Comparing low rate copper formulations against *Phytophthora infestans* in potatoes

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Table of contents

page

1 Introduction

Potato late blight caused by *Phytophthora infestans* causes substantial losses in organic potato production in the Netherlands. In the last years and especially in 2007, late blight was an enormous problem. It caused very low tuber yields and also the quality was poor. The risk of low and unpredictable yields is too high. That is why organic farmers plan to reduce the acreage with organic potatoes.
On the other hand the Dutch government stimulates organic cropping, inclusive potatoes. Their ambition is an annual growth of 5% in acreage of organic agriculture. To support this, a research program was started in which research into measures to reduce the negative effects of late blight was an important topic.
Resistant varieties against late blight could be the solution. Breeders are rather successful in this, but there is still no breakthrough. Growers still have to use rather susceptible varieties.
In common agriculture growers successfully use fungicides to protect their potato crop against late blight and also in some neighbouring countries some fungicides are allowed in organic potato growing.
At the moment – 2008 - in the Netherlands, copper products are, according to the Dutch pesticide law, not allowed at all to use to protect potatoes against late blight.
Between Dutch organic growers the late blight problems lead to discussions in which the a temporary registration of copper products is also suggested. Some growers do not want any pesticides at all, while others see that biological potatoes from abroad are sold in the super markets in years when Dutch organic potatoes are scarce. Those potatoes come from countries, where copper products are allowed. They speak about competition falsification.
In the research program to stimulate organic production the chose is made to also investigate the efficacy of copper and other products that are allowed in surrounding countries in organic farming.
In the experiment of 2008 6 different copper containing products are tested.

2 Materials and methods

2.1 Trial set up

The potatoes were grown on a sandy clay soil at the Applied Plant Research - PPO-AGV - location at Lelystad. The experiment was treated conform local good agricultural practice. Trial figures are listed in table 1. The trial design is presented in Appendix 1.

Table 1. **Trial figures**

	Lelystad
Soil	Light clay (13 % lutum)
Organic matter	2.4%
CaCO3	6.4%
Cultivar	Agria
Leaf blight resistance	5.5 – fairly susceptible
Tuber blight resistance	8 – fairly good resistance
Row distance	75 cm
Distance in the row	33 cm
Planting date and technique	2 May mechanically
Nitrogen fertilization; quantity and date	170 kg N per ha (13 May) and 50 kg (28 July)
Plot size net	5,25 m x 9,43 m
Number of treatments	7
Number of replicates	4

2.2 Spraying

Potato plants were sprayed for the first time when they reached a height of 10-15 cm, and the rapid growth started. Around 28 June the crop was closed.
Fungicide applications were carried out using a trial site sprayer with Airmix 110.04 nozzles. Nozzles were hanging approximately 50 cm above the foliage. Sprayings were carried out based on 300 l/ha. With the trial site sprayer up to ten treatments can be sprayed in one run; see photo 1.
The frequency of sprayings was decided by the DSS ProPhy to ensure that timing was as good as possible. The sprayings were carried out on 4, 16 and 20 June, on 2, 7, 11, 15, 18, 22 and 28 July and on 1, 5, 11, 15, 20, and 25 August (In total 16 times).
To prevent the development of weeds, before crop emergence, on 19 May, the soil was treated with 0,25 l Centium + 1 l Butisan + 0,5 l oil in 400 l of water per hectare.
On 29 August and 5 September haulm killing was carried out with 4 l Reglone per hectare.

2.3 Treatments

In the trial different copper products and one combination of products were tested. They are listed in table 2. K1; A fungicide in a dosage of 600 gram Cu/ha was used as a standard; the other products are also under code. There was no difference in the timing of the different treatments.

Table 2: **Treatments**

Factor code	Factor description
K0	untreated
K1	600 g/Cu/ha/spray
K2	150 g/Cu/ha/spray
K3	300 g/Cu/ha/spray
K4	500 g Cu/ha/spray
K5	100 g Cu/ha/spray
K6	100 g Cu/ha/spray + 4x product X[1]

[1]) Product X was added on 1, 5, 11 and 15 August

2.4 DSS and weather conditions

Sprays were timed according to the Decision Support System (DSS) Prophy. See for more information about DSS Prophy the world wide web for DSS and Prophy.
Timing of applications is based on previous spray, variety, crop growth, weather conditions, weather forecast, blight in the crop itself and blight pressure in the neighborhood.
In an experiment at a distance of 100 – 200 m, to raise the infection chances, artificial inoculation was carried out on 11 June. Subsequently artificial irrigation was carried out to prolong the leaf wetness period and from 26 June a gradual spread of late blight was observed.
Weather conditions during the growing season are presented in Appendix 3. March was a wet month with a total precipitation of 108 mm. April (30 mm), May (25 mm) and June (28 mm) were very dry months. And also from 1 to 7 July (5 mm) it was dry. From July 7 it became a wet and rather cool summer. From 7 July to 31 July, 88 mm of rainfall was recorded in Lelystad.

2.5 Disease observations and artificial inoculation

To determine the effects of the different products and product combinations late blight observations were carried out twice a week, according to the PD-scale; see Appendix 2. This scale was a little refined; for example 9.9 was one diseased leaflet per plot and 9.7 was 3-4 diseased leaflets per plot and so on.
Artificial inoculation was carried out in the evening of 30 July and became visible on 5 August. The aim of this artificial inoculation was to cause an even infection pressure in all plots.

2.6 Statistical analyses

Analysis of variance was made using GENSTAT 11.1. The control treatment K0 was excluded. The LSD; the least significant difference at p=0.05 means that differences between the blight scores higher than the mentioned value in the column are significantly different.

Photo 1: One of the beams of the Sosef-trial-spraying machine (in another experiment).
Every time the spraying machine goes to the experimental field 10 different products can be sprayed.

Photo 2: Just visible and older late blight spots on the leaves on 5 August in the experiment

Photo 3: Foci of infection of P. infestans in the experiment in K0 on 7 August

3 Results

3.1 Crop development

In Table 3 crop development is given as percentage soil cover with green foliage

Table 3: **Percentage soil cover**

Date	3/6	11/6	16/6	24/6	30/6
%	10	35	55	90	100

At the end of June the crop closed. The first natural infection of late blight was observed in the experiment on 28 July.

3.2 Disease development

The assessments of late blight in the foliage on 9 dates, are presented in table 4. Significant differences between the treatments K1 – K6 occurred from 4 August onwards. From the end of July the infection pressure was high. Rain showers on 26 July and plenty of late blight in the foliage in the surrounding experiments (see Appendix 3 too). The amount of late blight increased much faster in the control treatment K0 than in the other treatments in which copper was used. From the copper treatments, the lowest amount of copper (K5) was the weakest. Between the other treatments (K1, K2, K3, K4 en K6) the differences in diseased foliage were very limited or not significant. Remarkably was the low level infection in K2 (150 g Cu) and K6 (100 g Cu + 4x product X) protected the crop against late blight.

Table 4. **Leaf infestation PD-scale per date (10=completely free from late blight; 0=completely destroyed by blight)**

treatment	28/7	31/7	4/8	7/8	11/8	14/8	18/8	21/8	27/8
K0	9.7	8.6	8.1	5.8	2.8	0.9	0.6	0.1	0.0
K1	10	10	10	9.5	9.4	7.8	6.6	5.5	2.5
K2	10	10	10	9.5	9.2	7.5	6.1	4.8	1.7
K3	10	9.9	10	9.5	9.4	7.5	6.1	5.2	2.2
K4	10	9.9	10	9.5	9.4	8.0	6.2	5.5	2.3
K5	10	9.9	9.7	8.9	8.3	5.9	3.9	3.1	1.0
K6	10	10	10	9.4	9.2	8.3	7.6	6.3	3.3
LSD (0,05)*[1]			0.1	0.5	0.5	1.1	1.5	0.9	0.5

*[1] The control treatment K0 excluded

PD-scale:
9.9 = 1 lesion per plot
9.5 = 6-10 lesions per plot
9 = 1-3 lesions per plant
8 = up to 20 lesions per plant
6 = 25% total leaf surface dead
3 = 75% total leaf surface dead

For further explications of the PD-scale see Appendix 2.

4 Conclusions

- None of the treatments with the different copper formulations completely protected the crop from late blight. Treatment K6 (100 g Cu + 4x product X) resulted in the best protection, but was not significantly better than the standard K1 (600 g Cu). The amount of copper of K6 was only one sixth of that of K1.
- The addition of product X to K5 (K6) increased the protection of the crop against late blight significantly (compare K5 and K6).
- From 4 August onwards, significant differences between the treatments occurred. K5, the lowest quantity of copper, was infected to a higher extent than the other treatments, but was by far better than the control treatment K0.
- From 11 August, the foliage of K2 (150 g Cu) was more infected than K3 (300 g Cu), but these differences did not become significant.
- The foliage of K2 (150 g Cu) remained significantly less infected than K5 (100 g Cu).
- K3 (300 g Cu) and K4 (500 g Cu) were not significantly different from K1 (600 g Cu).
- There is a tendency that with more copper (K2 → K3 → K4 → K1; 150→ 300→ 500 → 600 g Cu) the protection of the crop was better. But this is not significant. Only between K2 (150 g Cu) and K5 (100 g Cu) there were significant differences. The difference between these products probably was not only the amount of copper but also a difference in (producers) formulation.
- Most remarkably was the effect of only 100 g copper per spraying compared to the untreated control (K0). With only 100 g copper per spraying the crop was infected much slower compared to no protection at all.

Appendix 1. Trial design

Factors and levels:

Factor code	Factor description
K0	untreated
K1	600 g/Cu/ha/spray
K2	150 g/Cu/ha/spray
K3	300 g/Cu/ha/spray
K4	500 g Cu/ha/spray
K5	100 g Cu/ha/spray
K6	100 g Cu/ha/spray + 4x product X

Total length 66 m and width 21 m. Per plot length 943 cm and width 525 cm.
4 replications
Variety; Agria, planting date; 2 May

7	H1	K2	**14**	H2	K6	**21**	H3	K2	**28**	H4	K3
6	H1	K5	**13**	H2	K3	**20**	H3	K1	**27**	H4	K4
5	H1	K4	**12**	H2	K0	**19**	H3	K6	**26**	H4	K0
4	H1	K3	**11**	H2	K5	**18**	H3	K0	**25**	H4	K5
3	H1	K6	**10**	H2	K1	**17**	H3	K5	**24**	H4	K2
2	H1	K1	**9**	H2	K2	**16**	H3	K3	**23**	H4	K6
1	H1	K0	**8**	H2	K4	**15**	H3	K4	**22**	H4	K1

Appendix 2. Assessments for late blight on plot level

PD*1 Scale	Symptoms (Based on good observations)
10	no visible decay
9,5	6 tot 10 lesions per PLOT
9	1 - some lesions per PLANT
8,5	Up to on average 10 lesions per PLANT
8	Up to on average 20 lesions per PLANT
7	10% leaf surface per PLOT dead: Plant looks sound but lesions easily to find when coming nearer.
6	Diseased surface per plant equivalent to the surface of 20 leaflets. 25% leaf surface PLOT dead
4	50% leaf surface PLOT dead. Plants look at first sight mainly "green"
3	75% leaf surface PLOT dead. Plot seems green with brown spots. Lower leaf layers dead
2	90% leaf surface PLOT dead. Plot seems brown-green. Only top leaves are green. Stem lesions often occur
1	97.5% leaf surface PLOT dead. Plot looks brown. Some top leaflets still have green parts. Stems have much lesions or are already dead
0	All leaves and stems are dead

***1 PD = The Plant Protection Service (PD) - an agency of the Dutch Ministry of Agriculture**

Appendix 3. Weather conditions

. Weather data Lelystad June-July 2008

date	T-gem (°C)	T-max (°C)	T-min (°C)	rainfall (mm)	RH-min (%)
01-06-08	16.7	21.8	13.3	4.4	70
02-06-08	21.3	28.6	14.2	0	45
03-06-08	19.3	22.7	15.7	1.4	66
04-06-08	17.1	21.4	12.7	0	68
05-06-08	16.4	19.4	15.3	0	80
06-06-08	19.8	25.1	13.7	0	34
07-06-08	18.9	24.5	13.7	0	57
08-06-08	20.4	26.5	13.7	0	44
09-06-08	20.1	26.1	13.7	0	39
10-06-08	17.7	24.3	12.2	0	55
11-06-08	15.6	19.2	11	0	50
12-06-08	13.5	15.7	11.5	3.8	57
13-06-08	12.4	15.3	10.6	2.8	64
14-06-08	13.5	17.4	8.6	0	46
15-06-08	12.9	17.8	9.9	8.4	51
16-06-08	13.4	18.4	9.7	0	52
17-06-08	13.7	20.4	3.9	0	36
18-06-08	15.3	20.8	9	0	49
19-06-08	15.9	20	12.5	0.4	54
20-06-08	16.1	20.2	10.6	0	48
21-06-08	17.3	22	10.8	0	51
22-06-08	20.2	25.9	16.1	0	32
23-06-08	14.6	16.1	11.4	0	60
24-06-08	13.9	19.6	6.7	0	39
25-06-08	16.6	22.4	11	0	49
26-06-08	16.7	19.6	12.5	0	44
27-06-08	15.6	18.4	11.8	3	51
28-06-08	17.3	20	15.3	3.4	62
29-06-08	16.7	18.8	13.3	0	55
30-06-08	16.8	20.4	11.4	0	40
01-07-08	18.5	25.5	10.6	0	39
02-07-08	21.1	30.2	14.9	1.8	36
03-07-08	17.8	20.8	15.7	2.4	80
04-07-08	16.8	20	13.7	0.6	50
05-07-08	16.2	22.4	9.4	0.4	44
06-07-08	17	20.4	13.7	0	44
07-07-08	14.7	17.3	12.9	8.2	57
08-07-08	14.1	15.7	12.5	18.4	64
09-07-08	14.4	17.6	10.6	2.8	62
10-07-08	16.2	18.4	13.7	9.2	80
11-07-08	16	19.2	13.3	0.2	62
12-07-08	14.2	16.5	12.5	8.8	56
13-07-08	14.3	16.9	10.6	0	56
14-07-08	16.2	20.8	9.4	0	51
15-07-08	17	18.8	15.7	0	70
16-07-08	16.6	17.6	14.5	0.4	55
17-07-08	14.5	16.5	12.5	2.6	68

Weather data Lelystad July -August 2008

date	T-gem (°C)	T-max (°C)	T-min (°C)	rainfall (mm)	RH-min (%)
18-07-08	15.4	18	12.9	1.4	67
19-07-08	15.7	17.6	14.1	18.2	70
20-07-08	13.9	15.7	12.2	4	58
21-07-08	13.5	16.1	11.8	3.6	63
22-07-08	14.7	18	12.5	1	67
23-07-08	18	21.6	14.9	0	58
24-07-08	19.2	24.7	12.5	0	43
25-07-08	20.9	27.1	14.9	0	47
26-07-08	21.1	26.3	17.6	8	63
27-07-08	20.7	24.7	16.9	1	62
28-07-08	23.1	28.2	19.6	0	52
29-07-08	20.8	22.7	17.3	0.2	62
30-07-08	20.4	25.9	14.5	0	44
31-07-08	22.5	29	16.1	0	43
01-08-08	19.9	21.6	16.5	13.4	53
02-08-08	17.8	22	13.7	0	56
03-08-08	17.9	19.6	16.5	5.2	73
04-08-08	17.2	18.8	15.7	23.2	62
05-08-08	17.9	21.2	14.1	0.6	60
06-08-08	19.7	23.9	16.5	0	65
07-08-08	18.4	20.4	16.1	4.6	83
08-08-08	16.7	18.4	15.3	4.2	71
09-08-08	16.4	20.4	13.7	0.6	53
10-08-08	17.2	20.8	14.5	3	50
11-08-08	16.2	18.4	14.1	0.2	69
12-08-08	15.9	20.8	11.4	1.2	50
13-08-08	15.5	19.2	12.9	2.4	59
14-08-08	15.4	18.8	11.8	4	54
15-08-08	14.4	19.6	8.6	0	55
16-08-08	15	20.8	8.6	0	44
17-08-08	15.8	21.2	11	10.2	53
18-08-08	15.2	18	12.9	6.4	83
19-08-08	16.7	19.6	14.9	0.8	66
20-08-08	16.1	18	14.1	6	78
21-08-08	16.2	19.2	13.7	1.8	67
22-08-08	14.9	18	12.5	0.6	75
23-08-08	13.8	17.6	10.2	0	66
24-08-08	14	18	9.4	0.2	64
25-08-08	16.7	20	13.7	0.2	60
26-08-08	16.9	17.6	16.1	0	80
27-08-08	16.1	17.3	14.9	0	81
28-08-08	17.3	19.2	15.7	0	70
29-08-08	17.5	20	14.5	0	75
30-08-08	17	22.7	11.8	0	57
31-08-08	19.4	26.7	12.5	0	50

Appendix 4. Late blight assessments

AGV6034 Late Blight assessments according to the PD-scale per date

plot	trm	28/7	31/7	4/8	7/8	11/8	14/8	18/8	21/8	27/8
1	0	9,9	9,8	9	6,75	3,5	1	0,5	0,2	0
12	0	9	7	6,5	3,5	2	0,5	0,5	0	0
18	0	10	8,5	8,25	6,5	3	1	0,5	0,2	0
26	0	10	9	8,5	6,5	2,5	1	1	0	0
2	1	10	10	9,9	9,5	9,5	8	7	5,7	2,8
10	1	10	10	10	9,7	9,4	7,5	6	5,2	2,3
20	1	10	10	10	9,5	9,7	7,5	6	5,2	2
22	1	10	10	10	9,2	9	8,2	7,5	6	2,8
7	2	10	10	10	10	9,5	8,5	8	6	2,3
9	2	10	10	10	9,4	9,3	8,5	6,7	5,2	2
21	2	10	10	10	9,5	9,4	7	5,2	4,2	1,4
24	2	10	10	10	9	8,5	6	4,5	3,6	1
4	3	10	10	10	9,2	9,3	7	6	5,2	2
13	3	10	9,5	10	9,6	9,6	8	6,2	5,7	2,3
16	3	10	10	10	9,2	9,1	7,5	6	4,7	2,3
28	3	10	10	10	9,8	9,5	7,5	6,2	5,2	2,3
5	4	10	10	10	9,3	9,3	7,5	5,2	4,7	2
8	4	10	9,7	10	9,9	9,4	8,3	7	6	2,3
15	4	10	10	10	9,2	9,3	8	6,7	6	2,8
27	4	10	10	10	9,5	9,5	8	6	5,2	2
6	5	10	10	9,9	9	8,75	7,5	6	3,6	1
11	5	10	9,5	9,6	8,5	8	5,7	3	3,2	1
17	5	10	10	9,6	9	8	5,7	3	3	1
25	5	10	10	9,8	9	8,25	4,7	3,5	2,7	1
3	6	10	10	9,9	9,6	9,5	8,5	8	6,7	3,3
14	6	10	10	10	9,8	9,5	8,5	7,5	6,2	3,3
19	6	10	9,9	10	9,1	8,5	8	6,7	6	3,3
23	6	10	10	10	9,1	9,1	8,2	8,2	6,2	3,3
average	K0	9,7	8,6	8,1	5,8	2,8	0,9	0,6	0,1	0,0
average	K1	10,0	10,0	10,0	9,5	9,4	7,8	6,6	5,5	2,5
average	K2	10,0	10,0	10,0	9,5	9,2	7,5	6,1	4,8	1,7
average	K3	10,0	9,9	10,0	9,5	9,4	7,5	6,1	5,2	2,2
average	K4	10,0	9,9	10,0	9,5	9,4	8,0	6,2	5,5	2,3
average	K5	10,0	9,9	9,7	8,9	8,3	5,9	3,9	3,1	1,0
average	K6	10,0	10,0	10,0	9,4	9,2	8,3	7,6	6,3	3,3
lsd (0.05)*[1]				0,1	0,5	0,5	1,1	1,5	0,9	0,5

*[1] lsd without untreated