Test of P2L liquid fertilizer in potato (Solanum tuberosum L.)

Report of two trials in 2018 on clay soils in The Netherlands

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WAGENINGEN UNIVERSITY & RESEARCH

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Photo cover: the trial field at Lelystad in July

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Summary

The Argentinian company F2L Fertilizantes developed the liquid phosphorus fertilizer P2L. The advice agency Agri Advice wants to organize the production, sales and distribution of this fertilizer for F2L Fertilizantes in Europe and requested Wageningen University & Research (WUR), Field Crops to execute trials with this product in The Netherlands. This research started in 2017 in a trail with dwarf French bean. In 2018 P2L was examined in two trials with potato (*Solanum tuberosum* L.).
Agri Advice expects that with P2L much lower phosphate rates will be sufficient in relation to the common phosphate fertilizers that are used in practice, while maintaining crop yield and quality. The idea is that a dose of 100 litres P2L (3% N, 9% P_2O_5 and 1.3% S) will be equal to a dose of 100 kg triple superphosphate (TSP; 45% P_2O_5) or to 100 litres of ammonium polyphosphate (APP; 10% N and 34% P_2O_5 or 11% N and 37% P_2O_5). The research question of Agri Advice is to examine this expectation in field trials under the Dutch growing conditions.

The trials with potato were conducted on a young marine limy sandy clay soil in the middle of the Netherlands (Lelystad) with the variety Bintje and on a young marine limy clay soil in the southwest of The Netherlands (Westmaas) with the variety Innovator. In both trials P2L was compared to triple superphosphate (TSP), which is a common P-fertilizer in The Netherlands. They were compared at the same fertilizer dose: 200 L/ha P2L (20 kg/ha P_2O_5) versus 200 kg/ha TSP (90 kg/ha P_2O_5), as well as at the same P_2O_5-rate: 20 kg/ha P_2O_5 (44 kg/ha TSP). Also, an untreated object was included as a control (no phosphate fertilizer).
The potatoes were planted in springtime and harvested after summer. Crop protection, weed control and fertilization with other nutrients were carried out according to farmers practice. Due to the dry summer of 2018, the crop was irrigated at both research sites.
At both sites the number of plants was counted per plot and crop development was judged starting from June until maturation of the crop. At the end of the growing season the rate of decease of the foliage was monitored.
After harvest the tubers were graded into different tuber size distributions and weighted. Rotten tubers, (partly) green tubers, misshapen tubers and tubers with growth cracks were separated and weighted as total loss. Also, the number of tubers was counted.
Next the under-water-weight of the tubers was determined. This is highly correlated to the dry matter and starch content of the tubers and is a quality parameter for the food processing industry and for the starch industry.
The data were statistically analysed using the software package Genstat.

At Lelystad nearly 100% of the seed potatoes emerged and emergence was no affected by the P-fertilizer treatments. At the site Westmaas, emergence was worse (78% at the control), but it was slightly improved by P-fertilization (81%), without differences between P-fertilizer types and doses.
At both research sites the crop development in summer clearly responded to the P-fertilization, whereby the development of the foliage at 20 kg/ha P_2O_5 with P2L was similar to that of 90 kg/ha P_2O_5 with TSP, whereas the development at 20 kg/ha P_2O_5 with TSP lagged behind.
There were no differences between the treatments with respect to the time and rate of decease of the foliage.

On average for both sites, the gross yield of tubers as well as the marketable yield (net yield >40 mm) were significantly increased by P-fertilization. P2L gave the highest gross yield at both research sites and also the highest marketable yield at the site Westmaas. On average for both sites, P2L also gave the highest marketable yield. However, the yield differences between the P-fertilizer treatments (P-fertilizer types and doses) were statistically not significant.
Due to a relatively high soil stock of phosphorus in the Dutch soils, yield response to P-fertilization is generally small and it’s difficult to distinguish differences between different P-fertilizers against the background of field variation.

Loss of tubers by growth cracks, misshapen tubers and green tubers seemed to be decreased by 90 kg/ha P_2O_5 with TSP and 20 kg/ha P_2O_5 with P2L, but not by 20 kg/ha P_2O_5 with TSP. However, this effect was not significant.
The number of tubers that was harvested, was little increased by P-fertilization (weakly significant). But there were no clear differences between the P-fertilization treatments (type of fertilizer and dose). The under-water-weight of the tubers was not affected by the fertilizer treatments.

Regarding the effect on crop growth in summer (development of the foliage) and yield, 200 L/ha of P2L (20 kg/ha P_2O_5) seemed to perform as well as 200 kg/ha TSP (90 kg/ha P_2O_5). However, more research is needed to confirm this with certainty.

1 Introduction

The Argentinian company F2L Fertilizantes developed the liquid phosphorus P2L. According to the F2L Fertilizantes considerable nutrient savings can be achieved (50% or more) by application of this fertilizer in relation to the current, most common phosphate fertilizers. On its website[1] F2L Fertilizantes cites various results of tests that are performed by the Argentinian Instituto Nacional de Tecnologia Agropecuaria (INTA).
The advice agency Agri Advice wants to organize the production, sales and distribution of these fertilizers for F2L Fertilizantes in Europe. For that, Agri Advice is testing the products in agronomic field trials with different crops in The Netherlands, Belgium, Germany and France. Agri Advice requested Wageningen University & Research (WUR), Field Crops to execute the trials in The Netherlands.

Agri Advice expects that also in Europe with P2L much lower and phosphorus rates will be sufficient in relation to the common phosphate fertilizers that are used in practice, while maintaining crop yield and quality. The idea is that a dose of 100 litres P2L (3% N, 9% P_2O_5 and 1.3% S) will be equal to a dose of 100 kg triple superphosphate (TSP; 45% P_2O_5) or to 100 litres of ammonium polyphosphate (APP; 10% N and 34% P_2O_5 or 11% N and 37% P_2O_5). The research question of Agri Advice is to examine this expectation in field trials under the Dutch growing conditions and to compare P2L to standard fertilizers.

In 2017 WUR Field Crops examined P2L in a trail with dwarf French bean. In 2018 P2L was examined in two trials with potato (*Solanum tuberosum* L.). Potato is the major arable crop in The Netherlands and is grown for the fresh market (ware potato), for processing by the food industry (amongst others French fries and chips) and for starch production and processing (starch potato). Potato has a high phosphate demand.

The implementation and results of the 2018 trials with potato are documented in this report.
The treatments, experimental design and implementation or the trials are described in chapter two. The results are presented in chapter three and they are discussed in chapter four.

[1] http://f2lfertilizantes.com

2 Materials and methods

The trials were conducted on a young marine limy sandy clay soil at the research site Lelystad of WUR in the middle of the Netherlands and on a young marine limy clay soil at the research site Westmaas of WUR in the southwest of The Netherlands. The soil fertility analyses of the trial fields is presented in Annex 1.

2.1 Treatments

At the site Lelystad the variety Bintje was grown and at Westmaas the variety Innovator. Both varieties have a high nitrogen demand.
In both trials P2L was compared to triple superphosphate (TSP), which is a common P-fertilizer in The Netherlands. The composition of both fertilizers is presented in Table 1.

Table 1 *Composition of the fertilizers*

Element	P2L	TSP
N	3%	-
P_2O_5	9%	45%
SO_3	1.3%	4.5%
Density (kg/litre)	1.1	-

On request of Agri Advice the fertilizers were compared at the same fertilizer dose. Besides they were compared at the same P_2O_5-rate. Also, an untreated object was included as a control (no phosphate fertilizer).
The applied rates of the fertilizers are mentioned in table 2. The recommended phosphate rates by the soil laboratory, with regard to the plant available soil stock of phosphorus, amounted 90 kg P_2O_5 per ha at the trial field of Lelystad and 75 kg P_2O_5 per ha at the trial field of Westmaas. However, the experience is that crops respond stronger to P-fertilization at Westmaas than at Lelystad. Therefore, it was decided to apply the same fertilizer amounts at both sites.
TSP was broadcast spread and P2L broadcast sprayed just before planting of the potatoes. They were mixes through the topsoil by the soil preparation. At the planting of the potatoes ridges were formed of the topsoil, whereby the major part of the phosphate fertilizer got into the ridges (close to the seed tubers).
With P2L also some extra nitrogen was applied. This was not compensated for by additional N-rates at the other treatments. Bintje in the trial at Lelystad got a nitrogen amount of 275 kg per ha and Innovator at Westmaas got 256 kg N per ha. Keeping in mind these rates, an effect of 7 kg N per ha more on potato yield or quality was not expected or to be negligible.
There were also slight differences between the treatments for the sulphate supply by the fertilizers, but these were also not compensated for.
The trials were set up as a randomized block design with five replicates. The lay out of the field trials is presented in Annex 2.

Table 2 *Treatments at both research sites*

Code	Fertilizer	Dose	P_2O_5-rate (kg/ha)	N-rate (kg/ha)	SO_3-rate (kg/ha)
A	None	0	0	0	0
B	P2L	200 L/ha	20	7	3
C	TSP	44 kg/ha	20	0	2
D	TSP	200 kg/ha	90	0	9

2.2 Implementation of the trials

	Lelystad	**Westmaas**
Preceding crop in 2017:	onions	winter wheat
Soil mineral N in the soil layer 0-60 cm	35 kg N per ha measured on 12th March	23 kg N per ha measured on 15th March
Variety:	Bintje	Innovator
Destiny:	fresh market or food processing industry	food processing industry
Seed tuber size	35-45 millimeters	50-60 millimeters
Spacing:	75 centimeters row-to-row distance and 33 centimeters plant distance within the rows	75 centimeters row-to-row distance and 34.2 centimeters plant distance within the rows
Soil tillage and planting:	soil preparation with a power harrow and planting on 24th April in one operation	soil preparation with a rotary tiller and planting on 8th May in one operation
Basic fertilization trial field: (broadcast applications)	300 kg per ha Muriate of potash (180 kg K_2O per ha) on 6th February 685 kg per ha calcium ammonium nitrate (185 kg N per ha) on 8th May just before hilling 333 kg per ha CAN (90 kg N per ha) on 11th June before canopy closure	500 kg per ha potassium sulphate (250 kg K_2O per ha) on 25th April 740 kg per ha CAN (200 kg N per ha) on 7th May 350 kg per ha NPK 16-0-30 (56 kg N and 105 kg K_2O per ha) on 25th June before canopy closure
P-fertilization treatments:	on 24th April just before planting	on 7th May
Hilling:	hilling with a special rotary tiller on 9th May	hilling with a special rotary tiller on 14th May
Emergence:	22th May	1th June
Irrigation:	overhead irrigation on: 26th June: 20 millimeters 17th July: 20 millimeters 28th July: 25 millimeters	overhead irrigation on: 12th July: 20 millimeters 25th July: 20 millimeters
Killing of the canopy:	19th September: 3 L/ha Reglone 25th September: 3 L/ha Reglone	4th September: 4 L/ha Reglone
Harvest:	9th October	14th September
Plot size - gross size: - net size (harvested area):	 12 m x 3 m 10 m x 1.5 m	 10 m x 3 m 8 m x 1.5 m

Crop protection and weed control were carried out according to farmers practice. Due to the dry summer of 2018, irrigation of the crop was necessary at both research sites. At Lelystad on 21th August 5 L/ha of Maleïne hydrazide (MH) was sprayed on the crop to suppress secondary tuber growth.
At the end of the growing season the crop was maturing naturally at both sites. When it had almost matured, the last green parts of the foliage were killed chemically.

The weather data of 2018 at the trial site are presented in Annex 3. The growing season of 2018 was characterized by a warm, sunny and very dry summer. Also April and May were warmer than normal. Furthermore April was a rather wet month. At Lelystad the first three weeks of May were rather dry and in the last week of May there was a lot of rainfall. At Westmaas it rained a lot at the end of April and the beginning of May, but the rest of May was rather dry. Due to these wet circumstances, the seed potatoes were planted two weeks later than at Lelystad.

2.3 Observations and measurements

After emergence, the numbers of plants were counted per plot on 24th May at the site Lelystad and at 14th June at the site Westmaas.

The aboveground crop development at both sites was visually judged starting from June until maturation of the crop. It was rated by a report mark (0-10). Also the soil cover by the foliage was estimated before canopy closure. At the end of the growing season the rate of decease of the foliage was monitored by estimation of the percentage of green foliage.

After harvest the tubers of the net plots were graded into different tuber size distributions and weighted. Rotten tubers, (partly) green tubers, misshapen tubers and tubers with growth cracks were separated and weighted as total loss. Also, the number of tubers was counted.
Of samples of five kilograms per plot the under-water-weight was determined. This is highly correlated to the dry matter and starch content of the tubers and is a quality parameter for the food processing industry and for the starch industry.

The data were statistically analysed using the software package Genstat. Analysis of variance (ANOVA) was performed on the data. The next effects were distinguished: the effect of P-fertilization average for all treatments versus no P-fertilization (control) and within P-fertilization the effect of fertilizer type and dosage. Effects are regarded as significant when the probabilities of the F-test (F pr.) is ≤0.05. When F pr. is >0.05 but ≤0.10 the effect can be regarded as weakly significant. When F pr. >0.10 it is not significant (n.s.).
Object means are presented supplied with letters that indicate significant differences according to the Students t-test at probability 0.05. Means without a common letter are significantly different according to the t-test (P<0.05).

3 Results

3.1 Results of the trial at Lelystad

3.1.1 Crop development Lelystad

The number of plants that emerged was not affected by the fertilizer treatments. On average there were 4.0 plants per m^2 (nearly 100% emergence).

On 6th June the foliage had covered the soil for about 50%. The crop development lagged somewhat behind at the treatments A and C compared to B and D. Between B and D there was no visible difference.
On 14th June the situation was somewhat different (Table 3). There was a clear respond of the crop to P-fertilization, but the drop development lagged somewhat behind at P2L-fertilization compared to TSP-fertilization.
On 28th of June the situation had changed again. The crop development was best at P2L-fertilization and at the high TSP-rate. The soil was fully covered by the foliage at all the P-fertilized treatments, whereas the soil cover amounted about 90% at the control (A). The crop started flowering at that moment.
On 18th July the foliage started collapsing. Mid of August it was observed that secondary tuber growth started to occur. The variety Bintje is very susceptible for this. It is caused by high temperatures in the potato ridges in combination with dry soil. As a result, the dormancy of the tubers is broken. When the soils cools down and there is sufficient moisture available again, the tubers are forming secondary tubers. To suppress the secondary tuber growth, Maleïne hydrazide (MH) was sprayed.

Table 3. *Judgement of the crop development[1] and estimation of the soil cover by the foliage*

Code	Fertilizer	P_2O_5-rate (kg/ha)	Crop development 14th June		Soil cover 14th June (%)		Crop development 28th June	
A	None	0	6.8	a	62	a	7.4	a
B	P2L	20	6.9	a	65	a	8.1	b
C	TSP	20	7.1	ab	67	ab	7.6	a
D	TSP	90	7.3	b	70	b	8.0	b
No P-fertilization (A) versus P-fertilization on average (BCD)								
A			6.8	a	62	a	7.4	a
BCD			7.1	b	67	b	7.9	b
F pr. P-fertilization[2]			*0.052*		*0.015*		*0.001*	
F pr. fertilizer type and dose[3]			*0.109*		*0.052*		*0.009*	

[1] A higher rate stands for more vigorous foliage.
[2] F pr. for the effect of P-fertilization on average (BCD) versus no P-fertilization (A)
[3] F pr. for the effect of fertilizer type and dosage (B, C and D mutually)

The foliage remained green for quite a long time. At 3th September it started yellowing. On 10th September 70% of the foliage was still green and the soil cover amounted 65%. On 17th September 50% was still green and the soil cover amounted 33%. Thereafter it was killed chemically. There were no differences between the treatments regarding the onset and rate of decease of the foliage.

3.1.2 Yield and quality at Lelystad

The gross yield of tubers as well as the marketable yield (net yield >40 mm) at Lelystad were somewhat increased by P-fertilization, but the effect was statistically not significant (Table 4). Also, there were nog significant differences between the P-fertilizer treatments (B, C and D).
There was a rather large loss of tubers due secondary tuber growth (Figure 1), unless the MH-application. This loss amounted to 13% of the gross yield. It was not significantly affected by the

fertilizer treatments. Loss of tubers by other causes amounted to 3% of the gross yield and was also not significantly affected by the fertilizer treatments. The other loss was mainly caused by growth cracks and next by misshapen tubers and green tubers. Rotten tubers hardly occurred.
The number of tubers that was harvested, seemed to be somewhat higher at the treatments B and C than at A and D, but the differences were statistically not significant (Table 5).
The under-water-weight of the tubers was not significantly affected by the fertilizer treatments (Table 5), but it was low. It did not achieve the minimum requirement of 360 grams for processing of French fries. Nevertheless, the tubers were suited for ware potatoes.

Table 4. *Yield of tubers at Lelystad (tons per ha)*

Code	Fertilizer	P_2O_5-rate (kg/ha)	Gross yield		Marketable yield		Loss by secundary tuber growth		Other loss of tubers	
A	None	0	74.9	a	56.7	a	9.8	a	2.8	a
B	P2L	20	76.8	a	57.5	a	10.7	a	2.2	a
C	TSP	20	76.7	a	57.8	a	10.0	a	2.6	a
D	TSP	90	75.8	a	57.0	a	10.6	a	2.4	a
No P-fertilization (A) versus P-fertilization on average (BCD)										
A			74.9	a	56.7	a	9.8	a	2.8	a
BCD			76.4	a	57.4	a	10.4	a	2.4	a
F pr. P-fertilization[1]			*n.s.*		*n.s.*		*n.s.*		*n.s.*	
F pr. fertilizer type and dose[2]			*n.s.*		*n.s.*		*n.s.*		*n.s.*	

[1] F pr. for the effect of P-fertilization on average (BCD) versus no P-fertilization (A)
[2] F pr. for the effect of fertilizer type and dosage (B, C and D mutually)

Table 5. *Number of tubers and under-water-weight at Lelystad*

Code	Fertilizer	P_2O_5-rate (kg/ha)	Number of tubers per m^2		Under-water-weight (grams)	
A	None	0	83.3	a	349	a
B	P2L	20	87.7	a	348	a
C	TSP	20	88.6	a	336	a
D	TSP	90	83.1	a	348	a
No P-fertilization (A) versus P-fertilization on average (BCD)						
A			83.3	a	349	a
BCD			86.5	a	344	a
F pr. P-fertilization[1]			*n.s.*		*n.s.*	
F pr. fertilizer type and dose[2]			*n.s.*		*n.s.*	

[1] F pr. for the effect of P-fertilization on average (BCD) versus no P-fertilization (A)
[2] F pr. for the effect of fertilizer type and dosage (B, C and D mutually)

Figure 1. *Secundary tuber growth*

The net yield (gross yield minus loss) in the different grading sizes is presented in Figure 2. The total net yield was not significantly affected by the fertilizer treatments. The grading distribution only slightly differed between the treatments. On average P-fertilization gave a somewhat higher yield in the size 28-40 mm, but there were no significant differences between the P-treatments (B, C or D). Treatment D gave a somewhat coarser grading distribution than B and C (a somewhat lower yield in the size 40-50 mm and somewhat higher in the size 50-70 mm), which must be due to the somewhat lower tuber number.

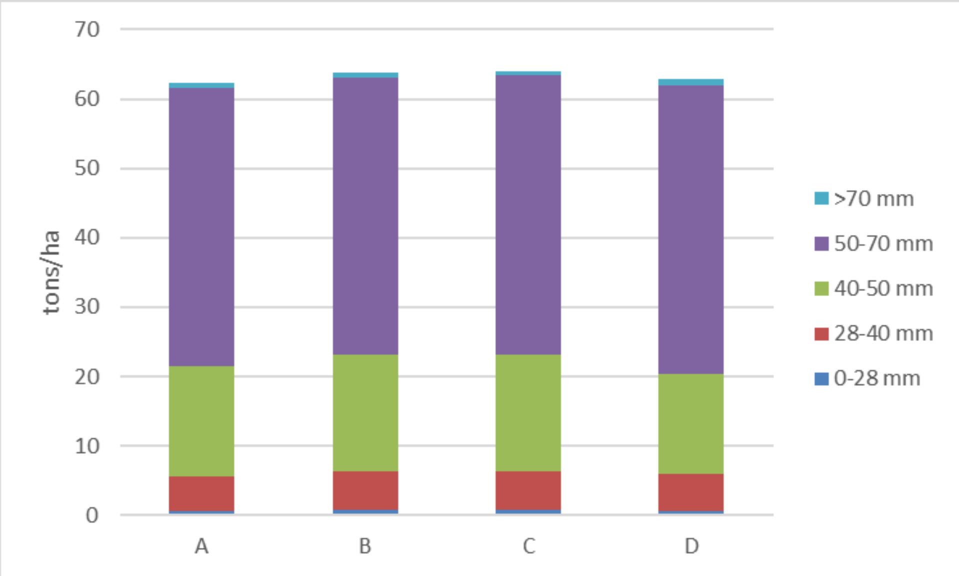

Figure 2a. *Grading of the net yield (tons per ha) at Lelystad (the codes correspond to the treatments mentioned in Table 2)*

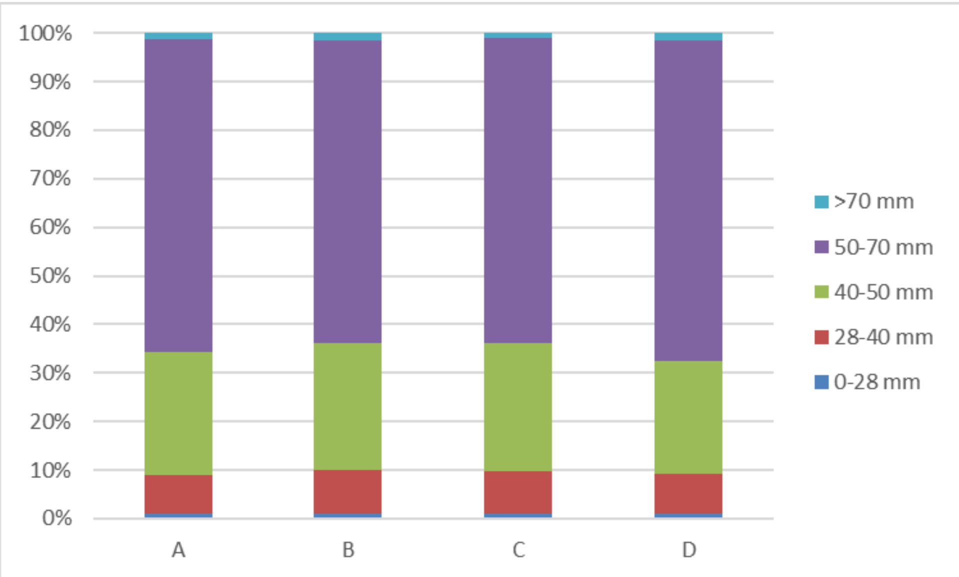

Figure 2b. *Relative grading of the net yield (as a percentage of the total net yield) at Lelystad (the codes correspond to the treatments mentioned in Table 2)*

3.2 Results of the trial at Westmaas

3.2.1 Crop development Westmaas

The number of plants that emerged was significantly improved by the P-fertilization (F pr. = 0.003). There were 3.0 plants per m^2 at treatment A (78% emergence) and 3.2 plants per m^2 (81% emergence) on average at the treatments B, C and D. There were no significant differences between B, C and D.
After emergence (1st June) it was warm and dry. The foliage of the potato crop remained small. A complete soil cover by the foliage was not achieved in summer.
On 15th June the crop development tended to be better after P-fertilization (B, C and D) than at the control (A), but the effect was not significant. On 12th of July the crop development was best at the treatments B and D, whereas is was at treatment C not better than at A.
In August the foliage started yellowing. End of August about 50% of the foliage had yellowed. The differences between the treatments concerning the onset and rate of decease of the foliage and the soil cover by the foliage were small and statistically not significant (Table 7).

Table 6. *Judgement of the crop development[1] and estimation of the soil cover by the foliage*

Code	Fertilizer	P_2O_5-rate (kg/ha)	Crop development 15th June		Soil cover 15th June (%)		Crop development 12th July		Soil cover 12th July (%)	
A	None	0	6.0	a	42	a	5.7	ab	76	ab
B	P2L	20	6.4	a	47	a	5.9	b	80	b
C	TSP	20	6.3	a	45	a	5.3	a	74	a
D	TSP	90	6.5	a	47	a	5.9	b	78	ab
No P-fertilization (A) versus P-fertilization on average (BCD)										
A			6.0	a	42	a	5.7	a	76	a
BCD			6.4	a	46	a	5.7	a	77	a
F pr. P-fertilization[2]			*n.s.*		*n.s.*		*n.s.*		*n.s.*	
F pr. fertilizer type and dose[3]			*n.s.*		*n.s.*		*0.087*		*0.068*	

[1] A higher rate stands for more vigorous foliage.
[2] F pr. for the effect of P-fertilization on average (BCD) versus no P-fertilization (A)
[3] F pr. for the effect of fertilizer type and dosage (B, C and D mutually)

Table 7. *Judgement of the vitality[1] of the foliage and estimation of the soil cover by the foliage*

Code	Fertilizer	P_2O_5-rate (kg/ha)	Vitality 13th August		Soil cover 13th August (%)		Vitality 29th August		Soil cover 29th August (%)	
A	None	0	5.5	a	73	a	4.3	a	58	a
B	P2L	20	5.5	a	75	a	4.5	a	64	a
C	TSP	20	5.5	a	76	a	4.4	a	61	a
D	TSP	90	5.4	a	77	a	4.3	a	60	a
No P-fertilization (A) versus P-fertilization on average (BCD)										
A			5.5	a	73	a	4.3	a	58	a
BCD			5.5	a	76	a	4.4	a	62	a
F pr. P-fertilization[2]			*n.s.*		*n.s.*		*n.s.*		*n.s.*	
F pr. fertilizer type and dose[3]			*n.s.*		*n.s.*		*n.s.*		*n.s.*	

[1] A higher rate stands for more green foliage (less decease): 0 = foliage is completely dead; 5 = foliage has started yellowing; 8 = foliage is fully green
[2] F pr. for the effect of P-fertilization o average (BCD) versus no P-fertilization (A)
[3] F pr. for the effect of fertilizer type and dosage (B, C and D mutually)

3.2.2 Yield and quality at Westmaas

The gross yield of tubers as well as the marketable yield (net yield >40 mm) at Westmaas were significantly increased by P-fertilization (Table 8). The differences between the P-fertilizer treatments (B, C and D) were statistically not significant, although P2L gave the highest yield.
Loss of tubers seemed to be somewhat lower at the treatments B and D than at A and D, but the differences were statistically not significant. The loss was caused by misshapen tubers, tubers with growth cracks and green tubers. Rotten tubers did not occur. There was hardly loss of tubers due secondary tuber growth.
The number of tubers seemed to be somewhat increased by P-fertilization, but the effect was not significant. Also the differences between the P-fertilization treatments (B, C and D) were not significant (Table 8).
The under-water-weight of the tubers was not significantly affected by the fertilizer treatments (Table 8) and amounted 419 grams on average, which is good for processing of French fries. For this purpose 380 to 420 grams is desired and the minimum requirement is 360 grams.

Table 8. *Yield, number of tubers and under-water-weight at Westmaas*

Code	Fertilizer	P_2O_5-rate (kg/ha)	Gross yield (tons/ha)		Marketable yield (tons/ha)		Loss of tubers (tons/ha)		Number of tubers per m²		Under-water-weight (grams)	
A	None	0	42.1	a	35.3	a	4.6	a	32.9	a	419	a
B	P2L	20	47.1	b	41.3	b	4.0	a	34.9	a	421	a
C	TSP	20	44.6	ab	37.7	ab	4.8	a	34.8	a	423	a
D	TSP	90	44.7	ab	39.0	ab	3.7	a	34.4	a	413	a
No P-fertilization (A) versus P-fertilization on average (BCD)												
A			42.1	a	35.3	a	4.6	a	32.9	a	419	a
BCD			45.5	b	39.3	b	4.2	a	34.7	a	419	a
F pr. P-fertilization[1]			*0.050*		*0.045*		*n.s.*		*n.s.*		*n.s.*	
F pr. fertilizer type and dose[2]			*n.s.*		*n.s.*		*n.s.*		*n.s.*		*n.s.*	

[1] F pr. for the effect of P-fertilization on average (BCD) versus no P-fertilization (A)
[2] F pr. for the effect of fertilizer type and dosage (B, C and D mutually)

The net yield (gross yield minus loss) in the different grading sizes is presented in Figure 3. The total net yield was increased by P-fertilization, which was reflected in a higher yield in the size 50-70 mm. For the rest, the grading distribution only slightly differed between the treatments and there were no significant differences between the P-treatments (B, C or D).

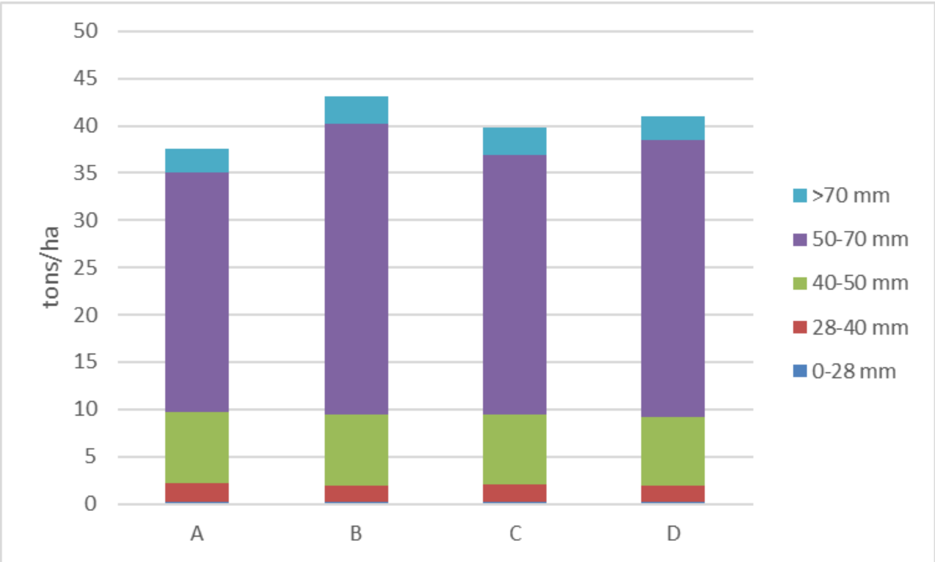

Figure 3a. *Grading of the net yield (tons per ha) at Westmaas*
(the codes correspond to the treatments mentioned in Table 2)

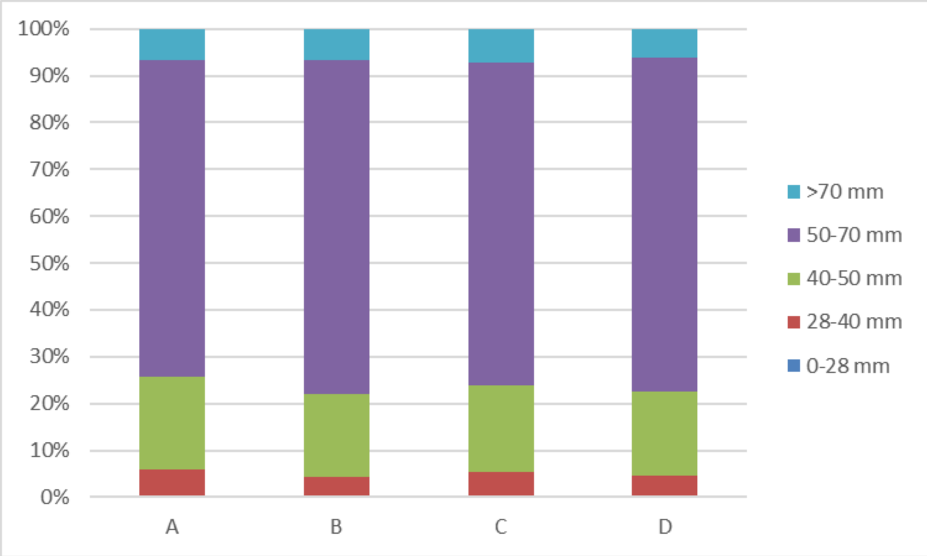

Figure 3b. *Relative grading of the net yield (as a percentage of the total net yield) at Westmaas (the codes correspond to the treatments mentioned in Table 2)*

3.3 Analyses of both trials together

As the treatments at both research sites were similar, a statistical analyses has been performed on both trials together. Beside the effects of P-fertilization and the effect of fertilizer type and dose, the interaction effect with research site is judged. A significant interaction effects means that the crop response to the treatments differs per site. When there is nog significant interaction effect, the response at both sites may be regarded as similar.
Average over both sites, the gross yield of tubers as well as the marketable yield (net yield >40 mm) were significantly increased by P-fertilization (Table 9). The differences between the P-fertilizer treatments (B, C and D) were statistically not significant, although P2L gave the highest yield.
Loss of tubers seemed to be somewhat lower at the treatments B and D than at A and C, but the differences were statistically not significant.
The number of tubers that was harvested, was somewhat increased by P-fertilization. The effect was weakly significant. The differences between the P-fertilization treatments (B, C and D) were not significant.
The under-water-weight of the tubers was not significantly affected by the fertilizer treatments.

Table 9. *Yield, number of tubers and under-water-weight of the two research sites on average*

Code	**Fertilizer**	**P_2O_5-rate (kg/ha)**	**Gross yield (tons/ha)**		**Marketable yield (tons/ha)**		**Loss of tubers[5] (tons/ha)**		**Number of tubers per m^2**		**Under-water-weight (grams)**	
A	None	0	58.5	a	46.0	a	3.7	a	58.1	a	384	a
B	P2L	20	62.0	b	49.4	b	3.1	a	61.3	ab	384	a
C	TSP	20	60.6	ab	47.7	ab	3.7	a	61.7	b	380	a
D	TSP	90	60.2	ab	48.0	ab	3.0	a	58.8	ab	380	a
No P-fertilization (A) versus P-fertilization on average (BCD)												
A			58.5	a	46.0	a	3.7	a	58.1	a	384	a
BCD			60.9	b	48.4	b	3.3	a	60.6	a	381	a
F pr. P-fertilization[1]			*0.041*		*0.044*		*n.s.*		*0.068*		*n.s.*	
F pr. fertilizer type and dose[2]			*n.s.*		*n.s.*		*n.s.*		*n.s.*		*n.s.*	
F pr. P-fertilization x site[3]			*n.s.*		*n.s.*		*n.s.*		*n.s.*		*n.s.*	
F pr. type and dose x site[4]			*n.s.*		*n.s.*		*n.s.*		*n.s.*		*n.s.*	

[1] F pr. for the effect of P-fertilization on average (BCD) versus no P-fertilization (A)
[2] F pr. for the effect of fertilizer type and dosage (B, C and D mutually)
[3] F pr. for the interaction effect between P-fertilization and trial site
[4] F pr. for the interaction effect between fertilizer type and dosage (B, C and D mutually) and trial site
[5] Excluding loss due to secondary tuber growth at Lelystad

4 Discussion and conclusions

The P-fertilizer treatments did not have an effect on the emergence of the potatoes at the site Lelystad. The emergence amounted nearly 100% at all treatments. At the site Westmaas, emergence was worse and it was slightly improved by P-fertilization (without differences between the P-fertilizer types and doses).

At both research sites the crop development in summer clearly responded to the P-fertilization, whereby the development of the foliage at 20 kg/ha P_2O_5 with P2L was similar to that of 90 kg/ha P_2O_5 with TSP, whereas the development at 20 kg/ha P_2O_5 with TSP lagged behind.
There were no differences between the treatments with respect to the time and rate of decease of the foliage.

The gross yield of tubers as well as the marketable yield (net yield >40 mm) were significantly increased by P-fertilization. P2L gave the highest gross yield at both research sites and also the highest marketable yield at the site Westmaas. On average for both sites, P2L also gave the highest marketable yield. However, the yield differences between the P-fertilizer treatments (P-fertilizer types and doses) were statistically not significant.
The soil stock of phosphorus is high in the Dutch soils, compared to foreign countries, to insure a good crop growth and yield. As a consequence, the crops mostly respond little or sometimes even not to P-fertilization. Yield increases are generally small and it's difficult to distinguish differences between different P-fertilizers against the background of field variation. To get sufficient evidence for a significant yield difference, more trials are needed and analyzed together.

The yield response to P-fertilization was more pronounced at the site Westmaas than at Lelystad. This could be due to the growth circumstances. But also the variety and the length of the growing period may have played a role. Innovator is a rather early maturing variety with a relatively weak root system. Weak rooting crops respond more strongly to phosphate than strong rooting crops. It also seemed to suffer from the heat in summertime and the drought (despite sprinkling) and the yield was rather low. At Lelystad on the other hand, the variety Bintje grew very well and the (gross) yield was high. Growth circumstances looked more favourable at Lelystad than at Westmaas. The crop produced many foliage that remained for a long time green. The crop at Lelystad emerged nine days earlier and deceased about three weeks later than at Westmaas, which means that the growing period was ample a month longer. A longer growing period can result in a weaker yield response to phosphate than a shorter growing period. Phosphate stimulates crop growth in the beginning of the growing season, but the effect may diminish later on in the growing season, especially when the growing season is long.

Loss of tubers by growth cracks, misshapen tubers and green tubers seemed to be decreased by 90 kg/ha P_2O_5 with TSP and 20 kg/ha P_2O_5 with P2L, but not by 20 kg/ha P_2O_5 with TSP. However, this effect was not significant.

The number of tubers that was harvested, was little increased by P-fertilization (weakly significant). But there were no clear differences between the P-fertilization treatments (type of fertilizer and dose).

The under-water-weight of the tubers was not affected by the fertilizer treatments.

Conclusion
Regarding the effect on crop growth in summer (development of the foliage) and yield, 200 L/ha of P2L (20 kg/ha P_2O_5) seemed to perform as well as 200 kg/ha TSP (90 kg/ha P_2O_5). However, more research is needed to confirm this with certainty.

Annex 1 Soil fertility of the trial fields

Research site Lelystad

eurofins | Agro

Fertilization Manager
Arable land
perceel G 88-2

Your client number is: 8127565

Wageningen Plant Research
Postbus 430
8200 AK LELYSTAD

Eurofins Agro
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NL - 6700 AD Wageningen
The Netherlands
T sampling: Bram Jansen: 0652002137
T customerservice: +31 (0)88 876 1010
E customerservice@eurofins-agro.com
I www.eurofins-agro.com

Copy

Analysis	Investigation/ordernr:	Date sampling:	Date report:	Grant issued by:
	768628/004308584	19-02-2018	09-01-2019	Eurofins Agro, Kortingsregeling Postbus 170, 6700 AD WAGENINGEN

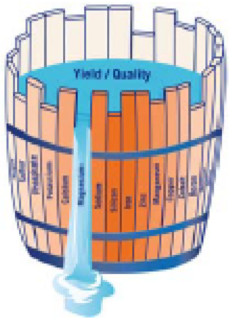
Results		Unit	Result	Target value
Chemical	Total N stock	kg N/ha	2590	3290 - 5180
	C/N ratio		12	13 - 17
	N-supplying capacity	kg N/ha	45	95 - 145
	S-plant available	kg S/ha	10	20 - 30
	Total S stock	kg S/ha	1680	785 - 1840
	C/S ratio		19	50 - 75
	S-supplying capacity	kg S/ha	39	20 - 30
	P-plant available	kg P/ha	3,5	5,8 - 9,6
	P-soil stock	kg P/ha	600	375 - 655
	K-plant available	kg K/ha	270	225 - 350
	K-soil stock	kg K/ha	515	330 - 475
	Ca-plant available	kg Ca/ha	540	230 - 540
	Ca-soil stock	kg Ca/ha	6215	4995 - 7495
	Mg-plant available	kg Mg/ha	105	160 - 270
	Mg-soil stock	kg Mg/ha	190	215 - 500
	Na-plant available	kg Na/ha	25	110 - 160
	Na-soil stock	kg Na/ha	50	75 - 110
	Si-plant available	g Si/ha	115420	19180 - 83130
	Fe-plant available	g Fe/ha	< 6430	7990 - 14390
	Zn-plant available	g Zn/ha	< 320	1600 - 2400
	Mn-plant available	g Mn/ha	< 800	3200 - 4160
	Cu-plant available	g Cu/ha	75	130 - 210
	Co-plant available	g Co/ha	< 10	15 - 25
	B-plant available	g B/ha	435	320 - 480
	Mo-plant available	g Mo/ha	< 10	320 - 15990
	Se-plant available	g Se/ha	10	11 - 14
Physical	Acidity (pH)		7,5	> 6,7
	C-organic	%	1,0	
	Organic matter	%	1,4	
	C/OS-ratio		0,71	0,45 - 0,55
	Carbonate lime	%	4,9	2,0 - 3,0
	Clay (<2 µm)	%	16	
	Silt (2-50 µm)	%	35	
	Sand (>50 µm)	%	43	
	<16 µm	%	27	
	Clay-humus (CEC)	mmol+/kg	107	> 99
	CEC-saturation	%	100	> 95
	Ca-saturation	%	91	80 - 90
	Mg-saturation	%	4,6	6,0 - 10
	K-saturation	%	3,8	2,0 - 5,0
	Na-saturation	%	0,7	1,0 - 1,5
	H-saturation	%	< 0,1	< 1,0
	Al-saturation	%	< 0,1	< 1,0

low | rath.low | good | rath.high | high

perceel G 88-2

Results		Unit	Result	Target value	low	rath.low	good	very good
	Soil crumbling	score	7,7	6,0 - 8,0				
	Soil slaking	score	3,8	6,0 - 8,0				
	Risk on wind erosion	score	8,6	6,0 - 8,0				

		Unit	Result	Target value	low	rath.low	good	rath.high	high
Biological	Moisture retention cap.	mm	57						
	Microbial activity	mg N/kg	18	60 - 80					



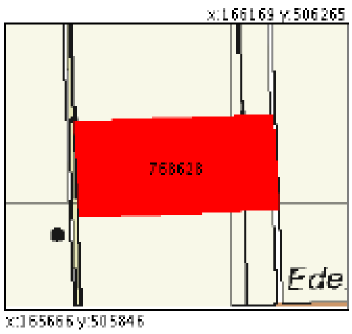
Essential nutrients
Each crop requires nutrients. The essential nutrients that a crop needs most are nitrogen (N), sulphur (S), phosphate (P), potassium (K), calcium (Ca) and magnesium (Mg). The other essential nutrients are the micro nutrients iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), boron (B), molybdenum (Mo) and chloride (Cl). A crop require relatively low concentrations of these micro nutrients, however a deficit can cause loss of yield and/or quality in every crop.

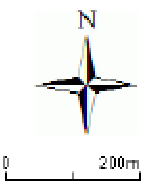
A number of other nutrients (sodium, silicon, cobalt, selenium) can also be important to - amongst other factors - the yield, quality, resilience, sturdiness, fertility, palatability and (animal) health.

Elements can also compete with each other. For example, if the Mg status is "good" but the K status is "high", then an Mg deficiency can still occur. Therefore, the recommended dosages take these interactions into consideration.

Fertilisation recommendations and legislation
The fertilisation recommendations aim to achieve an agronomical optimum yield and crop quality. The recommendations do not take any legal restrictions into consideration.

Oppervlakte (ha): 4,2



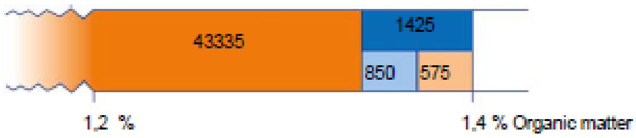


RD - projectie

perceel G 88-2

Organic matter

Figure: Organic matter balance



Yearly breakdown rate (percentage) of the total organic matter content (%): 3,2

- Stock of organic matter which will remain after 1 year in the sampled layer if no (effective) organic matter is supplied.
- Total required supply of effective organic matter as a result of the degradation of the organic matter.
- Supply through crop residues (average within provided rotation scheme or crops).
- Remaining to be supplied through e.g. animal manure, green manures and/or compost.

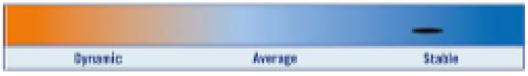
Crop (residue)	Input of effective organic matter
Ware potatoes	875
Sugarbeet	1275
Preserved peas	170
Winter wheat	1640
Spring-sown onions	300

Average input/year	850

In case of cereals we assume removal of straw.

For increasing the soil organic matter content by 0.1%: 3195 kg effective organic matter per hectare is needed.

Figure: Quality of the organic matter

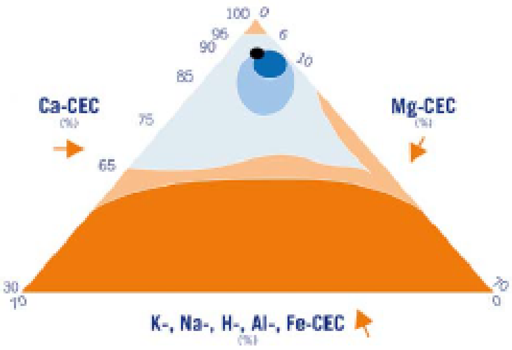


Organic matter consists primarily of C, N, P, S. If the organic matter contains relatively high amounts of N and/or S, this makes it attractive to soil organisms. Soil organisms happily eat this organic matter. N and S are released in the process and the amount of organic matter decreases slightly (dynamic organic matter). Organic matter can also contain a lot of C. This is generally less attractive to soil organisms (bacteria). As a result, the organic matter is not consumed as quickly by the soil organisms; making the organic matter more stable. Stable organic matter contributes - among other factors - to the workability of the soil and the looseness. Dynamic organic matter contributes primarily to the release of N and S and is therefore a source of these nutrients for the crop. The quality of the organic matter can be changed (gradually) by paying attention to the properties of soil improvers such as animal manure, compost and crop residues.

Physical

The assessment of soil structure is based on the Ca-CEC, K-CEC, and Mg-CEC ratio. Actual soil structure is - of course - not merely depending on ratio, but also on weather conditions, moisture condition of the soil, and the weight of the machinery.

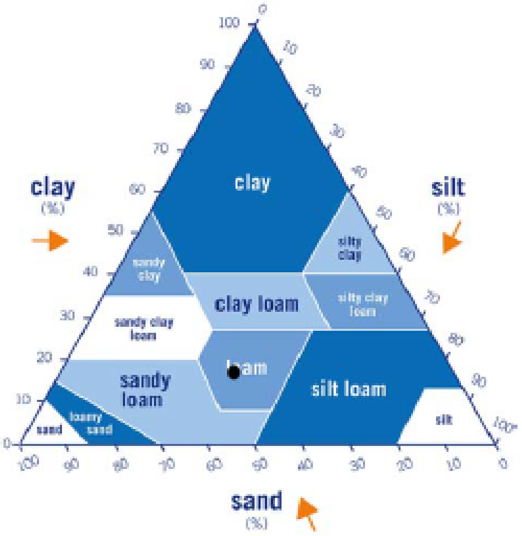
Figure: Structure triangle



- optimal structure
- good structure
- moderate structure
- very moderate structure
- poor structure
- current structure

perceel G 88-2

Physical **Figure: Texture triangle**

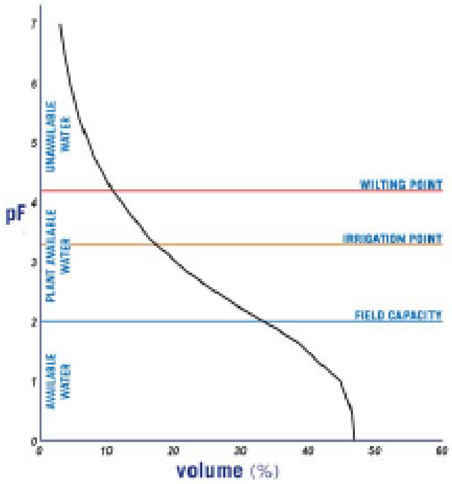


Besides clay, the silt and sand fractions are presented as well. Clay is smaller than 2 micrometer (µm), silt particles are 2-50 µm and sand particles are larger than 50 µm. The relative distribution of soil particles is used to estimate the risk of slaking. Slaking causes the soil pores to be clogged with smaller particles and degrades soil structure. The risk of slaking is greatest at 10-20% clay.

Median of the granular sand fraction (M50) = 87 µm.
M50 is a measure of the coarseness of sand. We use this when determining the water-binding capacity of the soil (pF/water-retaining ability).

Soil crumbling score is: good, however the evaluation of soil crumbling status is also depending on crop type.
There is a chance of soil slaking. It is adviseable to maintain SOM level, or even to improve SOM level, since organic matter realizes binding between soil particles.

Figure: Water retention curve



The amount of plant available water in the sampled layer is 57 mm. This is the maximum amount you should irrigate. All excess irrigation will drain off the parcel or will sink to deeper layers.

Crops have difficulties to obtain water when the actual moisture level is below pF 3,3. When you are able to measure the moisture level, start with irrigation if the moisture content of the parcel is at 17,4 % and irrigate 41 mm.

The actual moisture level can be measured by using a soil moisture sensor, or collect soil from ten spots in the parcel. Measure the weight of the moist soil and the weight after 24 h drying. The difference between moist and dry soil is an indication of the moisture level of the parcel.

Contact & info

Soil layer:	0 - 25 cm
Sample was taken by:	Eurofins Agro, Luuk Vereecken
Contact sample taking:	Bram Jansen: 0652002137
Bemonsteringsmethode:	volgens Eurofins Agro standaard MIN 1030 Q
Specification sampling:	Stratified

Research site Westmaas

eurofins | Agro

Fertilization Manager
Arable land
ZW 5345 Bem. + Pootafst.

Your client number is: 2772655

Wageningen Plant Research
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T sampling: Nico Barendregt: 0652002103
T customerservice: +31 (0)88 876 1010
E customerservice@eurofins-agro.com
I www.eurofins-agro.com

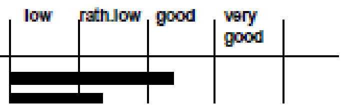
Copy

Analysis	Investigation/ordernr:	Date sampling:	Date report:	Grant issued by:
	796324/004363859	03-05-2018	09-01-2019	Eurofins Agro, Kortingsregeling Postbus 170, 6700 AD WAGENINGEN

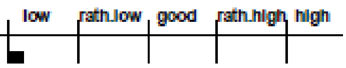
ZW 5345 Bemesting + Pootafstand

Results		Unit	Result	Target value
Chemical	Total N stock	kg N/ha	4290	3200 - 5040
	C/N ratio		9	13 - 17
	N-supplying capacity	kg N/ha	85	95 - 145
	S-plant available	kg S/ha	64	20 - 30
	Total S stock	kg S/ha	560	760 - 1790
	C/S ratio		71	50 - 75
	S-supplying capacity	kg S/ha	8	20 - 30
	P-plant available	kg P/ha	2,8	5,6 - 9,3
	P-soil stock	kg P/ha	720	365 - 640
	K-plant available	kg K/ha	285	220 - 340
	K-soil stock	kg K/ha	560	460 - 620
	Ca-plant available	kg Ca/ha	475	225 - 525
	Ca-soil stock	kg Ca/ha	10595	8545 - 12815
	Mg-plant available	kg Mg/ha	230	155 - 265
	Mg-soil stock	kg Mg/ha	300	340 - 650
	Na-plant available	kg Na/ha	35	110 - 155
	Na-soil stock	kg Na/ha	35	70 - 105
Physical	Acidity (pH)		7,3	> 6,6
	C-organic	%	1,3	
	Organic matter	%	2,3	
	C/OS-ratio		0,57	0,45 - 0,55
	Carbonate lime	%	7,4	2,0 - 3,0
	Clay (<2 µm)	%	21	
	Silt (2-50 µm)	%	33	
	Sand (>50 µm)	%	36	
	<16 µm	%	31	
	Clay-humus (CEC)	mmol+/kg	183	> 131
	CEC-saturation	%	100	> 95
	Ca-saturation	%	93	80 - 90
	Mg-saturation	%	4,4	6,0 - 10
	K-saturation	%	2,5	2,0 - 5,0
	Na-saturation	%	0,3	1,0 - 1,5
	H-saturation	%	< 0,1	< 1,0
	Al-saturation	%	< 0,1	< 1,0

	Unit	Result	Target value
Soil crumbling	score	6,8	6,0 - 8,0
Soil slaking	score	4,7	6,0 - 8,0

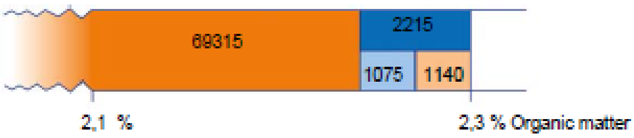


Results		Unit	Result	Target value
Biological	Microbial activity	mg N/kg	24	60 - 80



Organic matter

Figure: Organic matter balance



Yearly breakdown rate (percentage) of the total organic matter content (%): 3,1

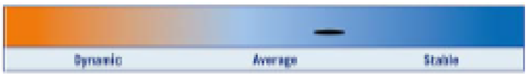
- Stock of organic matter which will remain after 1 year in the sampled layer if no (effective) organic matter is supplied.
- Total required supply of effective organic matter as a result of the degradation of the organic matter.
- Supply through crop residues (average within provided rotation scheme or crops).
- Remaining to be supplied through e.g. animal manure, green manures and/or compost.

Crop (residue)	Input of effective organic matter
Ware potatoes	875
Sugarbeet	1275

Average input/year	1075

For increasing the soil organic matter content by 0.1%: 3110 kg effective organic matter per hectare is needed.

Figure: Quality of the organic matter



Organic matter consists primarily of C, N, P, S. If the organic matter contains relatively high amounts of N and/or S, this makes it attractive to soil organisms. Soil organisms happily eat this organic matter. N and S are released in the process and the amount of organic matter decreases slightly (dynamic organic matter). Organic matter can also contain a lot of C. This is generally less attractive to soil organisms (bacteria). As a result, the organic matter is not consumed as quickly by the soil organisms; making the organic matter more stable. Stable organic matter contributes - among other factors - to the workability of the soil and the looseness. Dynamic organic matter contributes primarily to the release of N and S and is therefore a source of these nutrients for the crop. The quality of the organic matter can be changed (gradually) by paying attention to the properties of soil improvers such as animal manure, compost and crop residues.

ZW 5345 Bem. + Pootafst.

Physical

The assessment of soil structure is based on the Ca-CEC, K-CEC, and Mg-CEC ratio. Actual soil structure is - of course - not merely depending on ratio, but also on weather conditions, moisture condition of the soil, and the weight of the machinery.

Figure: Structure triangle

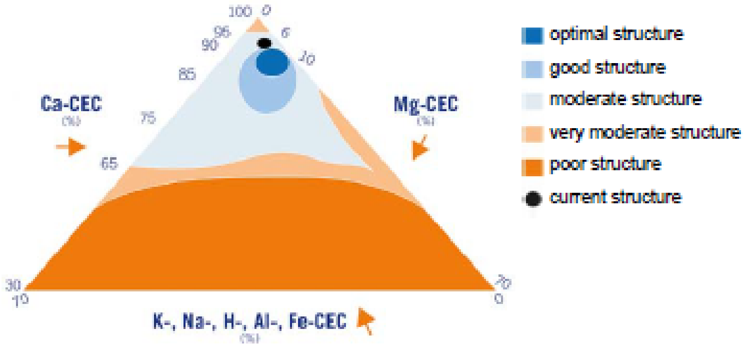
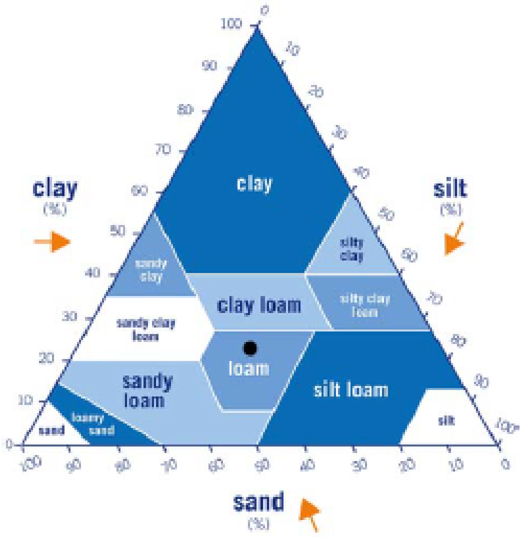


Figure: Texture triangle



Besides clay, the silt and sand fractions are presented as well. Clay is smaller than 2 micrometer (µm), silt particles are 2-50 µm and sand particles are larger than 50 µm. The relative distribution of soil particles is used to estimate the risk of slaking. Slaking causes the soil pores to be clogged with smaller particles and degrades soil structure. The risk of slaking is greatest at 10-20% clay.

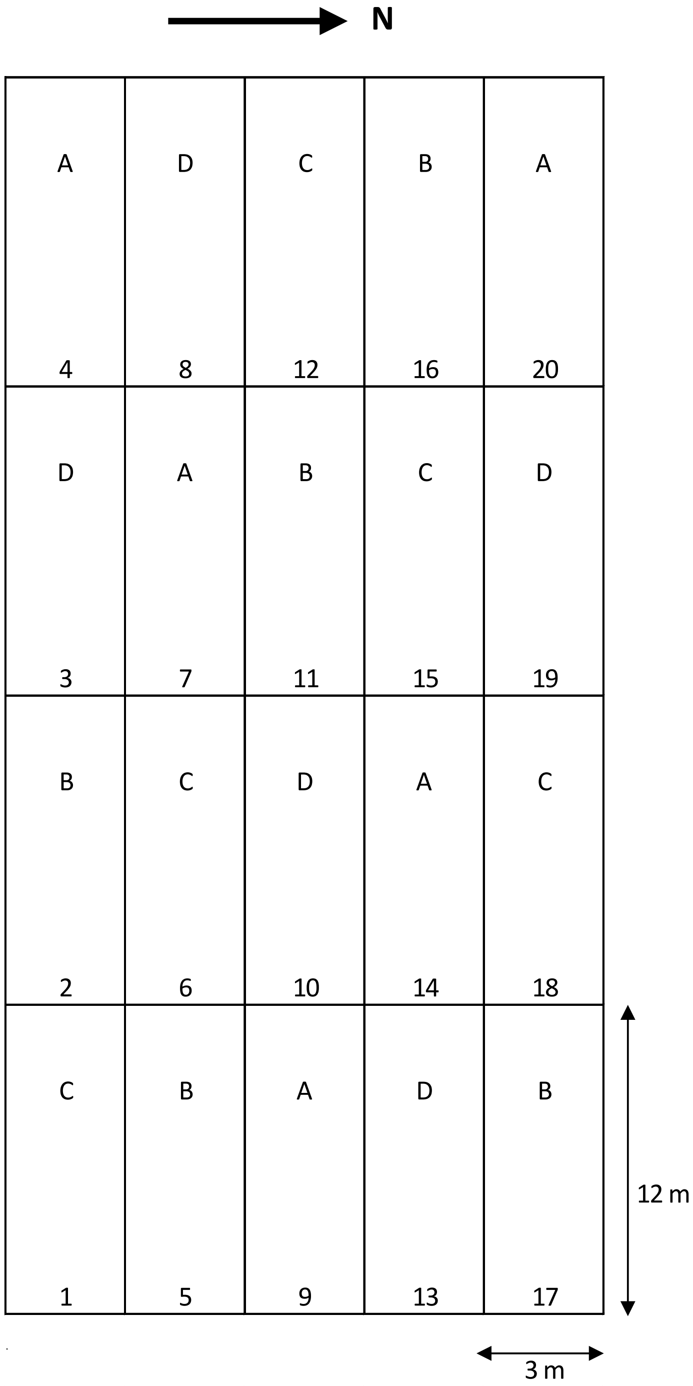
Soil crumbling score is: good, however the evaluation of soil crumbling status is also depending on crop type.
There is a chance of soil slaking. It is adviseable to maintain SOM level, or even to improve SOM level, since organic matter realizes binding between soil particles.

Contact & info

Soil layer:	0 - 25 cm
Sample was taken by:	Third party
Contact sample taking:	Nico Barendregt: 0652002103

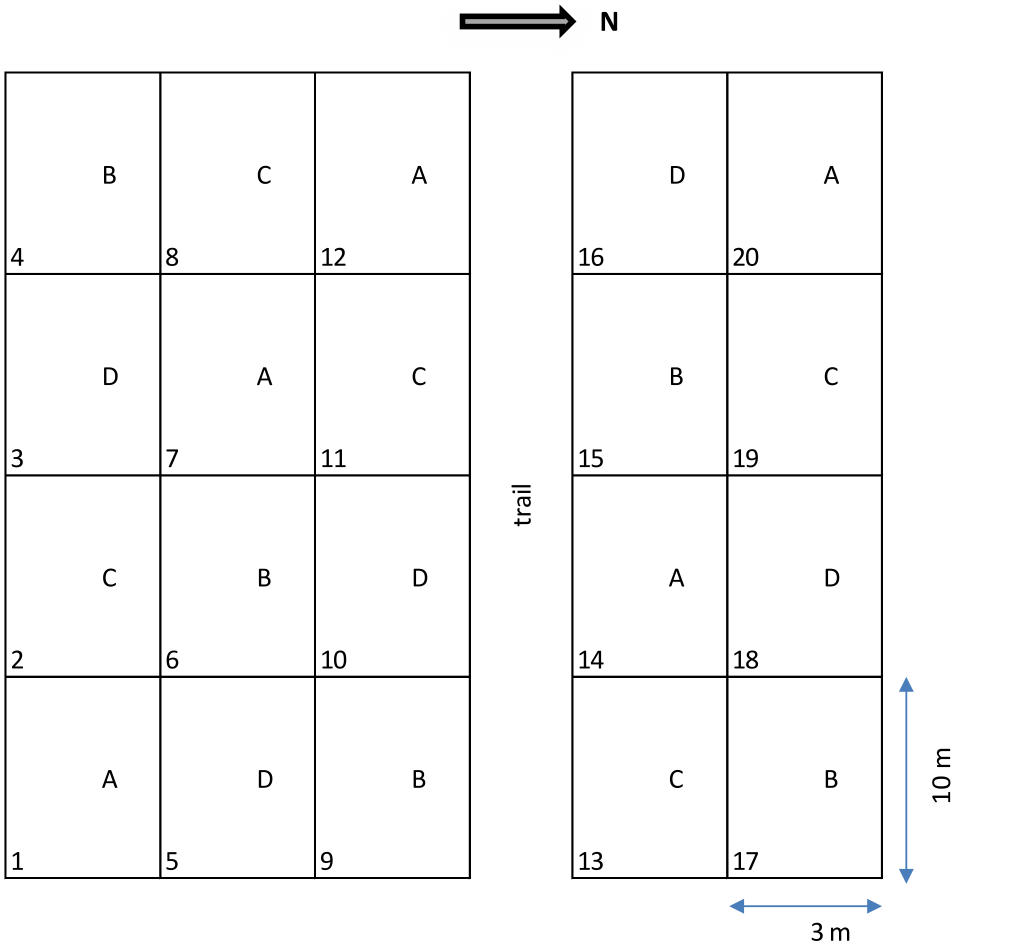
Annex 2 Field lay out of the trials

Lelystad



Code	Fertilizer	Dose	P_2O_5-rate (kg/ha)	N-rate (kg/ha)	SO_3-rate (kg/ha)
A	None	0	0	0	0
B	P2L	200 L/ha	20	7	3
C	TSP	44 kg/ha	20	0	2
D	TSP	200 kg/ha	90	0	9

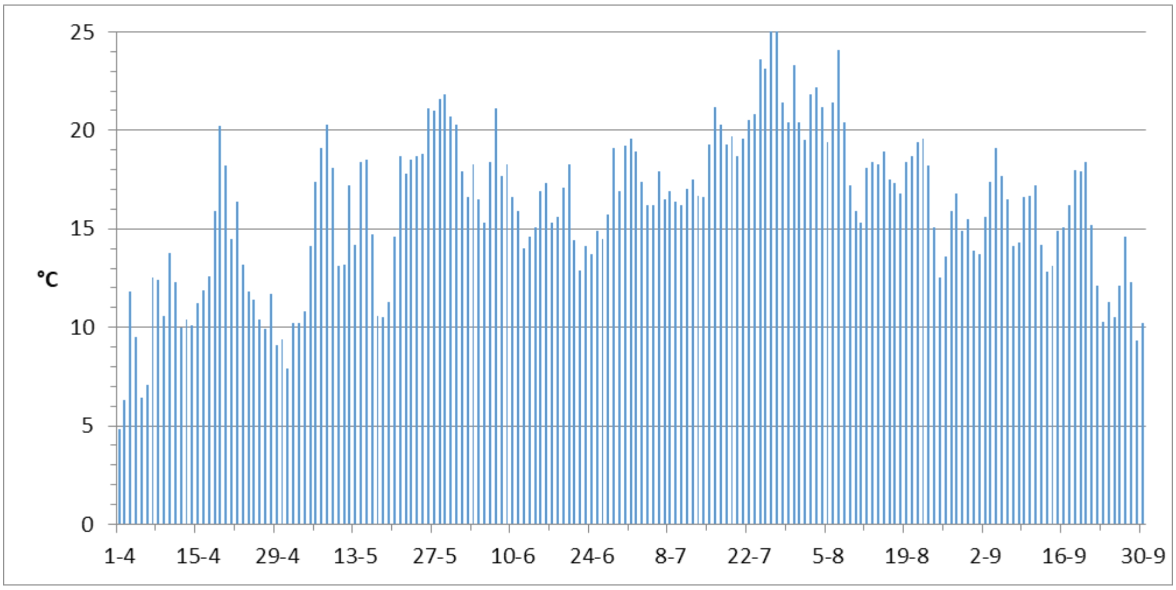
Westmaas



Code	Fertilizer	Dose	P_2O_5-rate (kg/ha)	N-rate (kg/ha)	SO_3-rate (kg/ha)
A	None	0	0	0	0
B	P2L	200 L/ha	20	7	3
C	TSP	44 kg/ha	20	0	2
D	TSP	200 kg/ha	90	0	9

Annex 3 Weather data

Average daily temperatures at the research site Lelystad

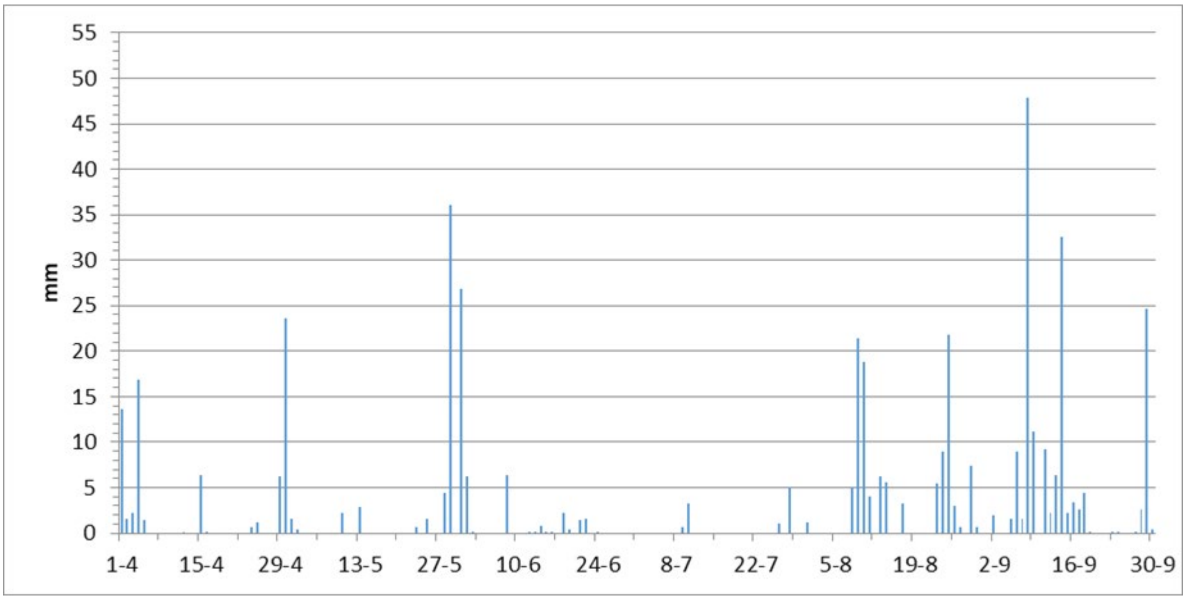


Average temperature (°C) per decade of days and normal temperatures[1]

Decade	April		May		June		July		August		September	
1	9,5	(7,6)	14,1	(11,7)	17,7	(15,0)	17,2	(17,1)	20,3	(17,9)	16,2	(15,4)
2	13,3	(8,4)	14,3	(13,0)	16,0	(14,9)	18,6	(17,4)	17,8	(17,5)	15,8	(14,3)
3	11,8	(10,8)	19,9	(13,7)	15,5	(15,9)	22,5	(17,9)	15,9	(16,4)	11,8	(13,5)

[1] Normal temperatures (average of 1981-2010) are displayed between brackets

Daily sum of precipitation (millimeters) at the research site Lelystad

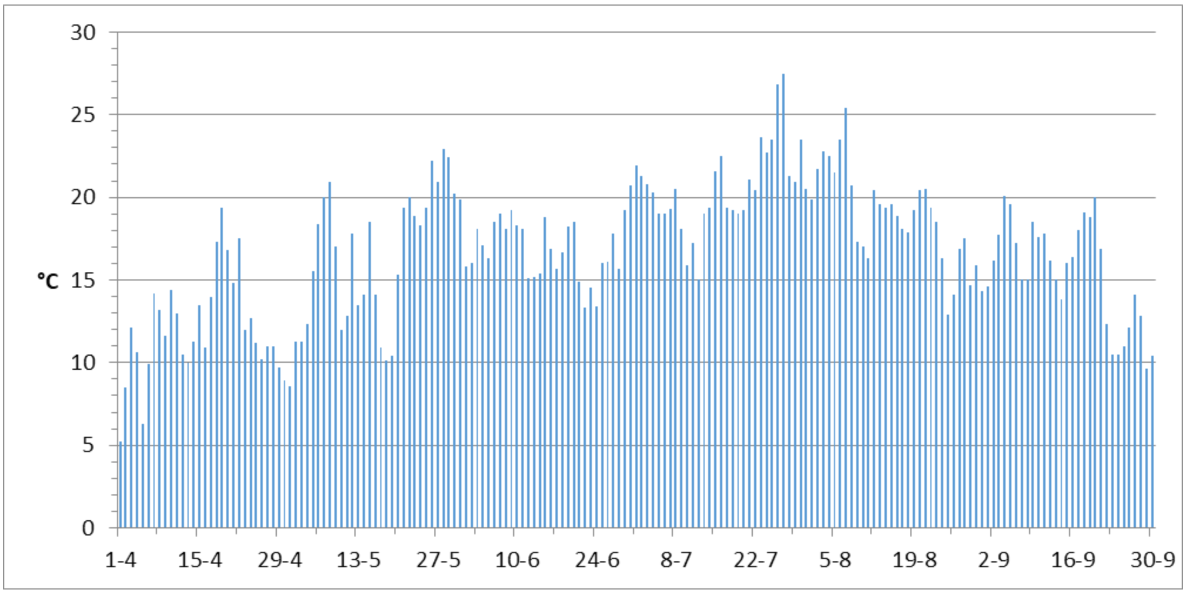


Sum of precipitation (millimeters) per decade of days and normal precipitation[1]

Decade	April		May		June		July		August		September	
1	35,6	(14,4)	4,2	(15,9)	12,8	(27,4)	3,8	(28,7)	45,2	(24,5)	73,2	(25,7)
2	6,8	(14,8)	2,8	(19,3)	4,2	(21,6)	0,0	(25,6)	19,0	(24,8)	63,2	(31,2)
3	31,6	(14,3)	69,4	(23,1)	3,2	(23,2)	7,2	(29,2)	47,8	(35,6)	28,2	(21,6)

[1] Normal precipitation (average of 1981-2010) are displayed between brackets

Average daily temperatures at the research site Westmaas

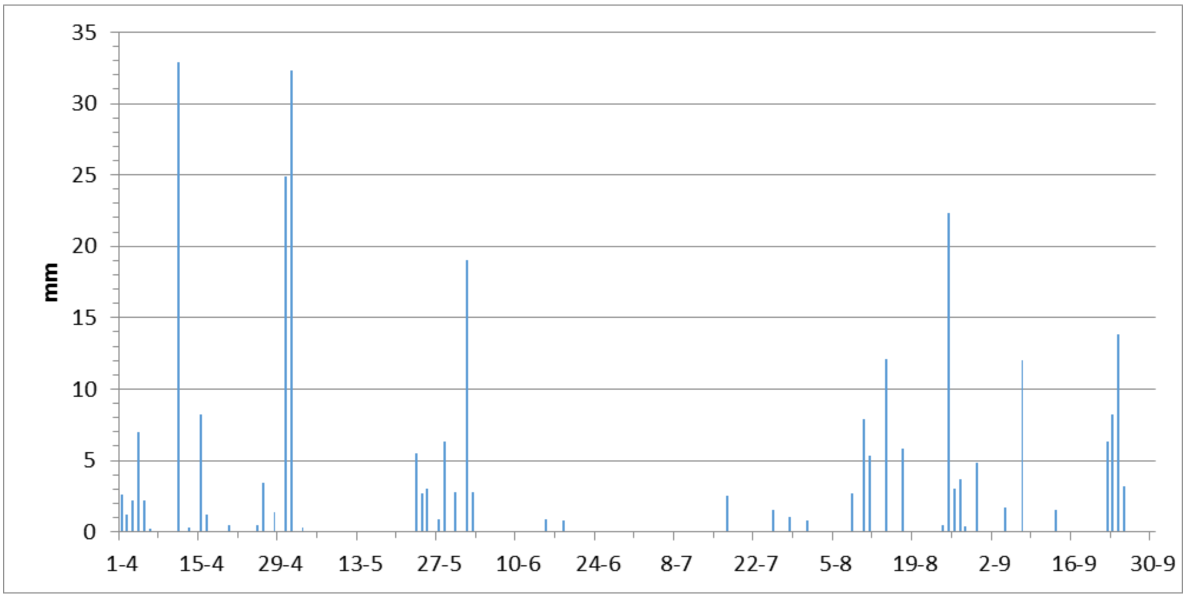


Average temperature (°C) per decade of days and normal temperatures[1]

Decade	April		May		June		July		August		September	
1	10,6	(8,0)	14,7	(11,7)	17,6	(15,1)	19,6	(17,4)	21,2	(18,3)	17,2	(15,8)
2	13,7	(8,6)	13,8	(13,2)	16,9	(15,2)	19,2	(17,7)	19,0	(17,9)	17,1	(14,7)
3	11,9	(10,8)	20,4	(13,7)	16,2	(16,2)	22,9	(18,3)	16,5	(16,7)	12,0	(14,0)

[1] Normal temperatures (average of 1981-2010) are displayed between brackets

Daily sum of precipitation (millimeters) at the research site Westmaas



Sum of precipitation (millimeters) per decade of days and normal precipitation[1]

Decade	April		May		June		July		August		September	
1	15,4	(14,4)	32,6	(17,8)	21,8	(26,4)	0,0	(26,7)	10,6	(22,3)	13,7	(25,4)
2	10,2	(15,0)	0,0	(16,4)	1,7	(19,6)	2,5	(25,0)	23,2	(22,4)	1,5	(32,5)
3	30,2	(14,5)	21,2	(21,7)	0,0	(21,4)	3,3	(26,9)	34,7	(34,4)	31,5	(23,8)

[1] Normal precipitation (average of 1981-2010) are displayed between brackets

To explore the potential of nature to improve the quality of life

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