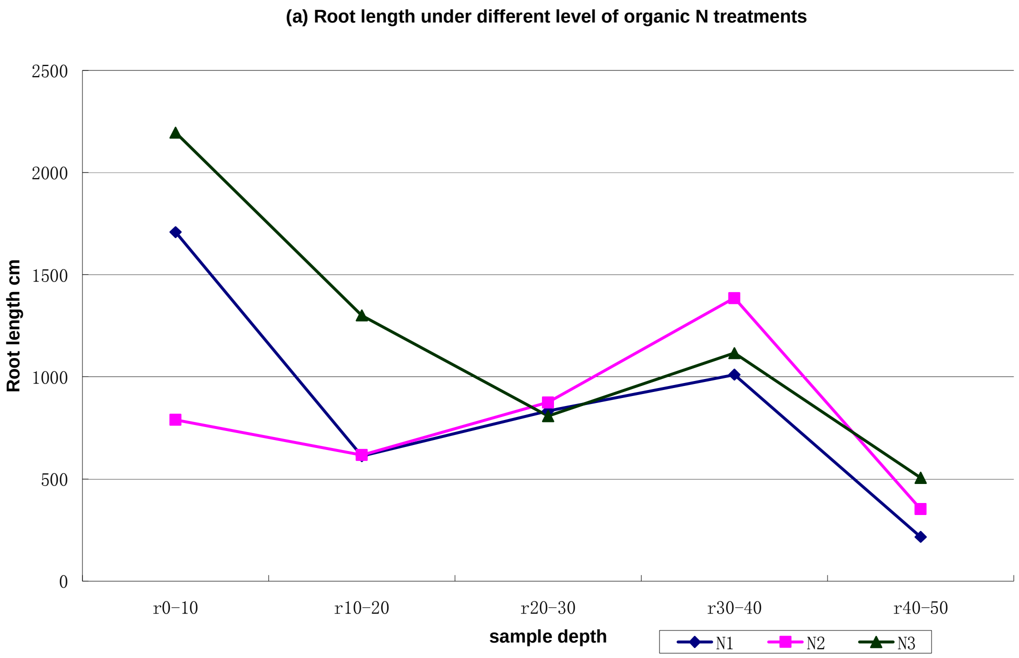


Figure 3.1(a) Mean root length under different level of organic N treatments; based on samples taken from the top of the ridge (r0-10, r10-20, r20-30, r30-40, and r40-50)

The mean root length of soil layer r0-10, where the stems of potato plants developed, was generally higher than other layers. The mean root length in general reaches the maximum value in the layer R30-40 (Figure 3.1 (a)); there were fewer roots in the side of the ridge, especially in the layer S10-20, around 600cm. Root length of side layer s0-10 under N3 is about two times higher than those in N1 and N2 (Figure 3.1(b)).

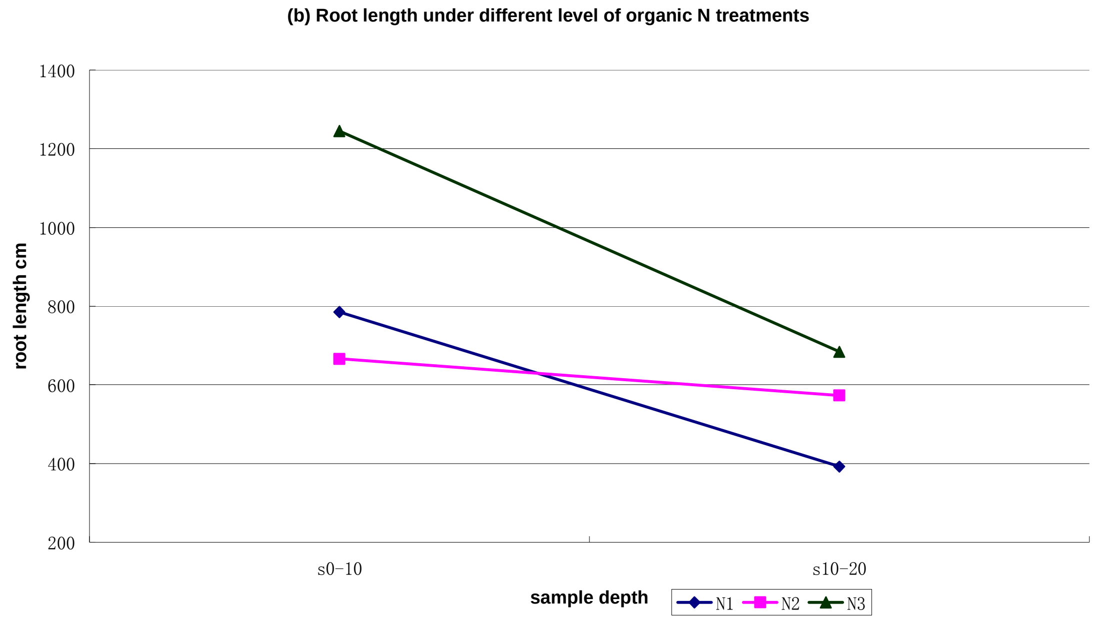


Figure 3.1(b) Mean root length under different level of organic N treatments; based on samples taken from the side of the ridge (s0-10 and s10-20)

3.2 Root diameters

Mean root diameters were calculated for separate soil layers and interacted with three N supply levels in table 3.2 and Figure 3.2. In general, root diameters of potatoes' root within 50cm of the root horizon, varied from about 0.20 till 0.37mm, averagely around 0.26mm in these three organic N treatments.

For those three different levels of nitrogen supplying, there was no significant effects on diameters of roots. Three levels were slightly different: N1, 0.26mm; N2, 0.26mm; and N3 for 0.27mm. The result of F test: F pr. for depth is 0.883, for N level 0.594, both are >> 0.05. This means there is no statistically significant on root-diameters due to the different treatment of nitrogen and the depth/position of root.

Table 3.2 Mean root diameters (mm) of potatoes under a range of organic N treatments

Depth\N_level	N1	N2	N3
R0-10	0.3234	0.2578	0.2247
R10-20	0.2292	0.2779	0.2914
R20-30	0.2577	0.2734	0.2764
R30-40	0.2493	0.2566	0.2989
R40-50	0.2556	0.2524	0.2787
S0-10	0.2340	0.2713	0.2479
S10-20	0.2755	0.2159	0.2633

As the data shows, there is no statistically significant of root diameters not only with three different nitrogen treatments, but also for the different depth or positions of from where root samples were taken. It seems like everywhere and under every N condition, the potatoes' root diameter keep constantly around 0.26mm.

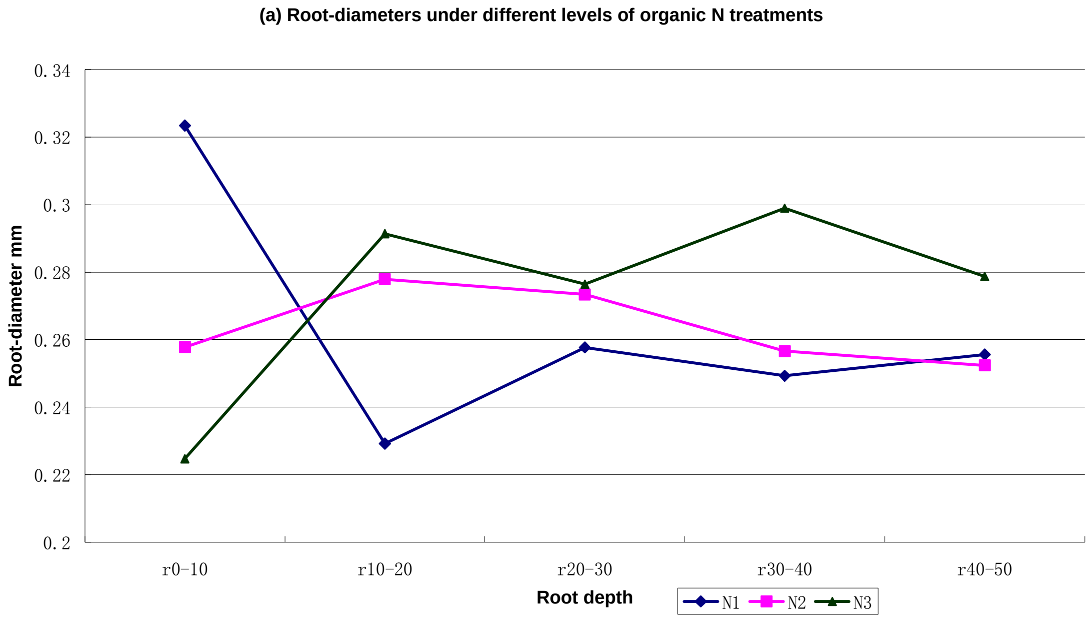


Figure 3.2 (a) Root diameters of potatoes under different interaction of N treatments and root pattern, based on samples taken from the top of the ridge (r0-10, r10-20, r20-30, r30-40, and

r40-50)

In order to see the detailed difference of interaction of nitrogen treatments and root depths, the figures were zoomed in with a small Y scales.

In Figure 3.2 (a) there was one extreme peaks in N1 trend line in the soil layer r0-10; and in Figure 3.2 (b) another peak of N1 tend line was in the soil layer s10-20; which was in an irregular pattern, this will be discussed in the discussion section. The N3 trend line reached the peak at 30-40cm from the top of ridge.

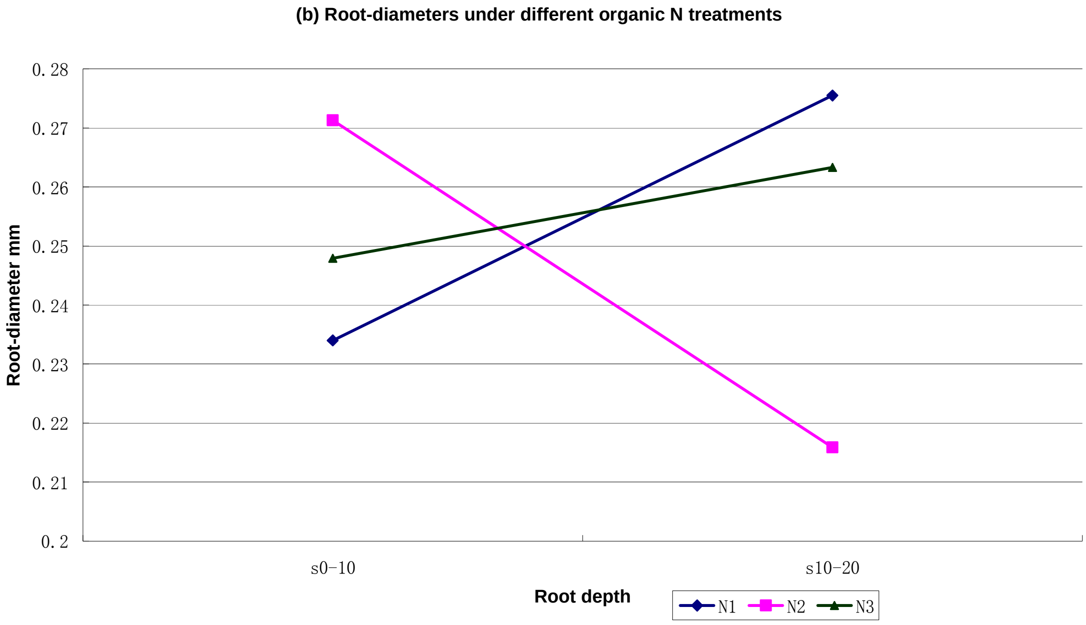


Figure 3.2 (b) Root diameters of potatoes under different interaction of N treatments and root pattern, based on samples taken from the side of the ridge (s0-10 and s10-20).

3.3 Root density

Root density was calculated in percentage of root volume in the volume of the soil sample (equals to volume of the core sampler/auger). Detailed data could be found in Table 3.3. The mean root density was 1.11 ranked from 0.22 to 3.12. The ridge was uniformly occupied by roots. Root density increased along the nitrogen conditions improving: the root density was 0.885 at N1 level; increased to 1.240 at N2, but dropped down a bit to 1.196 under N3 condition. This is the same with Figure 3.1 the root length cope with nitrogen conditions where also showed the peak at r30-40 under N2 condition rather than N3.

Table 3.3 Root density (in percentage) of different depth/position under three levels of N treatment

Depth\N_level	N1	N2	N3
R0-10	0.698	1.241	1.931
R10-20	0.548	1.147	0.928
R20-30	0.872	1.340	0.785
R30-40	1.056	1.713	1.351
R40-50	0.869	1.512	1.175
S0-10	1.193	0.783	1.107
S10-20	0.962	0.940	1.098

For different fraction of root samples, the root density concentrated near the layer r30-40, with a mean value of 1.373.

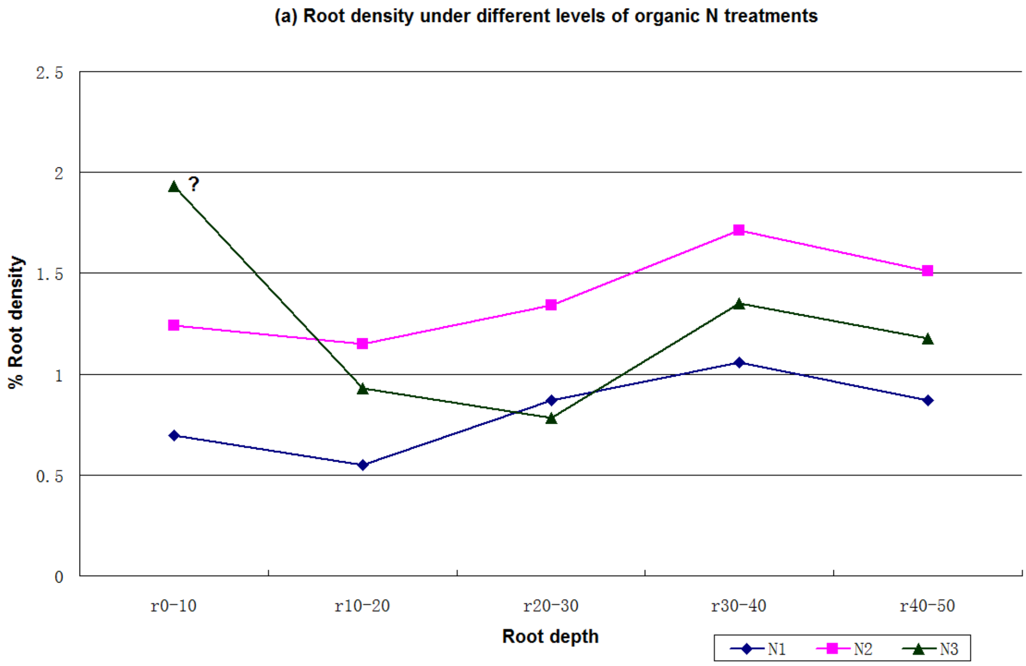


Figure 3.3 (a) Mean root density of different fraction of soil under three nitrogen levels, based on samples taken from the top of the ridge (r0-10, r10-20, r20-30, r30-40, and r40-50).

In Figure 3.3 (a) root density remains highest level under N2 conditions, excepting the extreme peak in layer r0-10 under N3 treatment (where lablled with a question mark). By seeing it dropped suddenly at r10-20, this data is not likely reliable; as N3 trend dropped notably from r0-10 to r10-20, which does not go in the same trend of the other two lines N1 and N2's situations. It will be discussed in the discussion section.

Similarly for three N level treatments, root density reached the peak level in the soil layer r30-40. The root density was enhanced by high nitrogen supplying especially in the soil profile r30-40. r30-40 is the most concentrated phase of root growth, with a lot of branches, just before withered; r0-10 is the currently growing part most developed from the stems, where N can easier up took by plants due to the mobility of N.

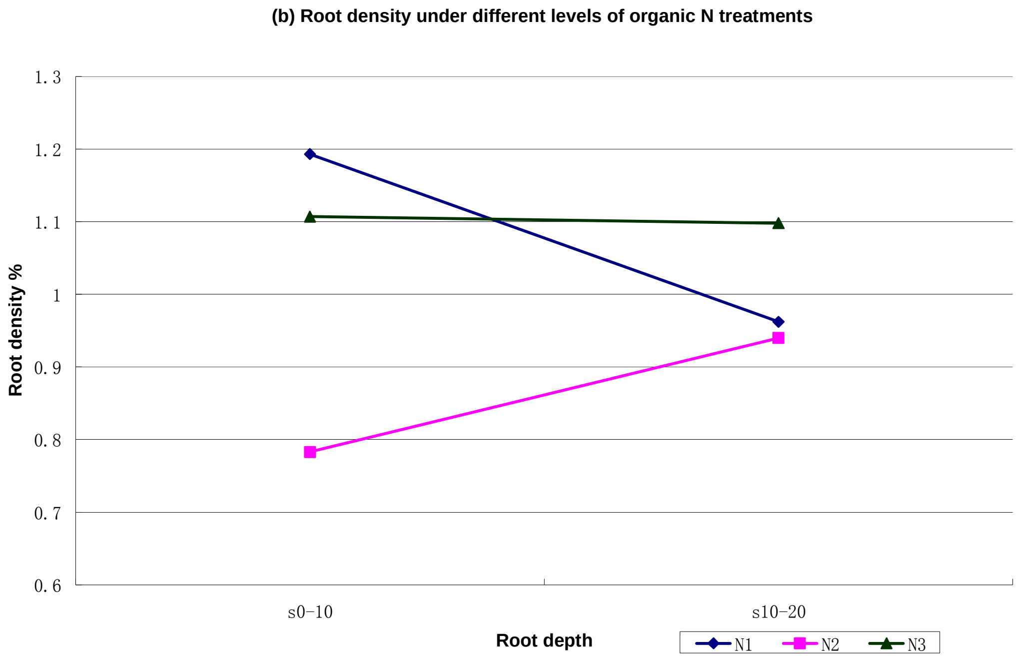


Figure 3.3 (b) Mean root density of different fraction of soil under three nitrogen levels, based on samples taken from the side of the ridge (s0-10 and s10-20)

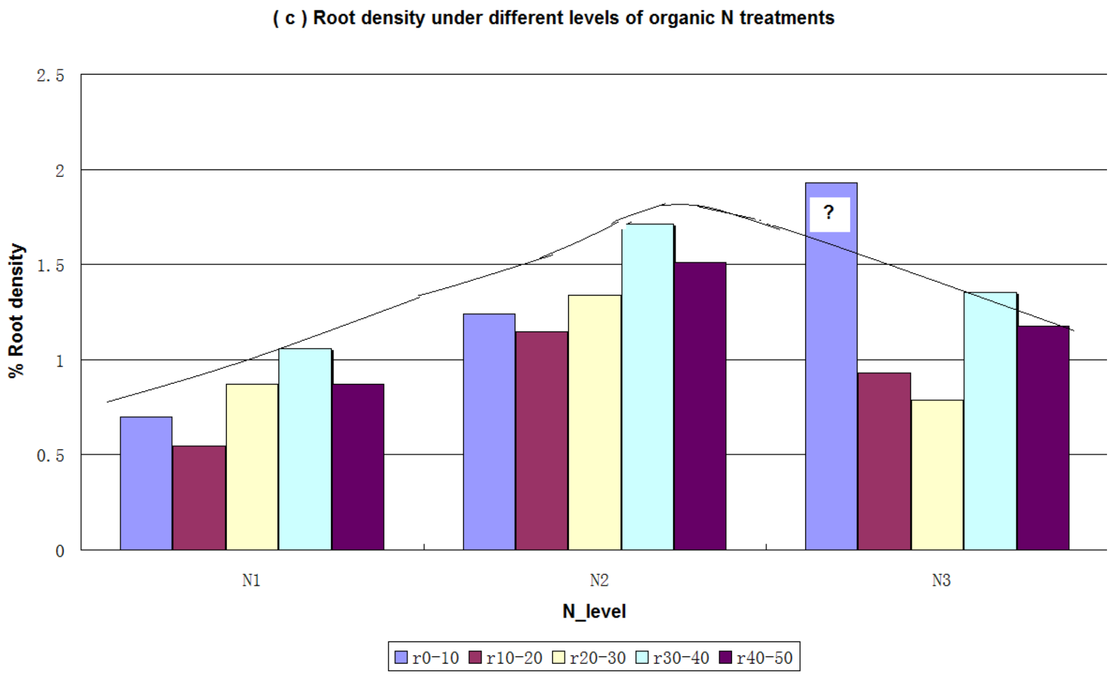


Figure 3.3 (c) Mean root density of different fraction of soil under three nitrogen levels, based on samples taken from the top of the ridge (r0-10, r10-20, r20-30, r30-40, and r40-50).

Figure 3.3 (c) shows that high N treatment always helps supporting more to the newly developed roots (the data of N3 level on soil layer r0-10 is doubted again); and under given conditions of this trail, the mediated level of nitrogen conditions i.e. N2 shows the most significant effects on stimulating root development, by seeing N2 has the highest level of root density at each soil layer. For N3, the graph shows the root formation is not stimulated further by increasing nitrogen supply. The possible explanation will be discussed in the discussion section.

3.4 Tuber yield

As the root sampling was done one week after the second intermediate tuber harvest, the tuber yields of the second intermediate harvest and final harvest of the variety Spirit are shown in table 3.4:

Table 3.4 Tuber yields (ton/ha) of Spirit of second and final harvest from Droevendaal

		Distribution class tubers (mm)				
	N-level	0-28	28-35	35-55	>55	**Total**
Second harvest	N1_90	0.3948	1.22	29.03	10.67	**41.3148**
	N2_150	0.3911	1.44	29.7	9.84	**41.3711**
	N3_300	0.6825	1.83	30.46	10.48	**43.4525**
Final harvest	N1_90	0.157	0.359	17.47	33.56	**51.546**
	N2_150	0.123	0.378	15.84	41.22	**57.561**
	N3_300	0.176	0.341	16.43	38.64	**55.587**

There is no big difference on tuber yields for the second harvest under N1 and N2 conditions (41.31 and 41.37); N3 shows higher yields in second harvest compared with N1 and N2, but lower yields in the final harvest than N2. The final harvest yields was all above 50 ton/ha; with highest yield under N2 condition as 57.56 ton/ha.

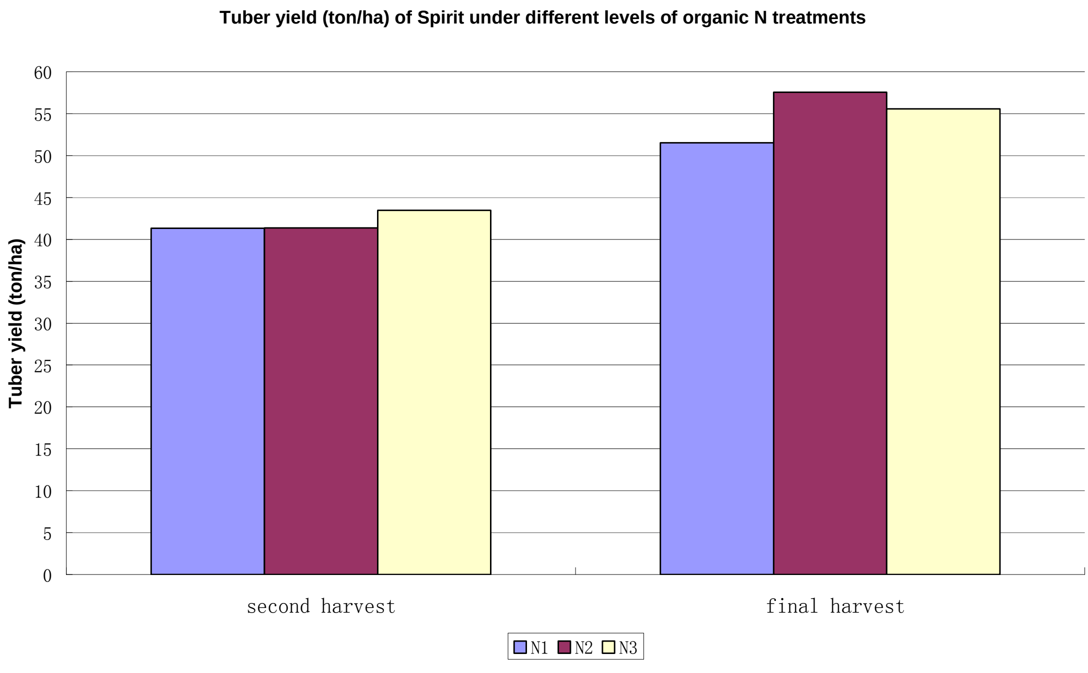


Figure 3.4 Mean tuber yield (ton/ha) of the second and final harvest of the variety Spirit under different levels of organic nitrogen treatments.

4 Discussions and Conclusion

The mean root length in general reaches the maximum value in the soil layer r30-40; there were fewer roots in the side of the ridge, especially in the soil layer s10-20; which indicated that the root system of potato crops are more concentrate and vertically distributed under 20cm of the top of ridge, but with plenty root branches around 0-10cm below the mother tubers planted i.e. the area of soil layer r30-40.

The mean root length of soil layer r0-10 was generally higher than other layers, a proper explanation could be that roots in this layer were developed from the stems of potato plants due to the mother tuber was planted in the area of layer r10-20; While roots in other layers should be developed from the tuber.

The peak in soil layer r30-40 probably is because this area of the root system has most root branches compared to other layers. Therefore, the total length of root in the layer r30-40 was a peak.

Higher nitrogen supply (N2 and N3) helps the initial root development, particularly for root length (in the layer r0-10, and r30-10), this response to nitrogen increasing corresponded with the earlier observations of van Delden et. al, that potato crop is expected to be in general more sensitive to (early) nitrogen limitations than other cereal crops. However, middle nitrogen level (N2) shows the highest mean root density in general over N1 and N3.

Another point should be kept in mind is that the ridges were closed after N-organic fertilizer apply. This might lead the higher amount of N in the upper part of the ridge (r0-10) than other parts of the potatoes field. So the preliminary conclusion needs to be checked again with a control experiment.

In term of root diameters, based on the very similar result under different N level, we may say increased amount of nitrogen applying does not give significant effects on root thickness, at least for potato variety Spirit the root diameter data indicated in this way.

Similarly, on different depths or wideness of the root pattern, hardly statistically significant difference of root diameter was found neither. This means that the root branches of potato crop has quite fine/average thickness through all the root horizons, at least within 50cm of the root system.

There was one extreme peak in soil layer r0-10 of N1 trend line when Figure 3.2 were zoomed in, which were in an irregular pattern. It was likely an unreliable data due to the experiment error; if take the other two trend lines of N2 and N3 as reference, it should located $\pm$ 0.2mm.

The possible explanation for these could be partly due to accumulation of nitrogen fertilizer on the top of the ridge when closing afterwards of N applying. However this was not expected to lead that much shift, there must be other unknown error happened during the root processing procedures where needs a repeating research. Anyway, in every soil layer and under every N condition, the potatoes' root diameter keeps constantly around 0.26mm.

<u>The root density</u> shows highest value under N2 conditions rather N3 at the most concentrated root layer r30-40; consider this phenomenon holistically, it might be explained in the following way: root growth could be enhanced by increasing nitrogen supply at the mediated level (N2); but N3 might created a luxury situation: when potato crops under a luxury nitrogen supply level (N3), perhaps there is no need anymore for the crop to explore or stimulate a big root system to uptake the nitrogen from soil?

The tuber yields of Spirit do not show big variation under three nitrogen levels, but the final yield does tell the same story that the highest yield is under N2 supply. To understand the mechanism behind of this phenomenon, further research needs to be done. There was no serious late blight occurred in 2008 in Droevendaal farm, which resulted a sound yields for Spirit, the final harvest yields was all above 50 ton/ha; with highest yield under N2 condition as 57.56 ton/ha.

To conclude the preliminary result from this pilot study shows that roots keep growing in all directions from the center of the plants, but more vertically than horizontally. The most sleek roots part is located at the soil layer r30-40, probably with lots of branches. This growth is then followed by a wave of decay starting with the oldest roots, near the soil layer r40-50 and bellower.

In order to answer the hypothesis: the more intensity the root system is, the higher nitrogen uptake efficiency the potato cultivar has; need to link the results on other parameters: leaf area, crop branching, and tuber yield from LBI project with root characteristics of Spirit. Aside this, Spirit is a mid-late mature variety, due to no fungicide use to against late blight in organic farming system, the resistance to late blight of Spirit also need to be considered.

Recommendation

Further research might be interesting to investigate what is the difference of potato root system under organic and conventional farming conditions? In terms of root system size and weight, depth of penetration in the soil, distribution within the soil profile, and mycorrhizal emergence around the root system.

If the root characteristics of potatoes crops will be studied under both organic and conventional farming conditions, the following point could be considered for next experimentation: Settle the environmental differences between organic trial and conventional one as little as possible to minimize the error during the experimentation. Droevendaal and Grebbedijk were both located in Wageningen; the soil texture, however, differ from each other. The soil type in organic Droevendaal farm was sandy soil unlike the clay soil in conventional farm Grebbedijk, which could interfere the experiment result by having different capacity of holding and/or transporting nutrients in the soil; root distribution and penetration would be different in different soil texture.

As well the time of root sample taking should be more frequently, for example after each intermediated harvest rather than just once.

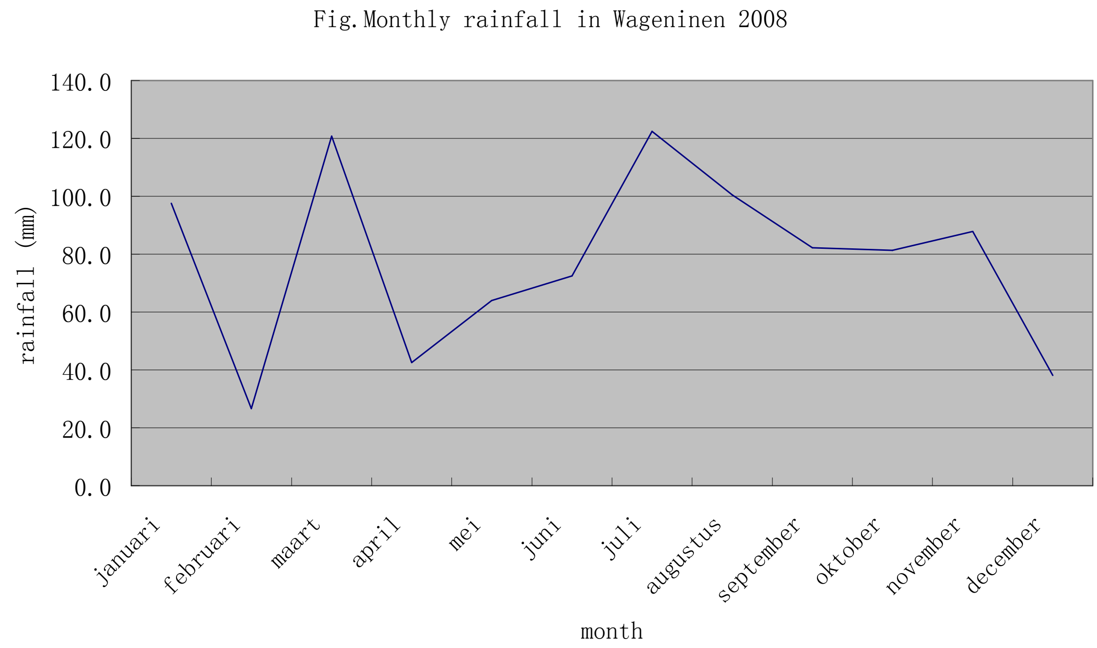
Investigate the mechanism of elongation and thickness of root system of crops, support the balance or combination of fertilizer planning for maximum the capacity of the root system regarding to root length and thickness in different climate conditions or soil structures.

Appendix

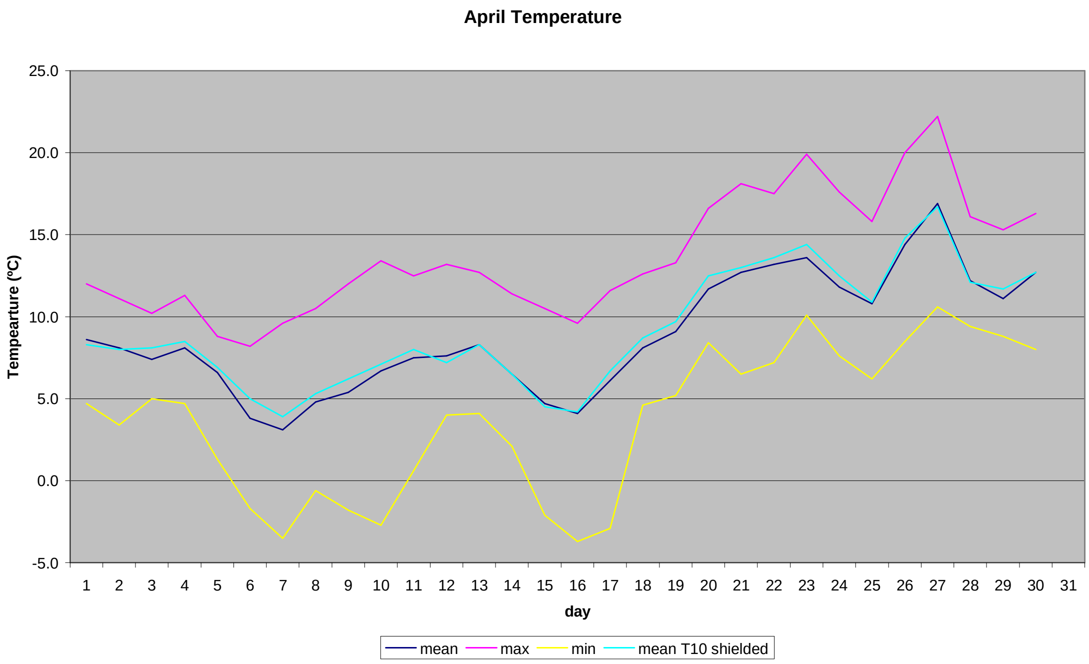
Appendix 1 The field scheme of organic farm Droevendaal (LBI, 2008)
(attached separately in excel file)

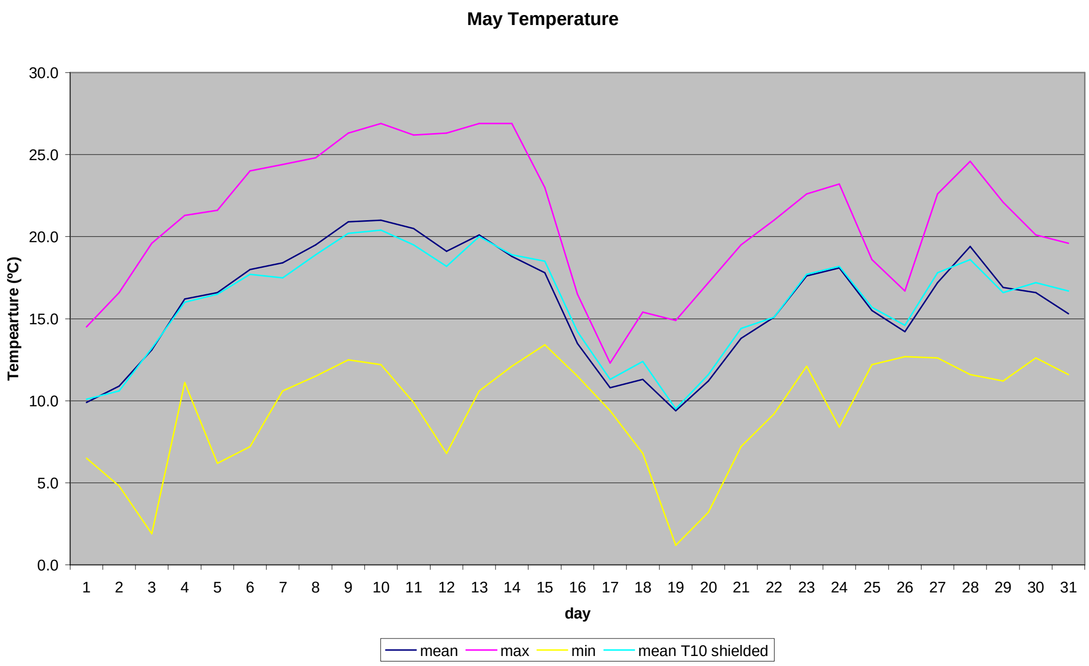
Appendix 2 The statistics data of root study (attached separately in excel file)

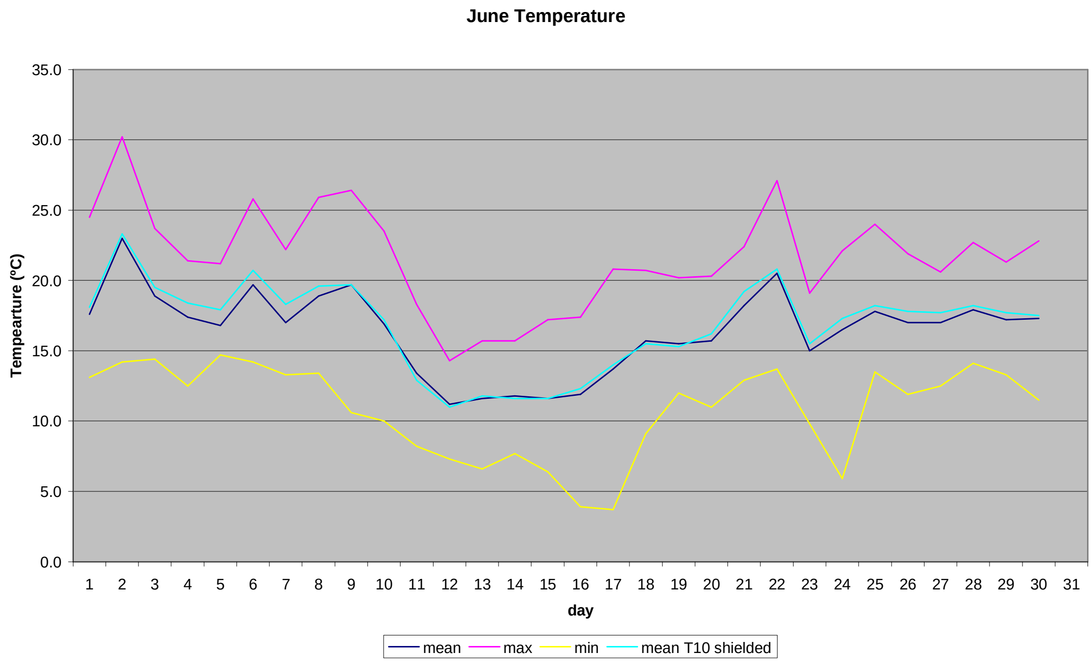
Appendix 3 The annual rainfall in Wageningen (Droevendaal, 2008)

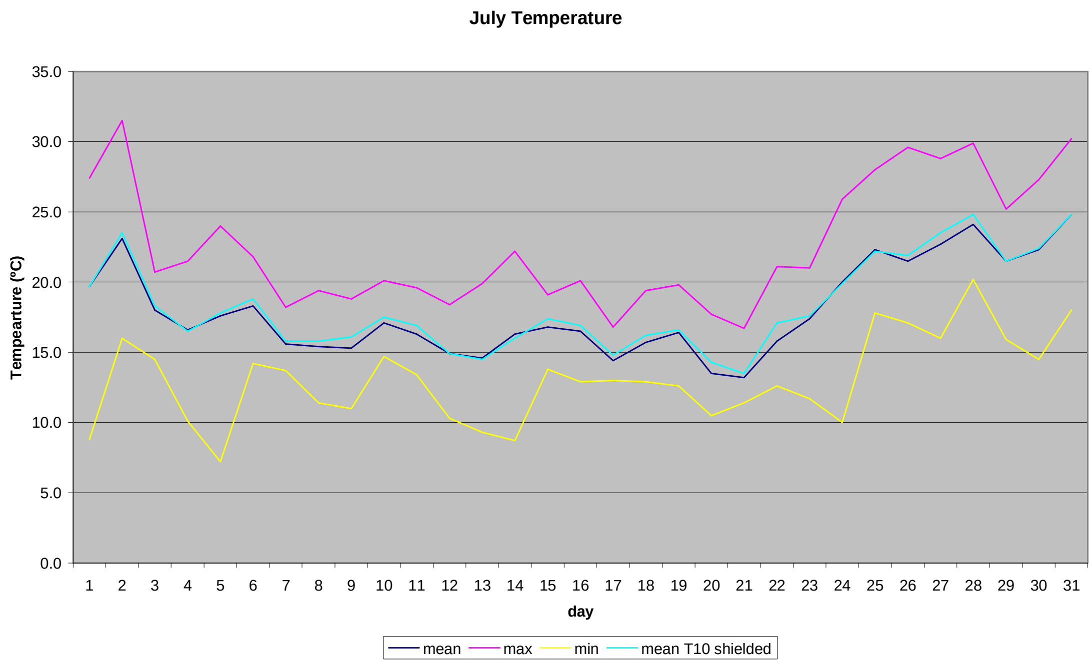


Appendix 4 The monthly temperature in Wageningen (Haarweg weather station, 2008)






June Temperature
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Tempearture (°C)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
day
mean
max
min
mean T10 shielded


July Temperature
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Tempearture (°C)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
day
mean
max
min
mean T10 shielded

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