Testing alternative insecticides and monitoring systems for the control of pygmy mangold beetles (*Atomaria linearis*) in sugar beet in 2019

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Summary

The efficacy of various insecticides on the control of pygmy mangold beetle (*Atomaria linearis*) was studied on two field trials: Dronten (low pressure of pygmy mangold beetle) and Zeewolde (high pressure of pygmy mangold beetle). Force (10g tefluthrin) applied as seed treatment was proven to be the most effective on belowground damage, Vydate 10G had a similar effect to Force in Dronten but had a much lower efficacy in Zeewolde. Additional foliar spray applications with insecticides did not result in higher plant stand density. Insecticide spray applications were applied three times. In Dronten, no effect of sprays was found on plants with stunted growth caused by aboveground feeding. In Zeewolde, Force with additional application of insecticides Bariard, IRS 770, IRS 785, IRS 789, IRS 792 or IRS 742, led to a significant lower number of plants that showed stunted growth than in the treatment with only Force. However, in this study the significant lower number of plants with stunted growth did not result in a higher yield, compared to the seed treatment with Force. Therefore, in this study, the added value of insecticide sprays was not shown. However, severity of damage by pygmy mangold beetles can vary over the years and also depends on temperature. Therefore, this study will be repeated in 2020.

Monitoring of pygmy mangold beetle with various traps showed a trend of mass flights when the air temperature exceeded 15 °C. Sticky traps were proven to be most effective in trapping pygmy mangold beetles compared to water pans. A preference for a specific color was not found.

Samenvatting

De effectiviteit van verschillende insecticiden voor de beheersing van bietenkevers (*Atomaria linearis*) is onderzocht op twee veldproeven: Dronten (lage bietenkeverdruk) en Zeewolde (hoge bietenkeverdruk). Force (10g tefluthrin) als zaadbehandeling gaf de beste beheersing van ondergrondse schade door bietenkevers wat resulteerde in meer planten per veldje vergeleken met onbehandeld. Vydate 10G had een vergelijkbaar effect op ondergrondse schade als Force in Dronten, maar had een lagere effectiviteit in Zeewolde. Aanvullende bespuitingen met insecticiden zijn drie keer toegepast, maar resulteerde niet in meer planten per veldje. In Dronten is ook geen effect gezien van de bespuitingen op het aantal planten met verstoorde groei, veroorzaakt door bovengrondse vreterij van bietenkevers. In Zeewolde, Force met aanvullende bespuiting met Bariard, IRS 770, IRS 785, IRS 789, IRS 792 of IRS 742 zorgde voor significant minder planten met afwijkende groei, vergeleken met Force zonder aanvullende bespuiting. Echter, ondanks dat deze behandelingen zorgden voor minder planten met afwijkende groei, was de opbrengst gelijk aan een behandeling met alleen Force. In dit onderzoek is de meerwaarde van een aanvullende bespuiting met insecticiden niet aangetoond. Echter, omdat de schade van bietenkevers per jaar kan verschillen en afhankelijk is van temperatuur, zal dit onderzoek in 2020 worden herhaald.

De monitoring van bietenkevers met verschillende vallen toonde een trend van massa vluchten wanneer de temperatuur 15 °C overschreed. Plakvallen waren effectiever in het vangen van bietenkevers vergeleken met vangbakken. Een voorkeur voor een bepaalde kleur is niet aangetoond.

1. Introduction

Since the ban on imidacloprid, clothianidin and thiamethoxam as seed treatment, pygmy mangold beetles (*Atomaria linearis*) are more difficult to control. These beetles are known to eat from sugar beet roots, which lead to plant losses during germination. In addition, when temperatures rise, pygmy mangold beetles will start eating from the leaves aboveground as well, causing damage during early plant growth (Dunning, 1982). Mass flights can occur when the temperature reaches 15 °C (Heijbroek & Huijbregts, 1995). Force (tefluthrin) can be applied as seed treatment in the Netherlands but is proven to be less effective than neonicotinoids on belowground damage and, since it is not systemic, it does not control aboveground damage (Heijbroek & Huijbregts, 1995; Raaijmakers, 2010). In the Netherlands, pyrethroid foliar applications are the only chemical alternative to control this pest aboveground during the growing season. However, due to negative side effects on beneficial organisms and risk of insecticide resistance, alternative insecticides to control pygmy mangold beetle damage are needed. In this research, various insecticides were applied in two field experiments to study their efficacy. Several chemical and biological insecticides were selected with an expected effect on beetles. Possibly, one or more of the insecticides may be an alternative to neonicotinoid seed treatments and pyrethroid foliar sprays.

These trials were conducted according to Good Experimental Practice (GEP, annex A) guidelines.

2. Materials and methods

2.1 Trial sites and statistical design

Largest damage by pygmy mangold beetles can be expected on clay soils with sugar beet as a pre-crop. Therefore, two sites were selected, in Zeewolde and Dronten (Annex B1, B3, C1, C3), where sugar beets were grown in 2018. Both trials were designed as randomized blocks in four replications. Gross plot size was 3m wide (six rows) by 15.5m long, with a net plot size of 3m by 12m (Annex B2, C2).

2.2 Drilling

The field trials were drilled with seeds from cultivar 'Florena KWS' (KWS SAAT SE & Co. KGaA, Einbeck, D.), using a standard precision sowing machine (Monosem) on 2 April 2019 (Zeewolde) and 9 April 2019 (Dronten). This sowing machine is equipped with a system to change seed batches quickly. Sowing distance between rows was 50cm and 17cm within the rows. The trials were drilled relatively deep at about 4cm, to slow down emergence of plants and thereby enhance the damage by pygmy mangold beetles. Treatment Vydate 10G and IRS 790 were applied in the seed furrow at drilling.

2.3 Treatments

All seeds, including the untreated control, were treated with the fungicides TMTD (thiram) and Tachigaren (hymexazol). Dosages were analyzed with HPLC at IRS and corresponded to the targeted dosages; seeds without Force contained on average 12.7g hymexazol and 5.8g thiram per unit (100,000 seeds). Seeds additionally treated with Force contained on average 10.6g hymexazol, 5.1g thiram and 10.8g tefluthrin per unit. Treatments consisted of a granular nematicide, foliar spray and/or insecticide seed treatment (Table 1). The first foliar sprays were carried out when pygmy beetles were first seen, eating from the plants aboveground. Due to high density of pygmy mangold beetles, all foliar spray treatments were carried out three times. Plots were sprayed on 26 April, 7 May and 13 May, 2019 in both Zeewolde and Dronten. An overview of spraying equipment and the weather conditions during the time of insecticide spraying are given in annex B4 and C4.

Table 1: Overview of the treatments in Zeewolde and Dronten. Insecticides not registered for use in Dutch sugar beet growing are named under IRS code. All foliar sprays were carried out three times.

treatment	*seed treatment*	*insecticide treatment*	*dosage*
1	-	-	-
2	Force (10g tefluthrin/unit)	-	-
3	-	Vydate 10G (oxamyl)	10 kg/ha (granular)
4	Force (10g tefluthrin/unit)	IRS 770	3 x 0.25 l/ha
5	Force (10g tefluthrin/unit)	IRS 788	3 x 1.5 kg/ha
6	Force (10g tefluthrin/unit)	IRS 785	3 x 0.25 kg/ha
7	Force (10g tefluthrin/unit)	IRS 787	3 x 75 l/ha
8	Force (10g tefluthrin/unit)	IRS 789	3 x 0.75 l/ha
9	Force (10g tefluthrin/unit)	IRS 791	3 x 0.175 l/ha
10	-	IRS 790 (+ IRS 742)*	10 kg/ha (+3 x 0.5 l/ha)*
11	Force (10g tefluthrin/unit)	IRS 742	3 x 3.0 l/ha
12	Force (10g tefluthrin/unit)	IRS 792	3 x 0.5 l/ha
13	Force (10g tefluthrin/unit)	Bariard (thiacloprid)	3 x 0.15 l/ha
14	Force (10g tefluthrin/unit)	IRS 768	3 x 1% in 500 l water/ha
15	Force (10g tefluthrin/unit)	IRS 771	3 x 1% in 500 l water/ha

* In Zeewolde treatment 10 consisted of IRS 790 + IRS 742; In Dronten treatment 10 was only IRS 790.

2.4 Assessments of efficacy

The effect of various treatments on damage by pygmy mangold beetle was measured below- and aboveground.

2.4.1 Root damage

During emergence, plants were counted in the central four rows of each plot, to establish plant loss caused by feeding from the roots. Final plant stand density was determined on 21 May. In addition, 24 plants were collected on 22 May from the central four rows of each plot from the field trial in Dronten. Roots were washed and assessed for belowground damage by counting the number of bites on each root.

2.4.2 Leaf damage

Damages to the leaves was assessed during early plant growth, when plants are most susceptible to pygmy beetle damage. On 3 May (Zeewolde) at BBCH10-BBCH14, the number of bites in the cotyledons, first true leaves and second leaf pair (if present) were counted. The percentage of leaf area damaged by pygmy beetles was also estimated for the first true leaves. In Dronten, only the damaged leaf area was scored (15 May). This was carried out in the central four rows on five plants per row. On 24 May (Zeewolde) and 27 May (Dronten), at BBCH16-BBCH18, plants with stunted growth in the center four rows were counted and compared to the total amount of plants in these center four rows. Plants were scored as stunted when they showed thickening of the leaves, missing leaves or blackened hearts caused by feeding (Photo 2).

2.4.3 Assessment of phytotoxicity, vigour and canopy closure

Phytotoxicity was measured on 24 May (Zeewolde) and 27 May (Dronten), which was respectively 11 and 13 days after the last insecticide application. Phytotoxicity was determined by counting the number of plants that showed chlorosis, necrosis, discolouration or stunting caused by insecticide foliar sprays. Vigour was determined on 27 May, by scoring the degree of development of the plants of a whole plot on a scale from 0 (bad) to 10

(excellent). On 11 June, canopy closure was established on a scale of 1 (open) to 10 (fully closed), where scores were given per plot, relative to each other.

2.4.4 Yield

The field trials were harvested on 28 October (Zeewolde) and 1 November, 2019 (Dronten) with the six row sugar beet harvester of IRS (PASSI). In Zeewolde, sugar beets from untreated, Vydate and IRS 790 + 742 plots were harvested by hand and cut in two or four before sampling, because sugar beets were too large to harvest mechanically. From each plot the gross weight was measured and a subsample of 60-80 kg was taken to the tare house of Suiker Unie (Dinteloord, NL). The soil tare, sugar-, potassium-, sodium-, amino nitrogen-, and glucose content was determined. Based on quality assessments and nett weight (=gross weight - soil tare), sugar yield (t/ha) and financial yield (€/ha, based on 35 €/ton sugar beets with 17% sugar) were calculated. Costs of spraying and products were not taken into account.

2.5 Monitoring systems

Several insect traps, from de Groene Vlieg Bio Control (dGV) (Nieuwe Tonge, NL), were placed to investigate which trap was most suitable to catch pygmy mangold beetles. These traps consisted of sticky plates or sticks, or water pans (Photo 1). After drilling, sticky traps were positioned on four places around the trial site (Annex B5 and C5). Due to limited availability of the red, yellow and green water pan, water pans were positioned on two places around the trial. Traps were regularly changed, once a week from drilling to BBCH10 and twice a week up till BBCH16. After BBCH16, traps were removed because it is known that pygmy beetles do not cause significant damage to larger plants. The number of pygmy beetles was counted per trap.

After drilling, temperature loggers were placed at approximately 1.5m aboveground (under hoods, shaded from direct sunlight) and at approximately 5-10 cm belowground. Temperature was registered once every hour. However, temperature measured under the hoods was much higher than the actual air temperature. Therefore, temperatures registered by KNMI weather station Lelystad were used instead (https://www.knmi.nl/nederland-nu/klimatologie/daggegevens).

Photo 1: Several monitoring systems from left to right: blue sticky plate, white sticky plate, yellow sticky plate, asparagus beetle stick, red water pan, yellow water pan, green water pan.

2.6 Statistical analysis

Data was analyzed by ANOVA (balanced) or REML (unbalanced) using Genstat 18th edition. When data did not follow normal distribution, a log transformation (Log10(x+0.001)) was performed to fit a normal distribution. A multiple comparison test was carried out using Fisher's protected LSD when the significance level was smaller than 0.05 ($P<0.05$). If no significant interaction was found between location and measurement, data were merged. An overview of which statistical tests were used for each measurement, are given in the results section.

3. Results and discussion

In general, damage by pygmy mangold beetles was much higher in Zeewolde compared to Dronten due to higher pygmy mangold pressure.

3.1 Plant emergence

Pygmy mangold beetles reduced the number of emerged plants at both field trials (Figure 1). Untreated, treatment with IRS 790 (Dronten) and treatment with IRS 790 + 742 (Zeewolde) had significantly the lowest number of plants. The treatment with only Force had significantly more plants than the untreated control. The treatment with Force + IRS 771 had the highest number of plants in Zeewolde. The treatment with Force + IRS 787 had the highest number of plants in Dronten. However, in both locations this was not significantly different from the treatment with only Force or Force with any additional spraying (except for Force + IRS 770 in Dronten). Additional spraying with insecticides did not result in higher number of plants. In Dronten, treatment with Vydate 10G had a similar effect compared to Force. However, in Zeewolde, the percentage of plants in plots treated with Vydate 10G was much lower than in plots treated with Force. It is possible that under high pest pressure, Vydate 10G is insufficient. On the other hand, drilling was carried out in dry soil and after drilling, there was only a limited amount of rain. Since it is known that the uptake of oxamyl (Vydate 10G) is slow in dry soils, efficacy may not have been optimal.

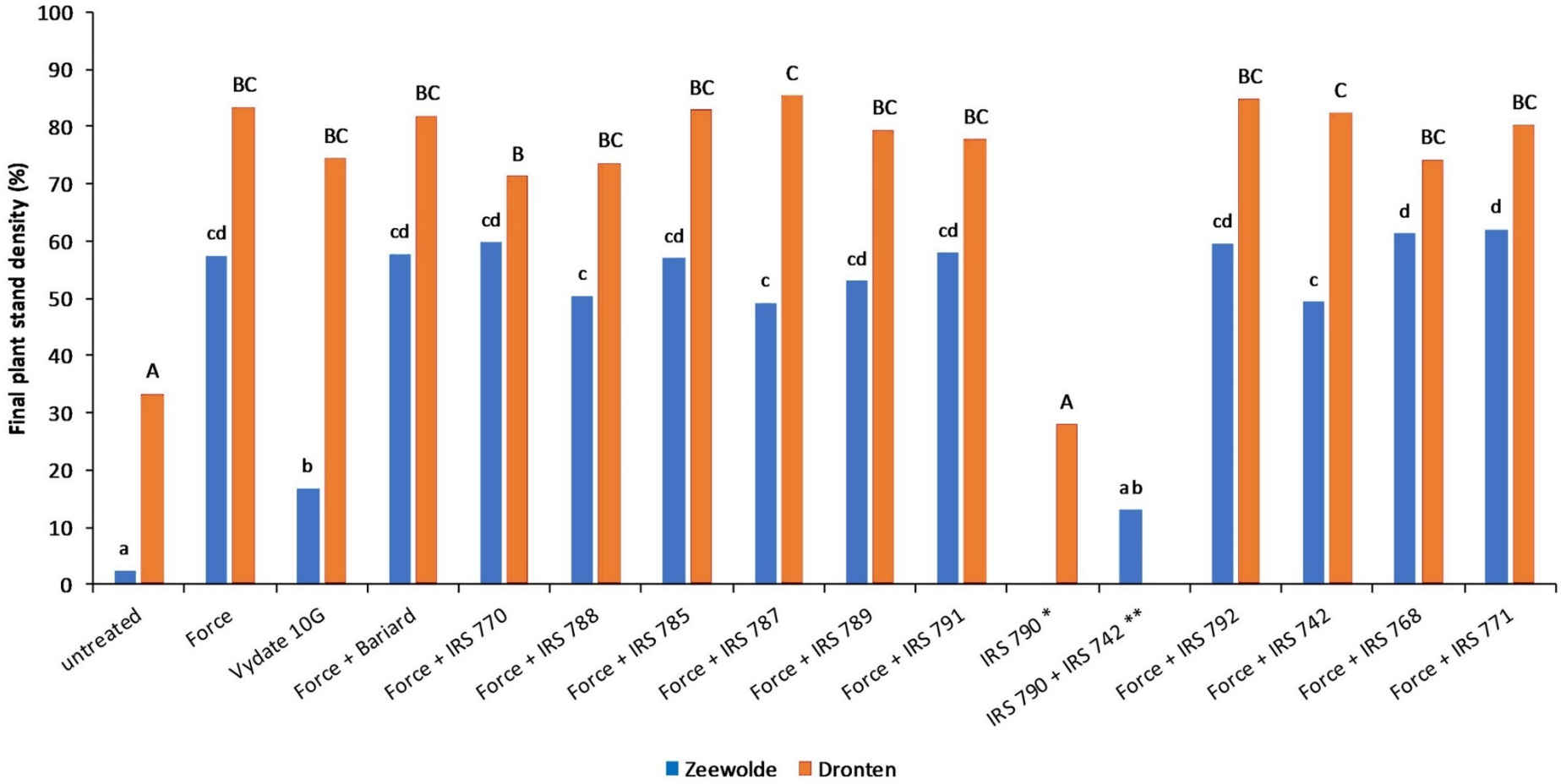

Figure 1: The average percentage of emerged plants on 21-5-2019, in relation to the number of seeds sown for Zeewolde ($P<0.001$; LSD=10.60) and Dronten ($P<0.001$; LSD=13.33). Different lowercase letters indicate significant differences between treatments at Zeewolde, uppercase letter indicate significant differences at Dronten. * = treatment only in Dronten; ** = treatment only in Zeewolde. Data was analyzed using REML analysis.

3.2 Root damage

In Dronten, untreated plants and plants treated with IRS 790 had most bites per root (Figure 2). These treatments also had lowest percentage of plants (Figure 1). This correlation has been found in previous research (Raaijmakers, 2010). However, in the current study, plants with fewest number of bites, such as Force + Bariard and Force + IRS 789, did not have more plants per plot than some treatments with significantly more bites. It is remarkable that plants treated with Force did not have significantly less bites than plants in untreated plots. However, in untreated plots less plants emerged (Figure 1). Plants in untreated plots with more bites most likely died before the root samples were taken. As a result, only plants with lower number of bites were naturally selected in untreated plots. Therefore, assessing the number of bites per root was not a reliable method to determine belowground damage.

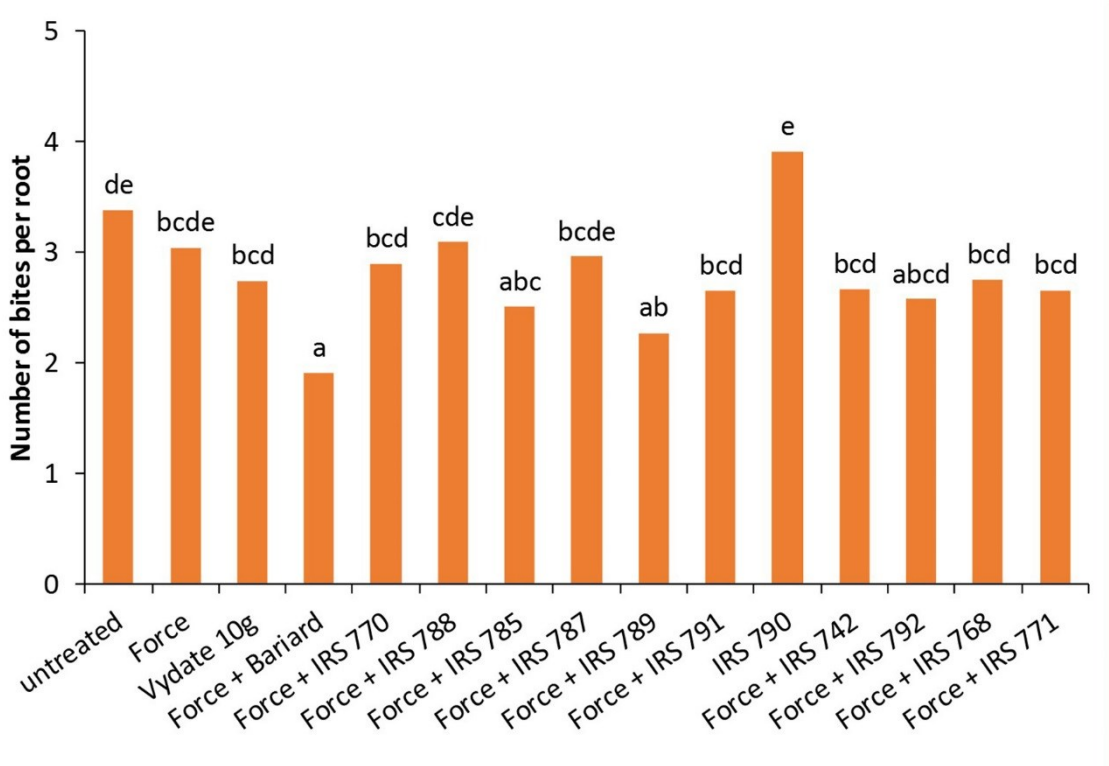

Figure 2: Mean number of bites per plant root for each treatment in Dronten (p=0.008). Different letters indicate significant differences. Data was log transformed (Log10(x+0.001)) to fit normal distribution and analyzed by ANOVA.

3.3 Leaf damage

The number of bites per leaf were assessed in Dronten and Zeewolde. However, this measurement was not representative for damage caused by abovegroud feeding (Photo 2). For example, the plant in Photo 2B only has three visual bites. However, after mass feeding on the plants' heart, this plant will not develop further. This damage is much more severe than plants that have many bites in the leaves but a healthy heart. Therefore this data was not further analyzed and percentage of plants that showed stunted growth was used instead.

Photo 2: Leaf damage by pygmy mangold beetle, pictures from field trial in Zeewolde. A: mass feeding from the heart of the plant (3 May). B: black heart of the plant after feeding from pygmy mangold beetle (3 May). C: plant with stunted growth due to pygmy mangold beetle feeding from leaves (24 May).

In Zeewolde, Force with additional application of Bariard resulted in lowest number of plants with stunted growth (Figure 3). This is followed by Force + IRS 785, Force + IRS 789, Force + IRS 792 or Force + IRS 742. Since Force is known not to be systemic, plants treated with Force are not protected from aboveground damage. However, plots treated with Force showed significant less plants with stunted growth than untreated plants. This may be because Force causes mortality of pygmy mangold beetles belowground, hence less pygmy beetles will appear aboveground. Vydate 10G gave similar protection to Force, it was expected that due to systemic activity, foliar tissue would be protected. Vydate 10G was less effective on belowground beetles than Force (lower plantstand density), but there was no significant difference in stunted plants compared to Force. This may indicate some activity of Vydate 10G in the leaves. However, dry soil conditions in combination with high pygmy mangold pressure resulted in low overall efficacy of Vydate in Zeewolde. In Dronten, no significant differences between treatments were found for percentage of plants that showed stunted growth. This is most likely because of lower pygmy mangold beetle pressure. Bites in the leaves were observed, but for most plants this didn't result in stunted growth.

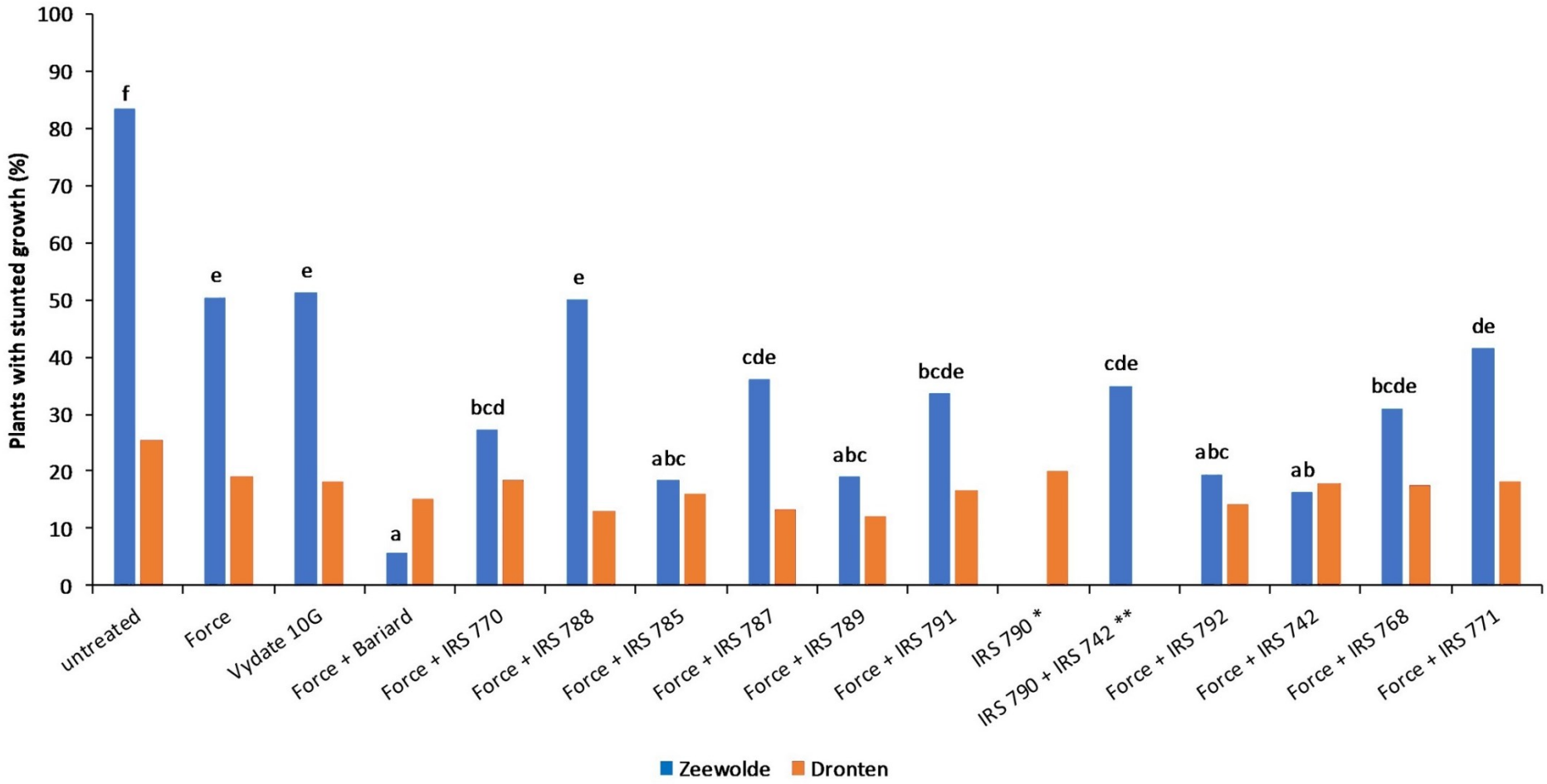

Figure 3: Percentage of plants that showed stunted growth on 24 May (Zeewolde) and 27 May (Dronten). Plants were scored "stunted" when they showed thickening of the leaves, missing leaves and/or blackened hearts caused by feeding of pygmy mangold beetles. Different letters indicate significant differences between treatments for Zeewolde ($p<0.001$; LSD=17.76). No significant differences were found between treatments in Dronten ($p=0.136$; LSD= 7.612). Data was analyzed by REML.

3.4 Phytotoxicity, vigour and canopy closure

No signs of phytotoxicity caused by insecticides were observed during the trial (Annexes B and C). Canopy closure was scored, however, because of the few plants per plot it was difficult to give scores and data is therefore unreliable. Data can be found in annex B6 and C6 but is not further discussed in this report. Results on plant vigour can be found in Table 2a and 2b. In both field trials, plants in plots with Bariard application and IRS 789 application had highest vigour, untreated plants had lowest vigour. Results in plant vigour in Zeewolde and Dronten are similar, except for plants treated with Vydate 10G. Plants in Dronten scored remarkably high on plant vigour compared to Zeewolde, which can be related to lower pygmy mangold beetle pressure.

Table 2a: Plant vigour in Zeewolde (27 May) on a scale from 1 (bad) to 10 (excellent). Different letters indicate significant differences in plant vigour for Zeewolde ($p<0.001$; LSD 5% = 1.59). Data was analyzed by ANOVA.

treatment	*vigour*	
untreated	1.5	a
Vydate 10G	3.0	ab
IRS 790 + IRS 742	4.3	bc
Force	4.5	bc
Force + IRS 791	4.5	bc
Force + IRS 787	4.8	cd
Force + IRS 788	5.3	cd
Force + IRS 792	5.3	cd
Force + IRS 768	5.5	cd
Force + IRS 771	5.5	cd
Force + IRS 770	5.8	cde
Force + IRS 742	6.3	def
Force + IRS 785	6.3	def
Force + Bariard	7.3	ef
Force + IRS 789	7.5	f
P[1]-value	<0.001	
LSD[2] 5%	1.59	

[1] P = probability
[2] LSD = least significant difference

Table 2b: Plant vigour in Dronten (27 May) on a scale from 1 (bad) to 10 (excellent). Different letters indicate significant differences in plant vigour for Dronten ($p<0.001$; LSD 5% = 1.03). Data was analyzed by ANOVA.

treatment	*vigour*	
untreated	3.8	a
IRS 790	4.5	ab
Force + IRS 768	5.5	bc
Force + IRS 785	5.5	bc
Force + IRS 788	5.5	bc
Force + IRS 770	5.8	c
Force + IRS 787	6.0	c
Force + IRS 792	6.0	c
Force	6.3	cd
Force + IRS 742	6.3	cd
Force + IRS 771	6.3	cd
Force + IRS 791	6.3	cd
Vydate 10G	6.5	cd
Force + Bariard	7.3	d
Force + IRS 789	7.3	d
P[1]-value	<0.001	
LSD[2] 5%	1.03	

[1] P = probability
[2] LSD = least significant difference

3.5 Yield

In Dronten, treatment IRS 790 had the lowest yield, although this was not significantly different from the untreated control (Table 3). This low yield was a result of the low plant stand density (Figure 1). This also holds for Zeewolde for treatment IRS 790 + IRS 742, Vydate and untreated plants (Table 4; Figure 1). In Dronten, treatments with Vydate and Force + spray applications did not significantly differ in yield (root weight, sugar weight and financial yield) compared to plants only treated with Force. This was as expected since there were no significant differences in percentage of plants showing stunted growth between treatments (Figure 3). Although in Zeewolde treatments with Force + Bariard, Force + IRS 785, Force + IRS 789, Force + IRS 792 and Force + IRS 742 resulted in a significantly lower number of plants with stunted growth compared to only Force, this did not result in higher yield. In both field trials, seeds treatment with Force and additional insecticide application did not result in higher yield compared to seed treatment with Force only. Spraying costs were not taken into account. In this study, the financial benefit of insecticide spraying was not shown. However, damage by pygmy mangold beetles can vary through the years. Relatively low temperatures in May this year (Figure 7) may have resulted in a low activity of aboveground pygmy mangold beetles. Therefore, this will study be repeated in 2020.

Table 3: Sugar beet yield (1 November): Root weight, sugar percentage, sugar weight and financial yield of the field trial in Dronten. Data was analyzed by REML.

treatment	*root weight (ton/ha)*		*sugar (%)*		*sugar weight (ton/ha)*		*financial yield (€/ha)*	
IRS 790	71.0	a	17.0	a	12.1	a	2388	a
untreated	74.0	a	17.0	ab	12.6	a	2452	a
Force + IRS 742	96.3	b	17.6	cd	17.0	b	3296	b
Vydate 10G	96.2	b	17.7	cd	17.1	b	3308	bc
Force + IRS 770	100.6	b	17.3	abc	17.4	b	3373	bc
Force + Bariard	101.6	b	17.4	bcd	17.7	b	3472	bc
Force	101.9	b	17.6	cd	17.9	b	3526	bc
Force + IRS 768	102.8	b	17.6	cd	18.1	b	3539	bc
Force + IRS 792	102.9	b	17.6	cd	18.1	b	3601	bc
Force + IRS 791	105.0	b	17.5	cd	18.3	b	3612	bc
Force + IRS 771	104.5	b	17.7	cd	18.5	b	3619	bc
Force + IRS 787	105.6	b	17.8	d	18.8	b	3621	bc
Force + IRS 785	103.6	b	17.8	d	18.4	b	3665	bc
Force + IRS 788	103.9	b	17.7	cd	18.4	b	3701	bc
Force + IRS 789	105.1	b	17.8	d	18.7	b	3779	c
P[1]-value	<0.001		<0.001		<0.001		<0.001	
LSD[2] 5%	13.14		0.44		2.39		479.6	

[1] P = probability
[2] LSD = least significant difference

Table 4: Sugar beet yield (28 October): Root weight, sugar percentage, sugar weight and financial yield of the field trial in Zeewolde. Data was analyzed by REML.

treatment	*root weight (ton/ha)*		*sugar (%)*		*sugar weight (ton/ha)*		*financial yield (€/ha)*	
untreated	23.1	a	13.1	a	3.0	a	360	a
IRS 790 + IRS 742	67.5	b	13.6	ab	9.2	b	1259	b
Vydate 10G	73.3	b	13.9	b	10.3	b	1518	b
Force + IRS 791	110.3	c	15.1	cd	16.6	c	2785	c
Force + IRS 771	113.8	cd	15.1	cd	17.2	cd	2829	c
Force + IRS 742	121.5	cd	14.8	c	18.0	cd	2914	cd
Force + IRS 770	116.5	cd	15.1	cd	17.6	cd	2947	cd
Force + IRS 787	116.7	cd	15.1	cd	17.7	cd	3006	cd
Force + IRS 792	123.9	cd	15.0	cd	18.5	cd	3012	cd
Force + IRS 788	119.4	cd	15.1	cd	18.0	cd	3021	cd
Force	125.2	d	14.9	cd	18.7	cd	3047	cd
Force + IRS 768	117.0	cd	15.4	cd	18.0	cd	3076	cd
Force + IRS 785	117.7	cd	15.4	d	18.1	cd	3119	cd
Force + IRS 789	123.9	cd	15.1	cd	18.7	cd	3135	cd
Force + Bariard	127.2	d	15.1	cd	19.2	d	3266	d
P[1]-value	<0.001		<0.001		<0.001		<0.001	
LSD[2] 5%	14.13		0.53		2.09		398.8	

[1] P = probability
[2] LSD = least significant difference

3.6 Monitoring

Higher pygmy mangold pressure in Zeewolde is clearly visible in the number of flying pygmy mangold beetles trapped, compared to Dronten (Figure 4). In Zeewolde, the asparagus beetle stick, blue-, yellow- and white sticky plates trapped significantly more pygmy mangold beetles compared to the water pans. In Dronten, the asparagus beetle stick trapped highest

number of pygmy beetles compared to all other traps, although this was not significantly different from the yellow water pan. No preference for a specific color was found for the water pans or for the sticky plates in this study.

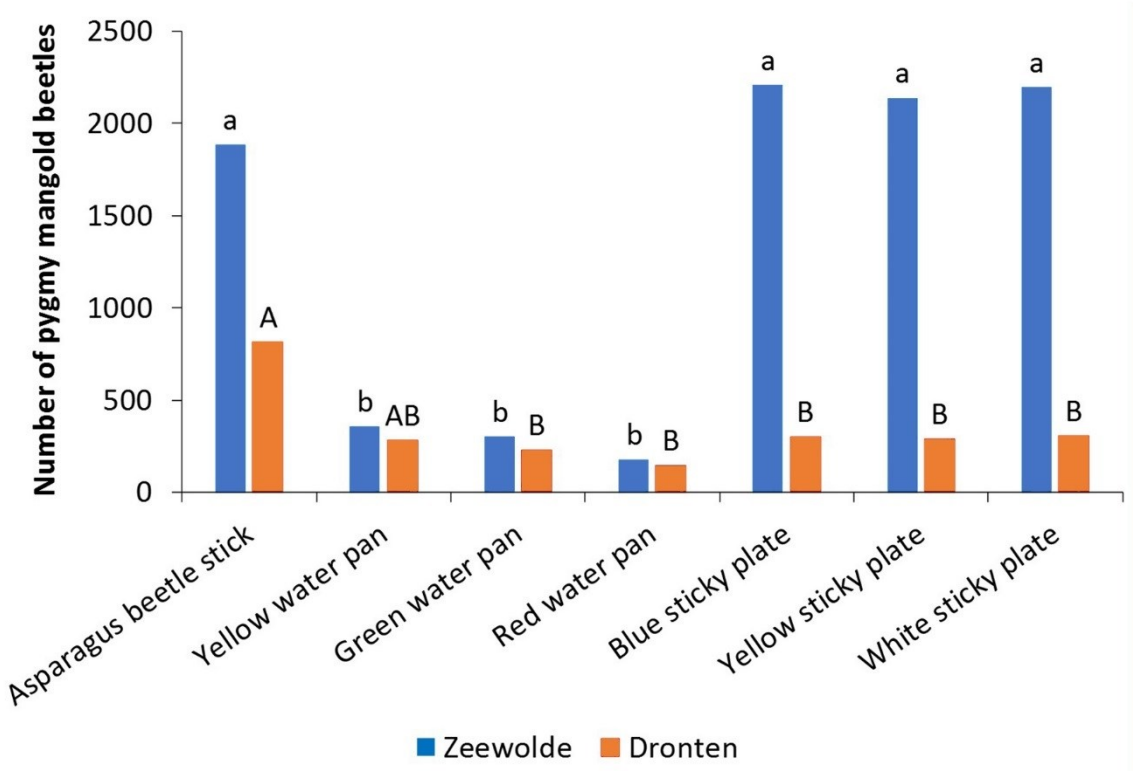

Figure 4: Total number of pygmy mangold beetles trapped in various monitoring systems from 10 April – 30 May, 2019. Different lowercase letters indicate significant differences between treatments at Zeewolde ($p<0.001$; LSD 5%=150.1), uppercase letter indicate significant differences at Dronten ($p=0.021$; LSD 5%=92.37).

Previous study has shown that mass flights can occur when the temperature approaches 15 °C (Heijbroek & Huijbregts, 1995). This trend was also seen in the trials in Dronten and Zeewolde. When air temperature exceeded 15 °C, a higher number of pygmy beetles was found in the traps (Figure 5).

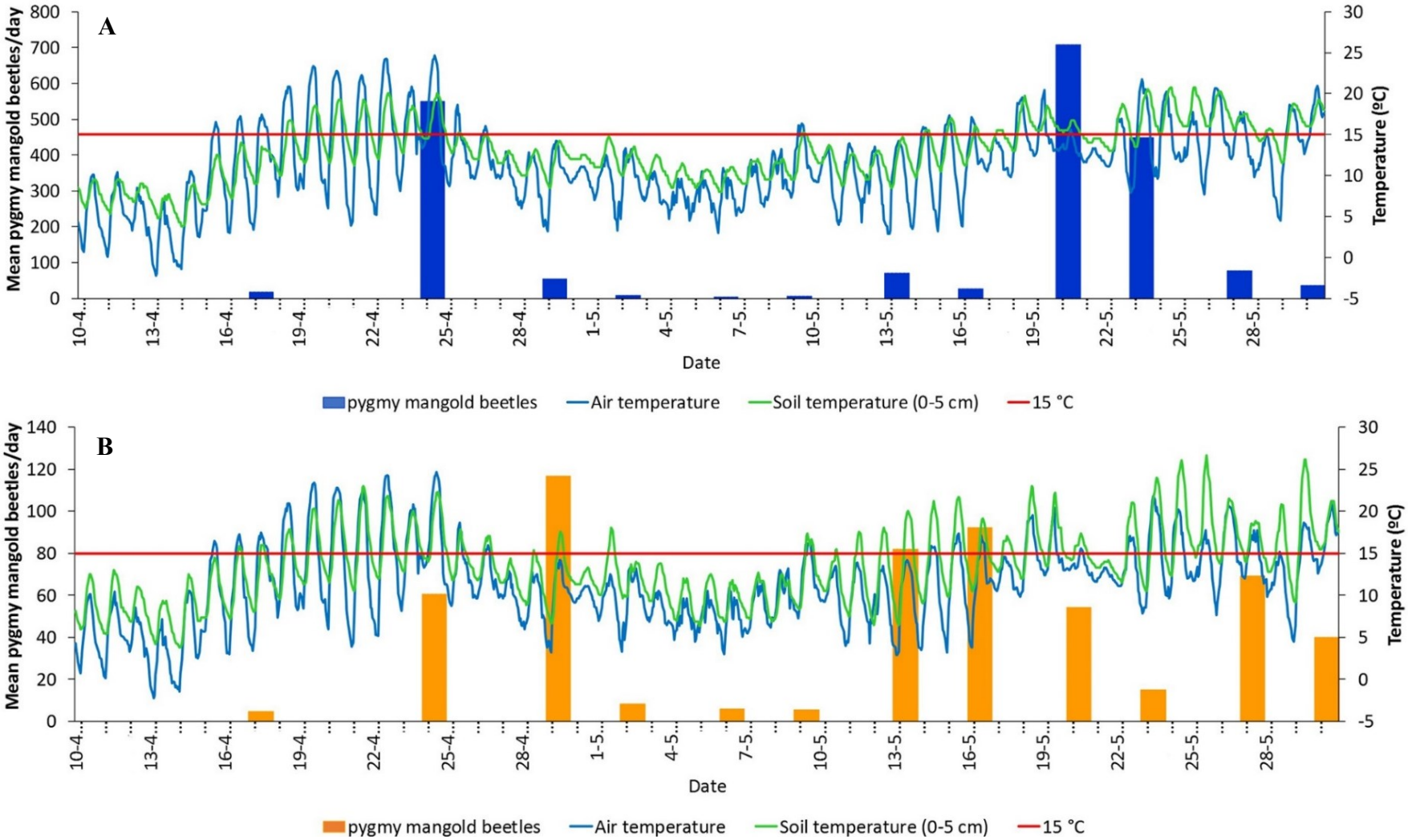

Figure 5: Air* and soil (5-10 cm deep) temperatures and mean number of pygmy mangold beetles trapped per day in monitoring systems combined, from 10-4 to 30-5 in Zeewolde (A) and Dronten (B). Traps were emptied once a week from 10-4 to 24-4 and twice a week from 24-4 to 30-5. Number of pygmy mangold beetles trapped is calculated by total number divided by the number of days between collections. Mean number per day is indicated with a bar on the day of collection.

* data retrieved from KNMI weather station Lelystad.

4. Conclusions

- Treatments with Force resulted in significantly higher plant numbers and financial yield compared to untreated. Plant stand density in and financial yield of plots treated with Vydate 10G was at low pressure of pygmy mangold beetles in Dronten similar to Force, but at high pressure of pygmy mangold beetles in Zeewolde, the efficacy of Vydate 10G was much lower than Force. Force with additional insecticide application did not result in higher plant stand density or higher yield.
- No relation between treatment, plant stand density and bites in sugar beet roots was found.
- A financial benefit of foliar insecticide applications was not proven in this study.
- At high pressure of pygmy mangold beetles in Zeewolde, Force with additional application of Bariard resulted in the lowest number of plants with stunted growth, but this was not significantly lower than by Force + IRS 785, Force + IRS 789, Force + IRS 792 and Force + IRS 742. All of these treatments had significantly less plants with stunted growth than untreated and Force only.
- At low pressure of pygmy mangold beetles in Dronten, no significant differences were found between Force and Force with additional insecticide application in the number of plants, stunted growth and yield.
- No phytotoxity was observed in any of the treatments.
- Sticky traps (asparagus stick, blue-, white- and yellow sticky plates) were most suitable for trapping pygmy mangold beetles. No preference for a specific color was found in this study. When air temperature exceeded 15 °C, more pygmy mangold beetles were trapped.

5. References

- Dunning, R.A. (1982). Pygmy beetle. *Leaflet-Ministry of Agriculture*.
- Heijbroek, W. & Huijbregts, A.W.M. (1995). Fungicides and insecticides applied to pelleted sugar-beet seeds—III. Control of insects in soil. *Crop protection*, *14*(5), 367-373.
- Raaijmakers, E.E.M. (2010). Report on the use of Force (A13219) seed treatment for the control of pygmy mangold beetles (*Atomaria linearis*) in sugar beet in 2010. IRS Rapport 10V08, Bergen op Zoom, p35.

Annex A GEP Certificate

Netherlands Food and Consumer
Product Safety Authority
Ministry of Economic Affairs

Certificate

of Official Recognition of Efficacy Testing Organisations in the Netherlands
This certifies that, in conformity with the request of March 26, 2014

STICHTING IRS

Residing: Van Konijnenburgweg 24, Bergen op Zoom, the Netherlands

has officially been recognised as an organisation for efficacy testing in the Netherlands.

As has been laid down in the 'Regeling gewasbeschermingsmiddelen en biociden' (Regulation Crop Protection Products and Biocides) of September 26, 2007 (Staatscourant 2007, 386).

This recognition commences on: June 19, 2014
and expires on: June 19, 2020

The above organisation is competent to carry out efficacy trials/tests in the categories mentioned in the annex of this certificate.

Utrecht, August 18, 2014

For the Minister of Economic Affairs,

H.A. Harmsma LL M, Bsc

Chief Inspector of the Netherlands Food and Consumer Product Safety Authority

CERTIFICATE NUMBER: NL_GEP_04149620

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Annex

Stichting IRS is officially recognised as being competent to carry out efficacy trials/tests in the following categories:

- Outdoor crops of sugar beet and cichory

This annex has been approved by H.A. Harmsma LL M, Bsc

Chief Inspector of the Food and Consumer Product Safety Authority

Annex B Zeewolde

Annex B1 Location field trial Zeewolde

Number and name site: 19-03-01.01 Pygmy mangold beetle Zeewolde
(Coordinates: 52.367121, 5.326214)

Annex B2 Trial scheme

Trial field: 19-03-01.01

Number of replications: 4

Nett plot size (m): 12x3 Gross plot size (m): 15.5x3

C **D**

4	3	5	10	2				12	1	11	14	2
9	13	15	8	14				5	3	7	10	13
6	11	1	7	12				8	9	4	6	15
5	7	8	11	9				13	6	3	2	10
12	15	4	1	6				11	15	5	8	1
3	2	14	13	10	3 m. gross	3 m. gross	3 m. gross	7	4	14	9	12

A **B**

Annex B3 General data

soil type:	clay soil	Organic matter=	4.3%
	pH-CaCl= 6.8	parts < 16 µm =	49%
	K-value = 29	Pw =	19 mg P_2O_5 per L of soil
	$CaCO_3$ = 6.5%		
preceding crops:	2018 sugar beet		
	2017 grass		
	2016 winter wheat		
	2015 potato		
	2014 potato		
drilling date:	2 April 2019		
variety:	Florena KWS		
distance in row:	17.0 cm		

Annex B4 Overview of weather conditions during spraying

Method:	**Foliar Spray**
Equipment:	"AZO-perslucht" (van der Wey)
Speed:	3.6 km/h
Nozzle type:	Airmix 110-05 (flat fan nozzle) + Airmix OC 05 (end nozzle)
Nozzle distance:	50 cm between Airmix 110-05; 70 cm for Airmix OC 05
Boom height:	40-50 cm
Pressure:	4.85 bar
Spray volume:	500 (l/ha)

Table B4.1. Overview of weather conditions during insecticide spraying.

conditions Zeewolde	*26-4-2019*	*7-5-2019*	*13-5-2019*
BBCH	10-12	12-14	14-16
time of spraying	12:00 – 14:30	13:00 – 15:30	19:30 – 21:30
clouds	partially clouded	heavily clouded	none, clear sky
wind speed (m/s)	2	3	4
relative air humidity (%)	55	60	50
temperature during spraying (℃)	15	12	12
other	dry canopy, wet soil	dry canopy	dry canopy, dry soil

Annex B5 Insect traps

Coordinates: 52.367121, 5.326214 (Zeewolde)

Annex B6 Field data

Table B6.1. Final plant stand (percentage of the number of sown seeds) per replication at the field trial in Zeewolde (21 May 2019).

	percentage of plants per replication				
treatment	*A*	*B*	*C*	*D*	*average*
Force + Bariard	66.6	41.4	51.7	71.2	57.7
Force	63.4	47.8	62.0	56.7	57.5
Force + IRS 742	53.5	56.0	47.1	40.7	49.3
Force + IRS 768	65.9	63.0	54.2	62.0	61.3
Force + IRS 770	59.9	61.3	50.6	67.3	59.8
Force + IRS 771	63.4	61.3	57.4	66.2	62.1
Force + IRS 785	66.2	47.1	57.7	56.7	56.9
Force + IRS 787	52.4	60.6	37.5	46.4	49.2
Force + IRS 788	55.6	52.1	49.6	44.3	50.4
Force + IRS 789	51.4	68.4	49.2	42.9	52.9
IRS 790 + IRS 742	19.8	15.9	5.3	11.0	13.0
Force + IRS 791	56.7	61.6	56.7	56.7	57.9
Force + IRS 792	68.7	70.5	59.1	40.0	59.6
untreated	5.7	2.5	1.4	0.4	2.5
Vydate 10G	25.9	12.8	18.8	9.9	16.8

Table B6.2. Percentage of plants with deviating growth per replication at the field trial in Zeewolde (24 May 2019).

	percentage of plants with deviating growth per replication				
treatment	*A*	*B*	*C*	*D*	*average*
Force + Bariard	66.6	41.4	51.7	71.2	57.7
Force	63.4	47.8	62.0	56.7	57.5
Force + IRS 742	53.5	56.0	47.1	40.7	49.3
Force + IRS 768	65.9	63.0	54.2	62.0	61.3
Force + IRS 770	59.9	61.3	50.6	67.3	59.8
Force + IRS 771	63.4	61.3	57.4	66.2	62.1
Force + IRS 785	66.2	47.1	57.7	56.7	56.9
Force + IRS 787	52.4	60.6	37.5	46.4	49.2
Force + IRS 788	55.6	52.1	49.6	44.3	50.4
Force + IRS 789	51.4	68.4	49.2	42.9	52.9
IRS 790 + IRS 742	19.8	15.9	5.3	11.0	13.0
Force + IRS 791	56.7	61.6	56.7	56.7	57.9
Force + IRS 792	68.7	70.5	59.1	40.0	59.6
untreated	5.7	2.5	1.4	0.4	2.5
Vydate 10G	25.9	12.8	18.8	9.9	16.8

Table B6.3. Vigour (1-10: 1 = bad, 10 = excellent) per plot per replication at the field trial in Zeewolde (27 May 2019).

	vigour (1-10) per replication				
treatment	*A*	*B*	*C*	*D*	*average*
Force + Bariard	7.0	7.0	7.0	8.0	7.3
Force	6.0	4.0	4.0	4.0	4.5
Force + IRS 742	6.0	7.0	6.0	6.0	6.3
Force + IRS 768	7.0	7.0	6.0	2.0	5.5
Force + IRS 770	5.0	7.0	6.0	5.0	5.8
Force + IRS 771	4.0	7.0	6.0	5.0	5.5
Force + IRS 785	7.0	6.0	6.0	6.0	6.3
Force + IRS 787	4.0	7.0	5.0	3.0	4.8
Force + IRS 788	5.0	6.0	6.0	4.0	5.3
Force + IRS 789	7.0	8.0	7.0	8.0	7.5
IRS 790 + IRS 742	6.0	5.0	3.0	3.0	4.3
Force + IRS 791	3.0	6.0	4.0	5.0	4.5
Force + IRS 792	5.0	7.0	6.0	3.0	5.3
untreated	2.0	2.0	2.0	0.0	1.5
Vydate 10G	5.0	2.0	3.0	2.0	3.0

Table B6.4. Canopy closure (1-10: 1 = open, 10 = fully closed) per plot per replication at the field trial in Zeewolde (11 June 2019).

	canopy closure (1-10) per replication				
treatment	*A*	*B*	*C*	*D*	*average*
Force + Bariard	9.0	8.0	7.0	8.0	8.0
Force	6.0	5.0	6.0	4.0	5.3
Force + IRS 742	6.0	8.0	7.0	5.0	6.5
Force + IRS 768	8.0	7.0	5.0	5.0	6.3
Force + IRS 770	5.0	5.0	5.0	5.0	5.0
Force + IRS 771	5.0	7.0	7.0	7.0	6.5
Force + IRS 785	7.0	7.0	6.0	5.0	6.3
Force + IRS 787	5.0	7.0	5.0	4.0	5.3
Force + IRS 788	6.0	5.0	5.0	5.0	5.3
Force + IRS 789	7.0	9.0	5.0	8.0	7.3
IRS 790 + IRS 742	7.0	5.0	2.0	5.0	4.8
Force + IRS 791	5.0	8.0	5.0	7.0	6.3
Force + IRS 792	7.0	8.0	6.0	6.0	6.8
untreated	1.0	1.0	1.0	1.0	1.0
Vydate 10G	4.0	2.0	3.0	1.0	2.5

Table B6.5. Average number of bites in the leaves per plant for each treatment per replication at the field trial in Zeewolde (3 May 2019).

	Average number of bites in the leaves per plant per replication				
treatment	*A*	*B*	*C*	*D*	*average*
Force + Bariard	2.4	3.2	2.5	3.2	2.8
Force	3.2	2.6	1.2	3.2	2.6
Force + IRS 742	2.7	4.1	4.0	2.9	3.4
Force + IRS 768	4.1	6.2	4.0	3.9	4.5
Force + IRS 770	4.4	7.1	3.8	1.7	4.3
Force + IRS 771	2.7	5.3	4.7	3.2	4.0
Force + IRS 785	3.2	0.5	3.4	2.4	2.4
Force + IRS 787	3.4	6.3	6.5	3.0	4.8
Force + IRS 788	4.1	4.4	3.5	3.4	3.8
Force + IRS 789	3.7	5.0	3.1	3.8	3.9
Force + IRS 791	4.0	6.1	3.8	2.8	4.2
Force + IRS 792	3.6	3.8	2.7	3.0	3.3
IRS 790 + IRS 742	2.9	2.8	2.5	3.0	2.8
untreated	4.9	4.9	5.6	*	3.8
Vydate 10G	5.1	1.7	4.3	4.8	4.0

Table B6.6. Average percentage of damaged leaf area (true leaves) per plant for each treatment per replication at the field trial in Zeewolde (3 May 2019).

	% damaged leaf area (true leaves) per plant per replication				
treatment	*A*	*B*	*C*	*D*	*average*
Force + Bariard	16.9	18.8	33.3	25.0	23.5
Force	32.5	29.9	38.9	34.7	34.0
Force + IRS 742	28.2	33.3	16.1	41.7	29.8
Force + IRS 768	9.6	6.9	36.9	57.1	27.6
Force + IRS 770	22.9	7.9	45.4	40.6	29.2
Force + IRS 771	29.4	30.3	61.3	22.9	35.9
Force + IRS 785	24.6	57.1	35.0	30.3	36.8
Force + IRS 787	58.0	7.6	43.3	71.2	45.0
Force + IRS 788	40.7	45.7	42.8	36.4	41.4
Force + IRS 789	34.2	25.3	64.2	36.9	40.1
Force + IRS 791	47.2	13.0	75.6	37.5	43.3
Force + IRS 792	9.6	7.2	48.2	21.4	21.6
IRS 790 + IRS 742	8.9	32.4	*	36.5	19.4
untreated	28.6	61.1	60.0	*	49.9
Vydate 10G	21.4	39.1	35.1	50.0	36.4

Table B6.7. Percentage of plants showing signs of phytotoxicity after insecticide application at the field trial in Zeewolde (24 May 2019).

	% plants with phytotoxicity				
treatment	*A*	*B*	*C*	*D*	*average*
Force + Bariard	0	0	0	0	0
Force	0	0	0	0	0
Force + IRS 742	0	0	0	0	0
Force + IRS 768	0	0	0	0	0
Force + IRS 770	0	0	0	0	0
Force + IRS 771	0	0	0	0	0
Force + IRS 785	0	0	0	0	0
Force + IRS 787	0	0	0	0	0
Force + IRS 788	0	0	0	0	0
Force + IRS 789	0	0	0	0	0
Force + IRS 791	0	0	0	0	0
Force + IRS 792	0	0	0	0	0
IRS 790 + IRS 742	0	0	0	0	0
untreated	0	0	0	0	0
Vydate 10G	0	0	0	0	0

Table B6.8. Yield (root weight, sugar content, sugar weight, financial yield) for each treatment per replication. Harvested on 28 October 2019.

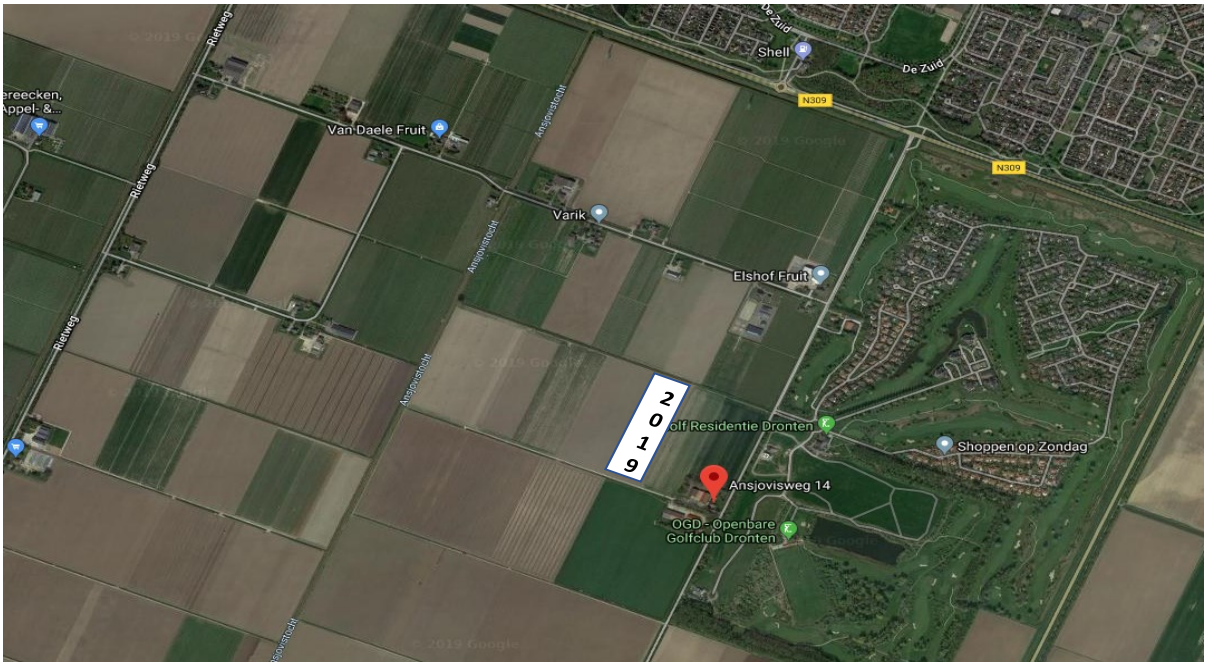
treatment	rep	*root weight (ton/ha)*	*sugar (%)*	*sugar weight (ton/ha)*	*financial yield (€/ha)*
Force	A	128.8	15.1	19.4	3216
	B	118.1	14.4	17.0	2640
	C	124.2	15.0	18.6	3096
	D	129.9	15.1	19.7	3235
Force + Bariard	A	128.8	15.1	19.4	3216
	B	118.1	14.4	17.0	2640
	C	124.2	15.0	18.6	3096
	D	129.9	15.1	19.7	3235
Force + IRS 742	A	130.9	15.1	19.7	3238
	B	123.4	14.7	18.1	2950
	C	123.6	14.8	18.3	3213
	D	131.0	15.8	20.6	3662
Force + IRS 768	A	111.2	14.8	16.5	2682
	B	134.4	15.4	20.7	3620
	C	127.2	14.3	18.1	2769
	D	113.1	14.7	16.7	2587
Force + IRS 770	A	116.4	15.5	18.1	3058
	B	116.7	15.4	18.0	3129
	C	118.0	15.1	17.8	3041
	D	*	*	*	*
Force + IRS 771	A	132.9	15.1	20.0	3326
	B	114.6	15.3	17.5	2940
	C	114.6	15.0	17.1	2847
	D	103.8	15.1	15.7	2675
Force + IRS 785	A	111.0	15.4	17.1	2858
	B	115.7	14.9	17.3	2835
	C	118.1	15.1	17.9	3062
	D	110.5	14.9	16.5	2559
Force + IRS 787	A	128.4	15.2	19.6	3280
	B	121.6	15.0	18.2	3041
	C	107.4	15.8	17.0	3048
	D	113.3	15.7	17.8	3108

Force + IRS 788	A	111.2	15.8	17.6	3386
	B	119.9	15.5	18.5	3139
	C	123.7	14.9	18.5	3066
	D	112.0	14.3	16.0	2432
Force + IRS 789	A	111.8	15.3	17.1	2979
	B	112.6	15.3	17.3	2993
	C	136.5	15.0	20.5	3428
	D	116.6	14.7	17.2	2686
Force + IRS 791	A	128.1	15.5	19.8	3438
	B	129.7	14.9	19.3	3165
	C	119.8	15.0	18.0	3022
	D	117.9	15.0	17.6	2915
Force + IRS 792	A	109.6	15.0	16.4	2661
	B	115.3	15.0	17.3	2925
	C	108.5	15.3	16.6	2860
	D	107.7	15.1	16.2	2693
IRS 790 + IRS 742	A	114.8	15.1	17.4	2872
	B	139.7	14.5	20.2	3035
	C	113.8	15.4	17.5	3049
	D	127.4	14.9	18.9	3092
untreated	A	79.2	14.1	11.2	1672
	B	83.0	13.3	11.0	1412
	C	52.2	13.4	7.0	943
	D	55.6	13.5	7.5	1011
Vydate 10G	A	40.0	13.0	5.2	628
	B	17.5	13.2	2.3	296
	C	32.0	12.9	4.1	464
	D	3.1	13.5	0.4	52

Annex C Dronten

Annex C1 Location field trial Dronten

Number and name site: 19-03-01.01 Pygmy mangold beetle Dronten
(Coordinates: 52.499175, 5.703982)



Annex C2 Trial scheme

Trial field: 19-03-01.01

Number of replications: 4

Nett plot size (m): 12x3 Gross plot size (m): 15.5x3

D

8	3	2
5	1	15
6	12	14
7	13	9
4	10	11
1	13	3
14	5	4
11	12	15
7	2	8
6	10	9
3	15	1
4	11	7
5	9	14
6	8	13
10	2	12
12	6	3
8	14	5
11	2	15
7	13	4
10	9	1

A

Annex C3 General data

soil type:	clay soil	Organic matter=	2.9%
	pH-CaCl= 7.4	parts < 16 µm =	unknown
	K-value = 23	Pw =	31 mg P_2O_5 per L of soil
	$CaCO_3$ = 7.6%		
preceding crops:	2018 sugar beet		
	2017 winter wheat		
	2016 potato		
	2015 unions		
	2014 sugar beet		
drilling date:	9 April 2019		
variety:	Florena KWS		
distance in row:	17.0 cm		

Annex C4 Overview of weather conditions during spraying

Method:	**Foliar Spray**
Equipment:	"AZO-perslucht" (van der Wey)
Speed:	3.6 km/h
Nozzle type:	Airmix 110-05 (flat fan nozzle) + Airmix OC 05 (end nozzle)
Nozzle distance:	50 cm between Airmix 110-05; 70 cm for Airmix OC 05
Boom height:	40-50 cm
Pressure:	4.85 bar
Spray volume:	500 (l/ha)

Table C4.1: Overview of weather conditions during insecticide spraying.

conditions Dronten	*26-4-2019*	*7-5-2019*	*13-5-2019*
BBCH	12	12	10; 11; 12; 14
time of spraying	15:00-17:00	17:00 – 19:00	17:30 – 19:30
clouds	heavily clouded	heavily clouded	none, clear sky
wind speed (m/s)	3	2	4
relative air humidity (%)	55	72	50
temperature during spraying (°C)	17	14	15
other	dry canopy, dry soil	rainy weather, dry canopy, wet soil	dry canopy, dry soil

Annex C5 Insect traps

(Coordinates: 52.499175, 5.703982)

Annex C6 Field data

Table C6.1. Final plant stand (percentage of the number of sown seeds) per replication at the field trial in Dronten (21 May 2019).

	plant stand density (%) per replication				
treatment	*A*	*B*	*C*	*D*	*average*
Force + Bariard	79.3	85.4	88.5	74.4	81.9
Force	82.2	87.8	81.5	82.2	83.4
Force + IRS 742	94.2	87.5	75.8	81.8	84.8
Force + IRS 768	79.0	86.4	58.1	73.3	74.2
Force + IRS 770	86.4	79.3	36.5	82.9	71.3
Force + IRS 771	78.6	91.4	68.7	82.5	80.3
Force + IRS 785	82.9	83.6	89.6	75.4	82.9
Force + IRS 787	88.5	86.4	85.7	80.8	85.4
Force + IRS 788	66.6	85.7	77.2	65.2	73.7
Force + IRS 789	79.0	86.1	79.3	73.3	79.4
IRS 790	10.6	28.0	25.1	48.2	28.0
Force + IRS 791	71.5	88.2	74.0	77.2	77.7
Force + IRS 792	78.6	82.5	83.2	85.0	82.3
untreated	24.1	43.9	20.5	45.0	33.4
Vydate 10G	74.0	75.4	70.1	77.9	74.4

Table C6.2. Percentage of plants with deviating growth per replication at the field trial in Dronten (27 May 2019).

	plants with stunted growth (%) per replication				
treatment	*A*	*B*	*C*	*D*	*average*
Force + Bariard	15.6	18.3	11.6	15.2	15.2
Force	16.8	22.6	19.1	18.1	19.2
Force + IRS 742	7.5	9.7	9.8	29.9	14.2
Force + IRS 768	13.9	23.4	10.4	22.7	17.6
Force + IRS 770	15.2	12.5	31.1	15.0	18.4
Force + IRS 771	16.7	15.1	24.7	16.3	18.2
Force + IRS 785	17.1	18.2	10.7	18.3	16.1
Force + IRS 787	8.8	13.1	11.6	20.2	13.4
Force + IRS 788	8.0	14.0	10.6	19.6	13.0
Force + IRS 789	7.6	9.1	18.8	13.0	12.1
IRS 790	13.3	24.1	21.1	21.3	20.0
Force + IRS 791	12.9	13.3	16.3	23.9	16.6
Force + IRS 792	12.6	22.3	16.6	19.6	17.8
untreated	17.6	32.3	32.8	18.9	25.4
Vydate 10G	16.7	12.7	24.2	19.5	18.3

Table C6.3. Vigour (1-10: 1 = bad, 10 = excellent) per plot per replication at the field trial in Dronten (27 May 2019).

	vigour (1-10) per replication				
treatment	*A*	*B*	*C*	*D*	*average*
Force + Bariard	7.0	8.0	7.0	7.0	7.3
Force	5.0	7.0	7.0	6.0	6.3
Force + IRS 742	7.0	7.0	5.0	6.0	6.3
Force + IRS 768	6.0	6.0	5.0	5.0	5.5
Force + IRS 770	6.0	6.0	5.0	6.0	5.8
Force + IRS 771	6.0	7.0	4.0	8.0	6.3
Force + IRS 785	5.0	6.0	5.0	6.0	5.5
Force + IRS 787	7.0	6.0	5.0	6.0	6.0
Force + IRS 788	4.0	6.0	6.0	6.0	5.5
Force + IRS 789	6.0	8.0	7.0	8.0	7.3
IRS 790	4.0	5.0	4.0	5.0	4.5
Force + IRS 791	6.0	7.0	6.0	6.0	6.3
Force + IRS 792	6.0	6.0	6.0	6.0	6.0
untreated	4.0	4.0	3.0	4.0	3.8
Vydate 10G	6.0	6.0	7.0	7.0	6.5

Table C6.4. Canopy closure (1-10: 1 = open, 10 = fully closed) per plot per replication at the field trial in Dronten (11 June 2019).

	canopy closure (1-10) per replication				
treatment	*A*	*B*	*C*	*D*	*average*
Force + Bariard	6.0	7.0	6.0	6.0	6.3
Force	5.0	6.0	5.0	6.0	5.5
Force + IRS 742	6.0	6.0	4.0	6.0	5.5
Force + IRS 768	5.0	5.0	6.0	6.0	5.5
Force + IRS 770	7.0	5.0	3.0	7.0	5.5
Force + IRS 771	6.0	5.0	4.0	7.0	5.5
Force + IRS 785	6.0	5.0	6.0	6.0	5.8
Force + IRS 787	7.0	6.0	5.0	6.0	6.0
Force + IRS 788	4.0	4.0	4.0	5.0	4.3
Force + IRS 789	6.0	6.0	6.0	7.0	6.3
IRS 790	3.0	4.0	3.0	5.0	3.8
Force + IRS 791	5.0	5.0	5.0	6.0	5.3
Force + IRS 792	6.0	7.0	5.0	6.0	6.0
untreated	2.0	3.0	2.0	4.0	2.8
Vydate 10G	6.0	6.0	6.0	7.0	6.3

Table C6.5. Number of bites per root per plot per replication at the field trial in Dronten (22 May 2019).

	number of bites per root				
treatment	*A*	*B*	*C*	*D*	*average*
Force + Bariard	1.5	1.8	2.7	1.5	1.9
Force	2.9	3.8	3.6	1.9	3.0
Force + IRS 742	2.6	2.2	3.0	2.9	2.7
Force + IRS 768	3.3	2.6	2.9	2.2	2.7
Force + IRS 770	2.4	3.6	2.4	3.2	2.9
Force + IRS 771	3.1	3.1	2.1	2.4	2.7
Force + IRS 785	1.9	3.2	2.1	2.7	2.5
Force + IRS 787	3.4	2.0	3.5	3.0	3.0
Force + IRS 788	2.8	3.2	3.3	3.1	3.1
Force + IRS 789	2.2	2.8	1.8	2.3	2.3
IRS 790	3.8	3.3	4.8	3.8	3.9
Force + IRS 791	2.4	3.3	2.6	2.2	2.6
Force + IRS 792	2.9	1.7	3.4	2.4	2.6
untreated	3.9	3.7	3.4	2.6	3.4
Vydate 10G	2.6	3.3	2.8	2.3	2.7

Table C6.6. Average percentage of damaged leaf area (first true leaves) per plant for each treatment per replication at the field trial in Dronten (15 May 2019).

	% damaged leaf area (true leaves) per plant per replication				
treatment	*A*	*B*	*C*	*D*	*average*
Force	12.0	30.1	42.6	6.4	20.9
Force + Bariard	12.7	6.3	12.2	4.2	8.1
Force + IRS 742	13.3	6.4	31.8		17.2
Force + IRS 768	7.1	23.5	33.5	8.1	15.9
Force + IRS 770	6.0	40.6	15.2	14.5	18.0
Force + IRS 771	4.8	30.8	10.2	1.4	8.3
Force + IRS 785	6.7	17.7	32.6	18.0	17.9
Force + IRS 787	26.8	9.5	49.6	17.1	27.3
Force + IRS 788	11.1	36.4	25.2	8.9	19.5
Force + IRS 789	11.2	24.9	11.9	6.7	14.2
Force + IRS 791	29.5	16.5	37.5	6.1	16.6
Force + IRS 792	4.4	12.3	36.5	5.3	14.7
IRS 790	33.8	36.6	62.9	20.0	37.1
untreated	34.9	17.6	36.9	15.7	25.5
Vydate 10G	8.6	8.6	3.4	3.5	5.9

Table C6.7. Percentage of plants showing signs of phytotoxicity after insecticide application at the field trial in Dronten (24 May 2019).

	% plants with phytotoxicity				
treatment	*A*	*B*	*C*	*D*	*average*
Force + Bariard	0	0	0	0	0
Force	0	0	0	0	0
Force + IRS 742	0	0	0	0	0
Force + IRS 768	0	0	0	0	0
Force + IRS 770	0	0	0	0	0
Force + IRS 771	0	0	0	0	0
Force + IRS 785	0	0	0	0	0
Force + IRS 787	0	0	0	0	0
Force + IRS 788	0	0	0	0	0
Force + IRS 789	0	0	0	0	0
Force + IRS 791	0	0	0	0	0
Force + IRS 792	0	0	0	0	0
IRS 790	0	0	0	0	0
untreated	0	0	0	0	0
Vydate 10G	0	0	0	0	0

Table C6.8. Yield (root weight, sugar content, sugar weight, financial yield) for each treatment per replication. Harvested on 1 November 2019.

treatment	rep	*root weight (ton/ha)*	*sugar (%)*	*sugar weight (ton/ha)*	*financial yield (€/ha)*
Force	A	106.1	17.4	18.5	3582
	B	101.1	17.2	17.4	3475
	C	93.7	17.8	16.7	3393
	D	106.6	17.8	19.0	3652
Force + Bariard	A	108.5	17.1	18.6	3564
	B	112.4	17.4	19.5	3691
	C	96.9	17.7	17.1	3496
	D	88.5	17.4	15.4	3138
Force + IRS 742	A	101.1	17.4	17.6	3359
	B	87.8	17.7	15.6	3086
	C	94.3	17.6	16.6	3218
	D	101.9	17.9	18.2	3522
Force + IRS 768	A	106.7	17.3	18.4	3655
	B	121.7	17.5	21.3	4094
	C	78.8	17.7	14.0	2758
	D	103.9	17.9	18.6	3647
Force + IRS 770	A	117.4	17.1	20.0	3781
	B	98.8	17.9	17.7	3423
	C	90.8	17.4	15.8	3156
	D	95.6	16.9	16.1	3133
Force + IRS 771	A	104.1	17.5	18.2	3301
	B	101.9	17.6	17.9	3649
	C	104.5	17.7	18.5	3691
	D	107.5	17.9	19.3	3833
Force + IRS 785	A	108.0	17.2	18.6	3774
	B	99.6	17.8	17.7	3489
	C	115.1	17.9	20.6	4070
	D	91.7	18.2	16.7	3329
Force + IRS 787	A	116.6	17.9	20.8	4096
	B	103.2	17.8	18.4	3375
	C	105.3	17.9	18.9	3748
	D	97.1	17.4	16.9	3266

Force + IRS 788	A	109.0	17.1	18.6	3528
	B	116.2	18.0	20.9	4282
	C	94.7	17.8	16.9	3471
	D	95.8	18.0	17.2	3521
Force + IRS 789	A	111.6	17.7	19.8	4026
	B	100.6	17.6	17.7	3593
	C	108.6	17.8	19.4	3779
	D	99.6	17.9	17.9	3716
Force + IRS 791	A	119.2	16.8	20.1	3884
	B	98.2	17.6	17.2	3519
	C	106.3	17.6	18.7	3646
	D	96.4	17.9	17.2	3399
Force + IRS 792	A	101.9	17.7	18.1	3596
	B	116.0	17.4	20.2	3861
	C	94.9	17.4	16.5	3359
	D	98.9	17.7	17.5	3586
IRS 790	A	64.5	16.3	10.5	1955
	B	74.0	17.0	12.6	2525
	C	61.2	17.0	10.4	2075
	D	84.3	17.5	14.8	2997
untreated	A	75.4	15.8	11.9	2135
	B	88.1	17.6	15.5	3058
	C	54.4	17.1	9.3	1823
	D	77.9	17.6	13.7	2794
Vydate 10G	A	98.6	17.4	17.2	3081
	B	104.0	18.1	18.8	3773
	C	97.9	17.8	17.4	3377
	D	84.5	17.6	14.9	3001