

Final Report

Evaluation of potential prunus rootstock for almond production – stage 2

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Project code:

AL16006

Project:

Evaluation of potential prunus rootstock for almond production – stage 2 (AL16006)

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Funding statement:

This project has been funded by Hort Innovation, using the almond research and development levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Publishing details:

ISBN 978-0-7341-4780-6

Published and distributed by: Hort Innovation

Level 7

141 Walker Street

North Sydney NSW 2060

Telephone: (02) 8295 2300

www.horticulture.com.au

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Summary

Almond plantings in Australia are predominantly grown on Nemaguard rootstock irrespective of soil type or management systems. While Nemaguard has several advantages, such as: nematode tolerance, easy propagation, relatively cheap, and moderately vigorous, it has some significant disadvantages such as: moderate vigour; moderate water and nutrient use efficiency; susceptibility to calcareous soils and lime induced chlorosis; susceptibility to root pathogenic disorders in a replant situation; and only moderate tolerance to salinity.

While there has been an increase in the availability of prunus rootstocks imported into Australia over the last decade there is limited information available on the performance of these rootstocks in Australian soils. In 2013 a 3.74ha rootstock evaluation trial was established by the Almond Board of Australia (ABA) at Lindsay Point, South Australia under project AL11012. The site was replanted to almonds with soils ranging from loam sand to sandy clay loam. A consistent watering and fertigation regime was applied to all trees via drip irrigation, composted manure delved in or foliar sprays.

This project, AL16006 evaluated eleven rootstocks compared with industry standard Nemaguard and measured their performance under Australian growing conditions and compatibility with the most common varietal grown in Australia, Nonpareil. Rootstocks included: Adafuel, Brights Hybrid, Cornerstone, Felinem, Garnem, GF557, GF677, GF749, Hansen 536, Krymsk 86, Monegro and Nemaguard.

Key parameters measured included flowering dates; seasonal and cumulative yield; fruit crack-out, weight and stick tights; tree vigour and production efficiency; light interception, tree size and anchorage; leaf and soil nutrition; nematodes; and graft compatibility.

A summary of tree size, yield and production efficiency (yield/trunk area) is provided in the table below and must be considered in context with the soil characteristics and management practice specific to this site.

Rootstock	2020 Trunk circumference (mm)	Fishers LSD	2021 Unadjusted average yield (8th leaf) (kg/ha)	Cumulative yield (kg/ha)	Fishers LSD	2017 Production efficiency (kg/cm ²)	Fishers LSD	2020 average height (m)	Fishers LSD
GF749	572.29	abc	3,846.56	15,597.21	a	0.077	ab	4.975	c
Monegro	608.75	cd	3,871.64	15,369.32	ab	0.084	ab	4.875	bc
Felinem	605.42	cd	3,211.19	15,168.62	ab	0.077	ab	4.925	bc
Garnem	572.1	abc	3,377.87	14,876.85	abc	0.061	bc	4.975	c
Hansen 536	619.58	d	3,103.80	14,276.15	abcd	0.040	c	4.900	bc
GF677	569.50	abc	3,464.41	14,088.51	abcde	0.080	ab	4.925	bc
Brights Hybrid	560.42	ab	3,914.46	13,519.39	abcdef	0.059	bc	4.925	bc
Spare Nemaguard	556.25	a	2,735.75	13,243.15	bcdef	0.070	ab	4.825	bc
Adafuel	600.21	bcd	3,106.40	12,587.77	cdef	0.095	a	4.925	bc
Cornerstone*	540.4	a	2,823.53	11,987.40	def	0.095	a	4.775	a
GF557	564.58	ab	2,520.11	11,885.96	ef	0.092	a	4.875	bc
Nemaguard	549.8	a	2,373	11,737.62	f	0.057	bc	4.650	a
Krymsk 86	568.8	abc	2,089	9,204	g	0.04	c	4.775	a
Standard Error		14	NA		1147		0.010		0.081
P value		<0.01	NA				0.008		0.012
LSD		40.2	NA		2321		0.028		0.164

By 2021 (8th leaf), the highest cumulative yields were observed for seven rootstocks, GF749 (15,597 kg/ha), Monegro (15,369 kernel kg/ha), Felinem (15,169 kernel kg/ha), Garnem (14,877 kernel kg/ha), Hansen 536 (14,276 kernel kg/ha), GF677 (14,089 kernel kg/ha) and Brights Hybrid (13,519 kernel kg/ha). The cumulative yields for the top seven rootstocks were not statistically different from each other. Of the top seven all but Brights Hybrid had

significantly higher cumulative yields than Nemaguard (11,737.62 kg/ha). GF749 was significantly higher than both Nemaguard and spare Nemaguard (13,243.15 kg/ha). Nemaguard, Adafuel, Cornerstone (see note) and GF557 showed some differences between the high yielding seven but not for all rootstocks. All rootstocks produced yields significantly higher than Krymsk 86 for this site and management practice. Krymsk 86 produced the lowest cumulative yield of 9,205 kernel kilograms per hectare and was the only rootstock with a cumulative yield significantly lower than both Nemaguard and all other rootstocks.

Using trunk circumference (mm) as a measure of tree growth the production efficiency (kg/cm²) was calculated by dividing the average annual yield with the tree trunk area (yield / growth). In 2017 Adafuel, Cornerstone and GF557 had significantly higher production efficiencies compared to Garnem, Brights Hybrid, Nemaguard, Hansen 536 and Krymsk 86 rootstocks. However, the significance of these differences was lost after 2017 meaning trees with larger trunks were no more, or less, productive than trees with smaller trunks after their 4th leaf.

By 2020, GF749 (4.98m) and Garnem (4.98m) had produced significantly taller trees than Nemaguard (4.65m), Cornerstone (4.78m) and Krymsk 86 (4.78m) but not significantly taller than other rootstocks.

Note: Cornerstone was planted one season later than other rootstocks in 2014 and as a result only reached 7th leaf maturity and yield compared to other rootstocks reaching 8th leaf maturity and yield. The delayed planting was further complicated in that while these trees were younger, they received the same fertilizer and irrigation amounts as the trees 12 months older. This enabled Cornerstone to achieve tree growth and cumulative yield after 7 years growth similar to that of Nemaguard which had 8 years growth. These factors made it difficult to directly compare Cornerstone performance against other rootstocks in this trial.

A second rootstock evaluation trial site 1.37ha was established at the Almond Centre of Excellence (ACE) experimental and demonstration orchard in Loxton, South Australia. Rootstocks included in this trial for comparison against Nemaguard and compatibility with varieties Nonpareil and Vella included Atlas, Viking, Garnem, Cornerstone, Rootpac R, Barrier 1.

Keywords

Almond; Rootstock; Adafuel; Brights Hybrid; Cornerstone; Felinem; Garnem; GF557; GF677; GF749; Hansen 536; Krymsk 86; Monegro; and Nemaguard.

Introduction

Almonds are predominantly grown across four states and five growing regions: Northern Adelaide Plains (South Australia), Riverland (South Australia), Sunraysia (Victoria), the Riverina (New South Wales) and the Swan region (Western Australia). Each of the growing regions has varying growing conditions such as soil type, crop history, climate, water resources, water availability, water quality, and disease and insect pressure.

Despite these varying conditions, most of the almonds are grown on Nemaguard rootstock. In 2021 76% (44,408 hectares) of Australian almond plantings are grafted to Nemaguard. Nemaguard rootstock has several advantages, such as: nematode tolerance, easy propagation, relatively cheap, virus free, and moderately vigorous. However, Nemaguard also has some significant disadvantages, such as: moderate vigour; moderate water and nutrient use efficiency; susceptibility to calcareous soils and lime induced chlorosis; susceptibility to root pathogenic disorders in a replant situation; and only moderate tolerance to salinity.

In the past decade, there has been an increase in the number of prunus rootstocks available that are suitable for almonds and many of these rootstocks have been imported into Australia. Some of these rootstocks claim to be better performing in chlorotic soil types, nematode tolerant, highly vigorous and easy to propagate.

Limited information is available on the performance of different rootstock in Australian soils. For the long-term sustainability and profitability of the Australian almond industry, new rootstocks are required that are compatible with Australian management systems. The need to assess and evaluate their compatibility with the common cultivar grown in Australia Nonpareil and measure their performance under Australian growing conditions was the rationale for establishing the initial rootstock evaluation trial site at Lindsay Point, South Australia in 2013 (project AL11012) by the Almond Board of Australia (ABA).

This project, AL16006, builds on the previous rootstock evaluation project (AL11012) in collecting and analysing field measures as well as establishing a second trial site at the Almond Centre of Excellence (ACE) experimental and demonstration orchard in Loxton, South Australia.

The ABA Plant Improvement Committee served as the Project Reference Group (PRG) to provide feedback and advice to this project.

Methodology

Trial establishment Lindsay Point

Lindsay Point trial site was managed as a commercial orchard by Lacton Farms using the same irrigation and fertiliser program across the 3.74-hectare trial site. The site was previously planted to grapevines on typical Mallee loam-sand (LS) to sandy-clay-loam (SCL) soils (Table 1).

Fourteen rootstock varieties were chosen for their high or medium vigour characteristics (Appendix A). These were sourced through commercially licensed nurseries (Table 2), grafted to Nonpareil (50%), Carmel (25%) and Peerless (25%), and planted in a replicated, randomised block design (Appendix C). A 'spare' Nemaguard treatment was included to complete the trial layout.

Trees were planted at a density of approximately 342 trees per hectare (7.3m row x 4m tree spacings) and managed using standard commercial management practices for irrigation and fertilizer applications across all replications.

Eleven rootstocks were successfully established in the trial enabling evaluation against Nemaguard (Table 2). Most trial trees were planted in August 2013 except for Cornerstone which was planted in October 2014. A summary of planting dates and tree establishment for each rootstock and scion combination is provided in Appendix E.

Table 1. Lindsay Point trial site characteristics.

Region	Town	Replant situation	Soil Type	Topsoil depth	Calcareous soil	Water source	Water quality	Irrigation (ML/ha)	Fertiliser (N:P:K)
Riverland	Renmark	Yes	LS to SCL	Shallow	Yes ~90cm	Murray River	Low salinity	12-14	320:45:350 Fe, Seasol, composted manure

Table 2. Rootstocks established at Lindsay Point under AL11012 for evaluation against Nemaguard in AL16006.

Rootstock	Parentage	Origin	Breeder	Source	Take (%)
Nemaguard	<i>P. persica</i> x <i>P. davidiana</i>	Georgia, USA	USDA	Ausbuds	100
GF557	<i>P. persica</i> x <i>P. dulcis</i>	Bordeaux, France	INRA	ABA	98
GF677	<i>P. persica</i> x <i>P. dulcis</i>	Bordeaux, France	INRA	ABA	99
GF749	<i>P. kansuensis</i> x <i>P. dulcis</i>	Bordeaux, France	INRA	ABA	93
Adafuel	<i>P. persica</i> x <i>P. dulcis</i>	Zaragoza, Spain	CSIC	ABA	96
Garnem	<i>P. persica</i> x <i>P. dulcis</i>	Zaragoza, Spain	CITA	ABA	93
Felinem	<i>P. persica</i> x <i>P. dulcis</i>	Zaragoza, Spain	CITA	ABA	100
Monegro	<i>P. persica</i> x <i>P. dulcis</i>	Zaragoza, Spain	CITA	ABA	99
Bright's Hybrid	<i>P. persica</i> x <i>P. dulcis</i>	California, USA	Bright's Nursery	Ausbuds	97
Hansen 536	<i>P. persica</i> x <i>P. dulcis</i>	California, USA	UC Davis	Ausbuds	75
Cornerstone*	<i>P. persica</i> x <i>P. dulcis</i>	California, USA	Burchell Nursery Inc	Mossmont Nurseries	100
Krymsk 86	<i>P. persica</i> x <i>P. cerasifera</i>	Krasnodar, Russia	Krymsk Breeding &	ANFIC	98

*Trial trees were planted in August 2013 except Cornerstone which was planted in October 2014.

Measurements and laboratory analysis

Characteristics and parameters measured and evaluated for each rootstock are presented in Table 3.

Characteristics for evaluation and parameters measured. A detailed description of the sampling methodology is provided in Appendix B.

Soil and leaf tissue nutritional laboratory analysis was conducted annually for each rootstock and replicate to monitor and compare the nutrient efficiency performance of each rootstock, in context of the soil fertility and

exposed to a common fertiliser program.

Nematode sampling for each rootstock plot was conducted for Replicate 1 in 2018 and each year following to monitor changes in the population. In 2021 nematode samples were collected for each rootstock across all replicates to determine the influence of nematodes on the performance of individual rootstocks.

Ongoing visual assessments for the presence or symptoms of trunk and branch pathogens was conducted each year. Follow-up pathology testing was done as needed.

Field observations

Several field observations were made between rootstocks including graft incompatibility, number of suckers appearing in winter and the degree of iron chlorosis observed.

Statistical analysis

Rho Environmetrics Pty Ltd undertook statistical analysis of results at the Lindsay Point rootstock trial site (Appendix G).

Table 3. Characteristics for evaluation and parameters measured.

Characteristic	Measurement	Units
Propagation	Ease of propagation	% tree establishment
Flowering	Pink bud, full bloom, finish	Dates
Production	Seasonal yield	kg/ha
	Accumulated yield	kg/ha
	Precocity	Yield data
Vigour	Cross sectional trunk area of scion and rootstock	cm ²
	Index of production efficiency	kg/cm ²
Tree Habit	Light interception	% light interception
	Tree size – vertically and horizontally	m
	Anchorage	0-5
Tree Nutrition	Leaf analysis	Full Inductively Coupled Plasma analysis
	Fruit analysis	Full Inductively Coupled Plasma analysis
	Soil analysis	Full Inductively Coupled Plasma analysis
Fruit	Crack-out - kernel	%
	Fruit size	Kernels/ounce
	Fruit weight	Grams
	Stick tights	Number per sample tree
Graft Compatibility	Cross sectional trunk area of rootstock and scion	0-5
Suckering	Number of suckers	# suckers/ha
Iron Chlorosis	Degree of chlorosis	0-5
Nematodes	Root lesion, root knot, ring	# and type of nematode/250g soil
Fungal Pathogens	Cankers, Phytophthora, Agrobacterium, Armillaria	0-5

Trial establishment Loxton

The trial site was established at the Almond Centre of Excellence Orchard totalling 1.37 hectares planted on ground which was previous dryland farming. The soil type was typical for Mallee soils with 30 to 60cm topsoil of light sandy clay loam (SCL) overlying carbonate subsoils (Table 4).

Five rootstock varieties were chosen for their high or medium vigour characteristics (Appendix A). These were sourced through commercially licensed nurseries (Table 5), grafted to Nonpareil (50%) and Vela (50%) being a self-compatible Adelaide University bred variety. The trial was planted in a replicated, randomised block design (Appendix D). Vela was chosen by the PRG as it has a similar flowering data as Nonpareil providing cross pollination and can be used for comparison of rootstock performance against Nonpareil. Nemaguard trees were planted around the perimeter of the trial.

Trees were planted over two years in 2019 and 2020 at a higher density than Lindsay Point with approximately 513 trees per hectare (6.5m row x 3m tree spacings) and managed using standard commercial management practices for irrigation and fertilizer applications across all replications.

This trial has been established under the current project for evaluation under future rootstock assessment project.

Table 4. Loxton trial site characteristics.

Region	Town	Replant situation	Soil Type	Topsoil depth	Calcareous soil	Water source	Water quality	Irrigation (ML/ha)	Fertiliser (N:P:K)
Riverland	Loxton	No	SCL	Shallow	Yes	Murray River	Low salinity	12-14	310:55:380

Table 5. Rootstocks established at Loxton for evaluation against Nemaguard.

Rootstock	Parentage	Origin	Breeder	Source
Nemaguard	<i>P. persica</i>	Georgia, USA	USDA	Ausbuds
Atlas	<i>P. persica</i> x (<i>P. dulcis</i> x <i>P. blireana</i>)	California, USA USA	Zaiger Genetics	Factree Nursery
Viking	<i>P. persica</i> x (<i>P. dulcis</i> x <i>P. blireana</i>)	California, USA	Zaiger Genetics	GF
Garnem	<i>P. persica</i> x <i>P. dulcis</i>	Zaragoza, Spain	CITA	ABA
Cornerstone	<i>P. persica</i> x <i>P. dulcis</i>	California, USA	Burchell Nursery	Mossmont Nurseries
Rootpac R [#]	<i>P. cerasifera</i> x <i>P. dulcis</i>	Barcelona, Spain	Agromillora	Agromillora
Barrier 1 [#]	<i>P. persica</i> x <i>P. davidiana</i>	CNR, Italy	Unknown	Unknown

[#]Observation sites only.

Outputs

The outputs of the project were:

- Data collection from the rootstock trial site established under AL11012 from 2017 to 2021 and evaluation of eleven rootstock varieties in Australian conditions enabling objective assessment against industry standard Nemaguard.
- Establishment of an additional 1.37 hectares rootstock evaluation site at the ACE Orchard Loxton including six rootstocks for assessment against Nemaguard in light sandy soils.
- An industry field day (3rd October 2017) provided an update on the trial and yield data and opportunity to view the tree growing habit.
- A summary of rootstock characteristics factsheet was developed provided to field day attendees (Appendix I).
- Industry Newsletter 'In-a-Nutshell' article (24/10/2019): 'In the Orchard – Rootstock Trial: evaluating the yield findings' <https://australianalmonds-com-au.cld.bz/In-a-Nutshell-Spring-2019/18/>
- Updates of results and trends communicated to industry stakeholders through grower enquires and 13 Project Reference Group Meetings (ABA Plant Improvement Committee) where project updates were provided.
- A harvest video was produced demonstrating the collection of trial fruit using conventional machinery presented to the ABA Plant Improvement Committee <https://vimeo.com/335065916/d6ad51a9db>
- Almond Bytes grab on data collection activities – hull rot assessment.
- A project management reports including program logic and a monitoring and evaluation plan with linkage to Hort Innovation and almond industry objectives. Risk register and stakeholder engagement / communication plan.
- A summary factsheet providing independent evaluation of recommendations for each rootstock.
- Milestone and Final reports.

Outcomes

The project provides information on the performance of Nonpareil grown on eleven rootstocks for comparison against industry standard Nemaguard planted in 2013 (Cornerstone planted in 2014). This information will help understand the influence of each rootstock under the specified growing conditions and management operations with the objective of improving the selection of plant material contributing to increasing almond orchard productivity and sustainable profitability. A summary of key findings is described below.

By 2021 (8th leaf), the highest cumulative yields were observed for seven rootstocks, GF749 (15,597 kg/ha), Monegro (15,369 kernel kg/ha), Felinem (15,169 kernel kg/ha), Garnem (14,877 kernel kg/ha), Hansen 536 (14,276 kernel kg/ha), GF677 (14,089 kernel kg/ha) and Brights Hybrid (13,519 kernel kg/ha). The cumulative yields for the top seven rootstocks were not statistically different from each other. Of the top seven all but Brights Hybrid had significantly higher cumulative yields than Nemaguard (11,737.62 kg/ha). GF749 was significantly higher than both Nemaguard and spare Nemaguard (13,243.15 kg/ha). Nemaguard, Adafuel, Cornerstone (see note) and GF557 showed some differences between the high yielding seven but not for all rootstocks. All rootstocks produced yields significantly higher than Krymsk 86 for this site.

Krymsk 86 produced the lowest cumulative yield of 9,205 kernel kilograms per hectare and was the only rootstock with a cumulative yield significantly lower than both Nemaguard and all other rootstocks.

Of note, Cornerstone was planted 12 months later, and younger trees received higher fertiliser and water. These differences in treatment made it difficult to directly compare Cornerstone performance against other rootstocks in this trial. However, after 7 years growth Cornerstone was to achieve a similar cumulative yield to Nemaguard that had 8 years growth.

Seasonal yields in 2020 and/or 2021 were lower than 2019 for all rootstocks except Brights Hybrid and Adafuel. Despite fluctuations in yield an assessment of biennial bearing did not indicate a strong tendency for any of the rootstocks however ongoing monitoring of annual yield will help to establish seasonal yield consistency and determine any biennial bearing tendencies for the less vigorous rootstocks.

In 2017 Adafuel, Cornerstone and GF557 had significantly higher production efficiencies (yield / trunk cross sectional area) compared to Garnem, Brights Hybrid, Nemaguard, Hansen 536 and Krymsk 86 rootstocks. However, the significance of these differences between rootstocks was lost after 2017 meaning trees with larger trunks were no more, or less, productive than trees with smaller trunks after their 4th leaf.

Observations for tree growth parameters canopy area and leaf area index (LAI) measured in February 2018, indicated that Krymsk 86 (34.83m²) had a significantly smaller canopy area than most rootstocks but not significantly different from Nemaguard (41.12m² and 43.55m²), GF557 (43.27m²) and Felinem (44.45m²). Krymsk 86 had a significantly lower LAI with light interception being a factor of canopy size.

By 2020, canopy areas were highest for Adafuel (50.09m²), Hansen 536 (49.40m²) and Brights Hybrid (48.75m²) but were not significantly different from other rootstocks except for Krymsk (34.83m²). Light interception (LAI) was significantly higher for Felinem, GF677, Hansen, Brights Hybrid, GF749 and Monegro compared with Krymsk 86 which may indicate a denser canopy for these rootstocks. By 2021 differences in canopy area were not significant indicating that the trees have filled their allocated space.

A small investigation of canopy temperature, late October 2017 and late February 2018, indicated that trees on Krymsk 86, Adafuel, Cornerstone and Nemaguard were more stressed on average than trees on other rootstocks. At this time, trees on Krymsk 86 were significantly smaller than trees on other rootstocks, and trees on Cornerstone and Nemaguard were also among the smaller trees. It is not clear, whether the smaller size of these trees was responsible for the higher canopy temperature, or whether the apparent stress caused the trees to grow less vigorously, resulting in smaller tree size.

By 2020, GF749 (4.98m) and Garnem (4.98m) had produced significantly taller trees than Nemaguard (4.65m), Cornerstone (4.78m) and Krymsk 86 (4.78m) but not significantly taller than other rootstocks.

In 2021, there was a significant correlation between yield and leaf calcium (Ca) and magnesium (Mg) levels. There was a highly significant difference between rootstock leaf with the highest uptake of both Ca and Mg observed for Hansen, Garnem and Monegro. These rootstocks are ranked in the top six highest yielding (cumulative yield) rootstocks. GF749 had high Ca and mid-range Mg levels. The lowest levels of leaf Ca and Mg were observed for the two Nemaguard rootstock plots and Krymsk 86.

In 2021, there was a significant correlation between yield and leaf sodium with high sodium levels correlating with low yields. The lowest levels of leaf sodium were observed for GF557, Monegro and GF749 and the highest levels were observed in Krymsk and Nemaguard. Both Krymsk and Nemaguard have been found to be poor excluders of sodium and chloride and may have contributed to low yield performance even when soil salinities were below the level of 1.5dS/m considered to affect yield (Walker *et al.*, 2017).

There were eight nematode species recorded during the four-year trial, three of importance to almonds include Root Knot Nematode (*Meloidogyne*); Ring Nematode (*Criconebella*); and Root Lesion Nematode (*Pratylenchus*). Of note were the levels of root knot detected in GF677 (low), GF557 (low) and GF749 (moderate). Their effect on yield will need to be monitored particularly for GF749 which currently has the highest cumulative yield. Continued monitoring of nematodes will help determine any association with bacterial canker complexes result where ring nematode are present and the relative impact of root lesion nematodes on yield.

In general some rootstocks appear to bring forward the start of flowering when compared with Nemaguard. For example, GF749 and Adafuel started flowering, on average, two days earlier, GF557 one day earlier, and Krymsk half a day earlier. Conversely, flowering start times appeared delayed for Felinem by 1.5 days and Hansen 536 by 0.75 days. Flowering periods were shorter for Krymsk 86 (22.5 days), GF557 and Adafuel (24.75days), and GF749 (25 days) and longer for Garnem (27days) and Monegro (27.25 days) when compared with Nemaguard (26 days). End of flowering appeared to be more variable for all rootstocks compared to Nemaguard. These observations were only taken for replicate 1 and were therefore not statistically analysed.

Fruit on Krymsk 86 matured rapidly reaching 97% Stage 3 hull split significantly earlier (18 January 2021) than the more vigorous rootstocks GF749, Monegro and Brights Hybrid. All rootstocks had reached 100% Stage 3 hull split by the 25 January except for Brights Hybrid which had only 53% of nuts reaching 100% Stage 3 hull split on the same day.

Field observations did not detect any differences in iron chlorosis, suckering, anchorage or graft compatibility.

Monitoring and evaluation

1. To what extent has the project achieved its expected outcomes?

One new rootstock trial has successfully been established on sandy soils at the ACE Orchard in Loxton. Another site was planned to be established at the Loxton Research Station however the location of this site was changed to the Riverina in consultation with the PRG given the large proportion (34%) of recent industry expansion in this area and their heavier soil profile. This site will be established under a separate project.

The ACE Orchard was planted over two years and changes were made to the rootstock selection due to the inability to acquire adequate material from nurseries. Rootstocks planted provide rootstocks located on both Lindsay Point e.g. Cornerstone and Garnem, and new rootstocks Atlas, Viking, Rootpac R and Barrier 1.

The rootstock parameters nominated were measured using a range of qualitative and quantitative assessments to determine rootstock performance. Seven rootstocks achieved similar cumulative yields (GF749, Monegro, Felinem, Garnem, Hansen 536, GF677 and Brights Hybrid) of which all but Brights Hybrid had significantly higher cumulative yields than Nemaguard and GF749 significantly higher than both Nemaguard and spare Nemaguard. Krymsk 86 did not perform well with smaller trees and significantly lower cumulative yield than Nemaguard. This information will help growers consider alternative rootstock and which one would be the most appropriate selection for their situation and management objectives. A spreadsheet of measured parameters has been developed and will capture future data collection identifying trends over time and comparison of rootstock performance for Australian soils.

2. How relevant was the project to the needs of intended beneficiaries?

The project has collected performance parameters and site information to identify differences between rootstocks specific to the site that can be compared against industry mainstay Nemaguard grown under commercial management practice.

Both qualitative and quantitative measure of rootstock performance have been obtained over four years. Ongoing assessment will confirm early observations as the trees have now grown into their allocated space and compete for light interception.

All changes to the project plan and data parameters collected were made in consultation with the PRG to ensure they continued to be of value and relevance to the industry.

3. How well (how appropriately) have intended beneficiaries been engaged in the project?

Thirteen PRG meetings with industry representatives were convened presenting updates on project results and seeking guidance on project delivery.

Formal communication to the almond industry was made via field days (2017), Factsheets and an article in the industry magazine In-a-Nutshell Spring edition 2019. COVID-19 and border restrictions have prevented planned field days in 2020 and 2021 and presentations via the ABA conference and R&D field day.

ABA staff regularly responded to enquires from growers and nurseries regarding rootstock selection.

5. What efforts did the project make to improve efficiency?

An excel spreadsheet has been established providing consistent formatting of data collected. This proved valuable in the presentation and interrogation of data and will be valuable for ongoing and future evaluation.

The ACE Orchard trial site in Loxton provided efficiencies by reducing travel to and from the site during land preparation and planting activities.

A trailer with half tonne bin and scales was designed within this project to connect to a pick-up machine and measure fruit yield ideal for small experimental treatment plots. This has been used for other trials at the ACE Orchard.

Recommendations

It is recommended that:

- Continued monitoring of key performance parameters at Lindsay Point would confirm trial observations and further establishing trends in the following areas:
 - Propensity for biennial bearing
 - Influence of Nematodes if populations increase
 - Influence of soil salinity and pH and nutrient uptake
 - Yield performance in trees older than 8th leaf.
- Data collection from newly established rootstock evaluation site at the ACE Orchard should continue to evaluate additional rootstocks under different planting densities and management practices.
- Explore options to increase the commercial supply for rootstocks of interest to facilitate access by nurseries and industry keen to pursue high performing rootstocks.
- Future rootstock evaluation projects consider future growing climates and incorporate the ability to test for rootstock resilience and drought tolerance into the trial design. Adequate lead time (at least 18-month) is built into future rootstock trials to ensure adequate supply of rootstock material and avoids complications in validating results between rootstock varieties.
- A summary of the highlights for each rootstock on various soil types be compiled in a technical document for grower and nursery reference.

Refereed scientific publications

None

References

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Intellectual property, commercialisation and confidentiality

None

Acknowledgements

The project team would like to acknowledge the financial contribution to enable this project to be undertaken facilitated through Hort Innovation, using the Almond research and development levy and with contributions from the Australian Government.

The project team would like to acknowledge the guidance, critical review and insights provided by the members of the ABA Plant Improvement Committee who served as the project reference group.

A special thank you to the Lacton Farm manager and owners for hosting the Lindsay Point trial and their continued input and contribution to data collection each year.

We also recognise the work done by previous ABA staff Ben Brown, Brett Rosenzweig and Andrew Downs in establishing the trial at Lacton under the project AL11012.

We wish to acknowledge the efforts of ABA staff Ben Wiblin and Anthony Wachtel in establishing the trial site at ACE Orchard Loxton and ongoing data collection activities.

We appreciate and value the technical contribution to the project made by the following organisations:

- South Australian Research and Development Institute (SARDI); and
- Rho Environmentrics Pty Ltd.

Appendices

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Appendix H. Soil sample analysis

Appendix I. Leaf sample analysis

Appendix J. All About Almonds – Evaluation of prunus rootstocks technical document

Appendix A1. Summary characteristics for key rootstocks in Australia

Rootstock	Parentage	Pathogen Resistance						Soil Adaptation		Effects on the Variety		
		<i>Root knot Nematode</i>	<i>Lesion Nematode</i>	<i>Ring Nematode /Bacterial Canker</i>	<i>Crown Gall</i>	<i>Armillaria</i>	<i>Phytophthora</i>	<i>Salt exclusion</i> ¹	<i>Chlorosis</i>	<i>Compatibility</i>	<i>Vigour</i>	<i>Propagation by Cuttings</i>
Nemaguard	Wild Peach x Peach	High	Medium	Medium	Medium	Susceptible	Medium	Sensitive	Susceptible	Good	Medium	NA
Barrier 1 (Empyrean 1)	Wild Peach x Peach	High							Tolerant	Good	High	
Cadaman (Avimag)	Wild Peach x Peach	High	Susceptible	Unknown	Susceptible	Susceptible	Unknown	Moderate	Medium	Good	High	Poor
Adafuel	Peach x Almond											
Bright's Hybrid	Peach x Almond	High	More Tolerant than Nemaguard	Susceptible	Susceptible	Susceptible	Susceptible	Tolerant/ Excluder	Tolerant	Good	High	Poor
Cornerstone	Peach x Almond	High	Susceptible	Susceptible	Susceptible	Susceptible	Susceptible	Excluder	Tolerant	Good	High	Good
Felinem	Peach x Almond	Moderate	Moderate		Susceptible				Resistant			
Garnem	Peach x Almond	High	Medium / Susceptible	Unknown	Susceptible	Unknown	Susceptible	Excluder	Tolerant	Good	High	Good
Monegro	Peach x Almond	Susceptible?		Susceptible?					Tolerant?	Good?		
GF557	Peach x Almond	Susceptible										
GF677 (Paramount)	Peach x Almond	Susceptible	Susceptible	Susceptible	Susceptible		Susceptible	Excluder	Tolerant	Good	High	Poor
GF749	Peach x Almond	Susceptible										
Hansen 536	Peach x Almond	High	More Tolerant than Nemaguard	Susceptible	Susceptible	Susceptible	Susceptible	Resistant/ Excluder	Tolerant	Good	High	Poor
Nickels	Peach x Almond	High	More Tolerant than Nemaguard	Susceptible	Susceptible	Susceptible	Susceptible	Moderate	Tolerant	Good	High	Poor
Krymsk (Kuban) 86	Peach x Plum	Susceptible	Medium	Susceptible	Medium	Unknown	Tolerant	Sensitive	Medium	Good	Medium	Good
Atlas	Peach x Almond x Apricot x Plum	High	Medium	Susceptible	Medium	Susceptible	Medium	Sensitive	Tolerant	Good	High	Good
Viking	Peach x Almond x Apricot x Plum	High	Medium	High	Medium	Susceptible	Medium	Moderate	Tolerant	Good	High	Good

¹ Walker, A.R., Smith, M.H., McDavid, D., Goonetilleke, S., Hassan, M., 2017. Resilience traits for almond rootstocks. Final report for IRSPR2-004. CSIRO Agriculture and Food, Urbrae, pp 61.

Appendix A.1 Summary of intellectual property and propagation methods for key rootstocks in Australia

Rootstock	Origin	Breeder	Source/Australian Agent	Major Propagator	Intellectual Property			Method of Propagation (Bold = most common in Australia <i>Italic</i> = most common Internationally)			Commercially available in Australia as a grafted tree
					Status	Date of Grant	Right Expires	Seedling	Cuttings	Micropropagation	
Nemaguard	Georgia, USA	USDA	Ausbuds	Ausbuds	Public			Yes	No	No	Yes
Barrier 1 (Empyrean 1)	Firenze, Italy	National Research Council of Italy Trees and Timber Institute	ANFIC	Olea & Little Tree Company				No	Yes		Yes
Cadaman (Avimag)	Bordeaux, France	INRA	GF	GF, Olea & Little Tree Company	Granted	28 Mar 2002	28 Mar 2027	No	Yes	Yes	No
Adafuel	Zaragoza, Spain	CSIC	ABA	Ausbuds	Public			No	Yes	Yes	
Bright's Hybrid	California, USA	Brights Nursery	Ausbuds	Ausbuds	Public			No	Yes	Yes	Yes
Cornerstone	California, USA	Burchell Nursery	Mossmont Nurseries	Ausbuds	Granted	26 Feb 2014	26 Feb 2039	No	Yes	Yes	Yes
Felinem	Zaragoza, Spain	CITA	ABA	Ausbuds	Granted	13 Feb 2014	13 Feb 2039	No	Yes	Yes	No
Garnem	Zaragoza, Spain	CITA	ABA	Ausbuds	Granted	13 Feb 2014	13 Feb 2039	No	Yes	Yes	Yes
Monegro	Zaragoza, Spain	CITA	ABA	Ausbuds	Granted	13 Feb 2014	13 Feb 2039	No	Yes	Yes	No
GF557	Bordeaux, France	INRA	ABA	Ausbuds	Public			No	Yes	Yes	
GF677 (Paramount)	Bordeaux, France	INRA	ABA	Ausbuds & Boulevarde	Public			No	Yes	Yes	Yes
GF749											
Hansen 536	California, USA	UC Davis	Ausbuds	Ausbuds	Public			No	Yes	Yes	
Krymsk (Kuban) 86	Krasnodar, Russia	Krymsk Breeding & Research Station	ANFIC	Olea & Little Tree Company	Granted	17 Nov 2010*	?	No	Yes	Yes	Yes
Nickels	California, USA	UC Davis	Mossmont Nurseries	Ausbuds	Withdrawn			No	Yes	Yes	No
Atlas	California, USA	Zaiger Genetics	GF	GF	Granted	14 June 2000	14 June 2025	No	Yes	Yes	Yes
Viking	California, USA	Zaiger Genetics	GF	GF	Granted	3 June 2003	3 June 2028	No	Yes	Yes	Yes

Legend	
ABA – Almond Board of Australia Inc ANFIC – Australian Nurseryman's Fruit Improvement Company Ltd CITA – Centro de Investigacion y Tecnologia Agroalimentaria de Aragon CSIC - Consejo Superior de Investigaciones Cientificas GFN – Graham's Factree Pty Ltd INRA – Institut National De La Recherche Agronomique USDA – United States Department of Agriculture UC Davis – University of California, Davis Campus	*Accepted (date of Grant unknown)

Methodology

Trial establishment Lindsay Point

The trial site at Lindsay Point was established under AL11012 at Lindsay Point totalled 3.74-hectares in replant situation. The soil type was typical for Mallee soils with 30 to 60cm topsoil (loam-sand (LS) to sandy-clay-loam (SCL)) overlying carbonate subsoils (Table B-1).

Fourteen rootstock varieties were chosen for their high or medium vigour characteristics (Appendix A). These were sourced through commercially licensed nurseries (Table 2), grafted to Nonpareil (50%), Carmel (25%) and Peerless (25%), and planted in a replicated, randomised block design (Appendix C). A 'spare' Nemaguard treatment was included to complete the trial layout.

Trees were planted at a density of approximately 342 trees per hectare (7.3m row x 4m tree spacings) and managed using standard commercial management practices for irrigation and fertilizer applications across all replications.

Table B-1: Lindsay Point trial site characteristics.

Region	Town	Replant situation	Soil Type	Topsoil depth	Calcareous soil	Water source	Water quality	Irrigation (ML/ha)	Fertiliser (N:P:K) other
Riverland	Renmark	Yes	LS to SCL	Shallow	Yes ~90cm	Murray River	Low salinity	12-14	320:45:350 Fe, Seasol, Composted manure

Eleven rootstocks were successfully established in the trial enabling evaluation against Nemaguard (Table B-2). Most trial trees were planted in August 2013 except for Cornerstone which was planted in October 2014. A summary of planting dates and tree establishment for each rootstock and scion combination is provided in Appendix E.

Table B-1: Rootstocks planted in August 2014 at Lindsay Point under AL11012 for evaluation against Nemaguard in AL16006.

Rootstock	Parentage	Origin	Breeder	Source	Take (%)
Nemaguard	<i>P. persica</i> x <i>P. davidiana</i>	Georgia, USA	USDA	Ausbuds	100
GF557	<i>P. persica</i> x <i>P. dulcis</i>	Bordeaux, France	INRA	ABA	98
GF677	<i>P. persica</i> x <i>P. dulcis</i>	Bordeaux, France	INRA	ABA	99
GF749	<i>P. kansuensis</i> x <i>P. dulcis</i>	Bordeaux, France	INRA	ABA	93
Adafuel	<i>P. persica</i> x <i>P. dulcis</i>	Zaragoza, Spain	CSIC	ABA	96
Garnem	<i>P. persica</i> x <i>P. dulcis</i>	Zaragoza, Spain	CITA	ABA	93
Felinem	<i>P. persica</i> x <i>P. dulcis</i>	Zaragoza, Spain	CITA	ABA	100
Monegro	<i>P. persica</i> x <i>P. dulcis</i>	Zaragoza, Spain	CITA	ABA	99
Bright's Hybrid	<i>P. persica</i> x <i>P. dulcis</i>	California, USA	Bright's Nursery	Ausbuds	97
Hansen 536	<i>P. persica</i> x <i>P. dulcis</i>	California, USA	UC Davis	Ausbuds	75
Cornerstone*	<i>P. persica</i> x <i>P. dulcis</i>	California, USA	Burchell Nursery Inc	Mossmont Nurseries	100
Krymsk 86	<i>P. persica</i> x <i>P. cerasifera</i>	Krasnodar, Russia	Krymsk Breeding &	ANFIC	98

*Cornerstone trial trees planted in October 2014.

Management

Tree rows were maintained weed-free using herbicides applied at recommended rates. The inter-row space was planted to cover crop in March each year using a pollination blend of rye grass etc. sown at a rate of 20 kg/ha. Trees were free-standing and a single wooden stake for support.

Winter hedging was applied in 2018/2019. Hives were stocked at 7 hives per hectare during pollination.

Irrigation was applied using under-tree micro drip. Soil was kept moist during fruit growth and allowed to dry out at harvest. Objective soil and plant water measurements were not maintained during the experiment. Plant nutritional requirements were determined using analysis of leaves chosen at random across the block and standard commercial fertilisers to achieve N:P:K ratios of 320:45:350 from 2017/18 to 2020/21. Four iron sprays and 7 to 9 foliar applications were applied including NZN, Lo Bi Urea, Potassium Nitrate, Seasol and composted manure delved in.

Measurements

Characteristics and parameters measured and evaluated against Nemaguard are presented in Table B-3.

Table B-2: Characteristics for evaluation and parameters measured.

Characteristic	Measurement	Units
Propagation	Ease of propagation	% tree establishment
Flowering	Pink bud, full bloom, finish	Dates
Production	Seasonal yield	kg/ha
	Accumulated yield	kg/ha
	Precocity	Yield data
Vigour	Cross sectional trunk area of scion and rootstock	cm ²
	Index of production efficiency	kg/cm ²
Tree Habit	Light interception	% light interception
	Tree size – vertically and horizontally	m
	Anchorage	0-5
Tree Nutrition	Leaf analysis	Full Inductively Coupled Plasma analysis
	Fruit analysis	Full Inductively Coupled Plasma analysis
	Soil analysis	Full Inductively Coupled Plasma analysis
Fruit	Crack-out - kernel	%
	Fruit size	Kernels/ounce
	Fruit weight	Grams
	Stick tights	Number per sample tree
Graft Compatibility	Cross sectional trunk area of rootstock and scion	0-5
Suckering	Number of suckers	# suckers/ha
Iron Chlorosis	Degree of chlorosis	0-5
Nematodes	Root lesion, root knot, ring	# and type of nematode/250g soil
Fungal Pathogens	Cankers, Phytophthora, Agrobacterium, Armillaria	0-5

Flowering dates were measured by the farm manager at Lindsay Point using a whole tree assessment for the start of flowering (when 1 to 5 percent of buds had flowered), full bloom (most buds had flowered with 5 percent yet to bloom and 5 percent petal fall) and end of flowering (when 1-5 percent of blossoms remain on the tree). Flowering observations were collected each flowering season 2017 - 2020 for Replicate 1 only.

For each three tree Nonpareil / rootstock monitoring plot, fruit was harvested using commercial processes (shake, sweep and pick-up) and collecting nuts into a half-tonne bin (Figure B-1). The fruit was weighed and divided by three to provide an average tree weight for each plot (two tree plots were divided by two).

For each monitoring plot a random sample of 100 nuts were weighed and sorted into kernel, shell and hull and each portion weighed to determine the “crack-out” as a percentage of the sample weight. The crack-out

information was used to calculate the average kernel weight per tree converted to yield per hectare assuming 342 trees per hectare. Yield data was collected each year from 2016 to 2021.

The cross-sectional area of trunk was calculated from 2015 – 2020 by measuring the butt circumference approximately 10 cm above the graft union noting any signs of scion swelling or overgrowth as an indication of potential graft incompatibility. An index of production efficiency was calculated using total average yield and cross-sectional area of the tree trunk.

An estimate of canopy area (m²) was calculated for the Nonpareil monitoring trees using an Unmanned Aerial Vehicle (UAV) imagery with a combination of RGB imagery collected by SARDI and analogous imagery collected by ABA. The combined imagery provided an in-season comparison during 2017/18, and an assessment of canopy growth across a three-and-a-half-year period (Appendix 2).

Leaf area index (LAI) as a measure of the total leaf surface area was assessed in February 2018 using a Li-Cor LAI-2000 Plant Canopy Analyser. A series of readings across the orchard floor generated a LAI for each rootstock trial plot, across four replicates. Analysis of variance (5% significance) was used to compare LAI across rootstocks.



Figure B-1. A purpose-built trailer with scales attached behind a commercial almond harvester enabled more efficient pickup and weighing of fruit from trial plots.

Laboratory analysis

Soil analyses (pH (water and CaCl), EC, Organic Carbon, Nitrate, Ammonia, PBI, Sulphur, Potassium (KCl), Colwell K and Colwell P) provide context for nutrient uptake by each rootstock whether caused by a lack of an element or the result of unfavourable soil conditions.

Leaf nutrient analysis (Nitrogen, Nitrate, Phosphorus, Potassium, Calcium, Magnesium, Sodium, Sulphur, Copper, Boron, Iron, Manganese, Zinc, Aluminium, Chloride, Cobalt and Molybdenum) provide an indication of how efficient each rootstock is at taking up nutrients from their environment.

Both soil and leaf assessments were conducted annually for each treatment and replicate to monitor and compare the nutrient efficiency performance for each rootstock exposed to a common fertiliser program.

Leaf tissue and soil samples were collected in January each year for analysis through Australian Precision Ag Laboratory (APAL) South Australia using APAL guidelines. Representative leaf and petiole samples were collected from each three-tree Nonpareil trial plot by selecting the first mature leaf, generally the 4th or 5th leaf, taken from the growing tip of current season, non-fruiting growth. A paper sample bag was half-filled with leaves from north, south, east, west aspects for each plot and replicate. Representative soil samples were collected at the same time

one metre from the base of the Nonpareil tree and 10cm from the drip line. Three samples per plot were combined to make up 200-300g of soil in the sample bag.

Nematode sampling for each rootstock plot were conducted for Replicate 1 in 2018 using the same protocols as for soil nutrient analysis to identify and establish a baseline population of parasitic and free-living nematodes. Samples were collected for Replicate 1 each year. In the final year nematode samples were collected for each rootstock across all replicates to determine the differences in nematode populations and the performance of each rootstock. Soil samples were identified to genus level and the number of nematodes per 250gms of dry soil SARDI Horticultural Diagnostic Service.

Ongoing visual assessments for the presence or symptoms of trunk and branch pathogens was conducted each year. Follow-up pathology testing was done as needed. One Garnem tree was affected by phytophthora which resulted in the exclusion of all data collection from this tree.

Field observations

General field observations were made between rootstocks including anchorage, graft incompatibility, number of suckers appearing in winter and the degree of iron chlorosis observed by the farm manager.

Statistical analysis

Rho Environmetrics Pty Ltd undertook statistical analysis for various parameters collected from the Lindsay Point rootstock trial (Appendix G).

Trial establishment Loxton

The trial site at Loxton was planted in 2019 and 2020 at the Almond Centre of Excellence Orchard totalling 1.37 hectares planted on ground which was previous dryland farming. The soil type was typical for Mallee soils with 30 to 60cm topsoil of light sandy clay loam (SCL) overlying carbonate subsoils (Table B-4).

Five rootstock varieties were chosen for their high or medium vigour characteristics (Appendix A). These were sourced through commercially licensed nurseries (Table B-5), grafted to Nonpareil (50%) and self-compatible Adelaide University bred variety Vela (50%), and planted in a replicated, randomised block design (Appendix D). Nemaguard trees were planted around the perimeter of the trial.

Most trial trees were planted in July 2019 except for one replicate for each Atlas, Viking and Cornerstone which were planted in July 2020. The time delay in accessing Rootpac R and Barrier 1 meant it would be difficult to compare against other varieties therefore the PRG decided to establish only one plot for observational purpose.

Trees were planted at a higher density than Lindsay Point with approximately 513 trees per hectare (6.5m row x 3m tree spacings) and managed using standard commercial management practices for irrigation and fertilizer applications across all replicates.

Table B-3: Loxton trial site characteristics.

Region	Town	Replant situation	Soil Type	Topsoil depth	Calcareous soil	Water source	Water quality	Irrigation (ML/ha)	Fertiliser (N:P:K)
Riverland	Loxton	No	SCL	Shallow	Yes	Murray River	Low salinity	12-14	310:55:380

Table B-4: Rootstocks established at Loxton for evaluation against Nemaguard.

Rootstock	Parentage	Origin	Breeder	Source
Nemaguard	<i>P. persica</i>	Georgia, USA	USDA	Ausbuds
Atlas	<i>P. persica</i> x (<i>P. dulcis</i> x <i>P. blireana</i>)	California, USA USA	Zaiger Genetics	Factree Nursery
Viking	<i>P. persica</i> x (<i>P. dulcis</i> x <i>P. blireana</i>)	California, USA	Zaiger Genetics	GF
Garnem	<i>P. persica</i> x <i>P. dulcis</i>	Zaragoza, Spain	CITA	ABA
Cornerstone	<i>P. persica</i> x <i>P. dulcis</i>	California, USA	Burchell Nursery Inc	Mossmont Nurseries
Rootpac R [#]	<i>P. cerasifera</i> x <i>P. dulcis</i>	Barcelona, Spain	Agromillora	Agromillora
Barrier 1 [#]	<i>P. persica</i> x <i>P. davidiana</i>	CNR, Italy	Unknown	Unknown

[#]Observation sites only.

ROOTSTOCK TRIAL LEGEND		
NP	= Nonpareil (non-pollinator)	
C	= Carmel (pollinator)	
P	= Peerless (pollinator)	
o	= monitored trees	
ROOTSTOCKS		
1	Nemaguard	
2	GF557	
3	GF677	
4	GF749	
5	Adafuel	
6	Garnem	
7	Felinem	
8	Monegro	
9	Brights Hybrid	
10	Hansen 536	
11	Cornerstone	
12	Nickels	
13	Krymsk 86	
14	Cadaman (Was Penta)	
15	Atlas (was Tetra)	
16	Spare (Nemaguard)	
7.30	m	Spacing between rows
4.00	m	Spacing between trees
0.06	Hectares per block	
3.74	Hectares planted	



N



R1	R2
R3	R4

ND	No Data
o	Dead Data tree
NP	Original Trial tree replanted

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Tree 1	1	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
	2	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
	3	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
	4	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
	5	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
	6	2	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP
	7	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	8	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	9	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	10	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP
	11	3	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP
	12	NP	C	o	P	NP	C	ND	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	13	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	14	NP	C	o	P	NP	C	ND	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	15	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP
	16	4	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP
	17	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	18	NP	C	ND	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	19	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	20	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP
	21	5	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP
	22	NP	C	o	P	NP	C	o	P	NP	C	ND	P	NP	C	o	P	NP	C	NP
	23	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	24	NP	C	o	P	NP	C	o	P	NP	C	ND	P	NP	C	o	P	NP	C	NP
	25	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP
	26	6	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP
	27	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	28	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	29	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	30	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP
	31	7	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP
	32	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	33	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	34	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	35	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP
	36	8	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP
	37	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	38	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	39	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP
	40	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP
	41	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP
42	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
43	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
44	9	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
45	NP	C	ND	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
46	NP	C	ND	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
47	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
48	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
49	10	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
50	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
51	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
52	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
53	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
54	11	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
55	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
56	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
57	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
58	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
59	12	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
60	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
61	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
62	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
63	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
64	13	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
65	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
66	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
67	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
68	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
69	14	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
70	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
71	NP	C	Sick	P	NP	C	o	P	NP	C	ND	P	NP	C	o	P	NP	C	NP	
72	NP	C	o	P	NP	C	o	P	NP	C	ND	P	NP	C	o	P	NP	C	NP	
73	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
74	15	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
75	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
76	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
77	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
78	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
79	16	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	
80	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
81	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
82	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	o	P	NP	C	NP	
83	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	P	NP	C	NP	

Rootstock Trial Map - ACE Orchard

North

Row Spacings: 6.5m x 3m

Row	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Tree 1	Rootpac R	Black text		2019 plante		1	NP	V	NP	V	NP	V	NP	V	NP	V
2	Atlas	White text		2020 plant		2	NP	V	NP	V	NP	V	NP	V	NP	V
3	Viking					3	NP	V	NP	V	NP	V	NP	V	NP	V
4	Garnem					4	NP	V	NP	V	NP	V	NP	V	NP	V
5	Barrier 1					5	NP	V	NP	V	NP	V	NP	V	NP	V
6	Cornerstone					6	NP	V	NP	V	NP	V	NP	V	NP	V
7	Nemaguard					7	NP	V	NP	V	NP	V	NP	V	NP	V
8	Boarder Nemaguard				8	NP	V	NP	V	NP	V	NP	V	NP	V	V
			9	NP	V	NP	V	NP	V	NP	V	NP	V	V		
			10	NP	V	NP	V	NP	V	NP	V	NP	V	V		
			11	NP	V	NP	V	NP	V	NP	V	NP	V	V		
12			12	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
13			13	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
14			14	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
15			15	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
16	16	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V
17	17	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V
18	18	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
19	19	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
20	20	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
21	21	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
22	22	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
23	23	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
24	24	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
25	25	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
26	26	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
27	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
28	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
29	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
30	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
31	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
32	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
33	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
34	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
35	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
36	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V
37	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	NP	V	V

91m

115m

Appendix E. Results and discussion – Lindsay Point

Propagation

The percent establishment (%) was used as a measure of ‘ease of propagation’ as reported to the project reference group in August 2014 under AL11012 (Table E-1). The ability to replace trees was dependent on rootstock availability at the time of trial establishment. If the rootstock material was not available during trial establishment e.g. GF749, Adafuel, Monegro the trial trees were replaced with Nemaguard rootstock. This was the case for two monitoring trees (GF749 and Felinem) where Nemaguard was used as replacement trees but were excluded from data collection.

Three rootstock varieties Nickels (7%), Penta (42%) and Tetra (23%) resulted in poor establishment for all varieties Carmel, Nonpareil and Peerless and high number of measurement trees failed on first planting due to poor tree health or other factors. Cadaman and Atlas were originally recommended replacements for Penta and Tetra respectively but were unable to be accessed during trial establishment.

Of the fourteen rootstocks planned, for comparison against control Nemaguard eleven were successfully established for evaluation under AL16006 (Appendix C). Two Nemaguard treatments were planted to complete the randomise design and referred to as ‘Nemaguard’ and ‘spare Nemaguard’.

Table E-1: Tree establishment (reported to the project reference group in August 2014 under AL11012).

Rootstock	Missing trees / tree deaths				Establishment	Comment
(Total trees planted)	Carmel (20)	Nonpareil (40)	Peerless (20)	Nonpareil (12)	(%)	Nonpareil trees – trial trees
Nemaguard	0	0	0	0	100	Planted August 2013
GF557	0	1	1	0	98	Planted August 2013
GF677	0	0	1	0	99	Planted August 2013
GF749	1	2	2	1	93	Planted August 2013, missing trees replanted to Nemaguard in 2017
Adafuel	0	1	3	0	96	Planted August 2013, missing trees replants to Nemaguard 2017
Garnem	0	0	0	0	100	Planted August 2013
Felinem	1	4	0	1	93	Planted August 2013, missing trees replanted in July 2015
Monegro	0	1	0	0	99	Planted August 2013, missing trees replanted to Nemaguard 2017
Bright's Hybrid	0	0	3	0	97	Planted August 2013
Hansen 536	12	2	9	0	75	Planted August 2013, missing trees replanted in 2014
Cornerstone	0	0	0	0	100	Planted October 2014
Nickels	20	37	20	9	7	Planted October 2014, but excluded from trial due to poor establishment
Krymsk 86	0	0	2	0	98	Planted August 2013
Penta / Cadaman	9	25	13	6	42	Planted August 2013 but excluded from trial due to poor establishment. Alternative rootstock Cadaman chosen to replace Penta were not delivered. These plots were excluded from the trial.
Tetra / Atlas	18	28	17	8	23	Planted August 2013 but excluded from trial due to poor establishment. Alternative rootstock Atlas chosen to replace Tetra were not delivered. These plots were excluded from the trial.
Spare Nemaguard	0	1	0	0	99	Planted August 2013, missing tress replanted to Nemaguard 2017

Flowering

Flowering dates were recorded by the farm manager for each rootstock at the ‘start of flowering’, ‘full bloom’ and ‘end of flowering’ from 2017 -2020. The timing of each flowering stage was compared with Nemaguard average dates for each stage as presented in Table E-2. The variation in days was calculated for each rootstock with the minimum, average and maximum variation presented in Figure E-1.

The average ‘start of flowering’ for Nemaguard was observed to occur on August 6 (day 0). Average ‘full bloom’ occurred eleven days later, and average ‘end of flowering’ occurred by September 1, totalling 26 days duration from average ‘start of flowering’ to average ‘end of flowering’.

On average earlier flowering was observed for GF557, GF749, Adafuel and Krymsk rootstocks for each flowering stage and delayed for Felinem, and Hansen 536.

End of flowering appeared to be more variable for all rootstocks in comparison to Nemaguard.

As flowering observations were only collected for one replicate the significant difference was not assessed.

Table E-2: Variation in flowering days for rootstocks compared against Nemaguard (2017-2020).

Rootstock	Start of flowering (days)			Full bloom (days)			End of flowering (days)			Duration
	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	
Nemaguard	3/8	6/8	9/8	13/8	17/8	21/8	29/8	1/9	4/9	26.25
GF557	-3	-1	1	-2	-1.25	-1	-10	-2.5	1	24.75
GF677	-2	-0.75	0	-1	-0.25	1	-4	-0.5	2	26.5
GF749	-4	-2	0	-4	-2.25	0	-11	-3.25	2	25
Adafuel	-3	-2	0	-3	-3	-3	-10	-3.5	0	24.75
Garnem	-1	-0.25	0	-3	-0.5	1	-1	0.5	2	27
Felinem	0	1.5	3	1	1	1	-1	1.25	3	26
Monegro	-1	0.75	2	-3	-0.25	2	1	1.75	3	27.25
Bright's Hybrid	-2	-0.5	1	-2	-0.25	1	-4	-0.25	3	26.5
Hansen 536	0	0.75	2	0	0.5	1	0	1.25	3	26.75
Cornerstone	-1	-0.25	1	-3	-0.75	1	-5	-0.25	3	26.25
Krymsk 86	-3	-0.5	1	-3	-1	0	-11	-4.25	1	22.5
Spare (Nemaguard)	0	0.25	1	-1	0	1	-1	0	1	26

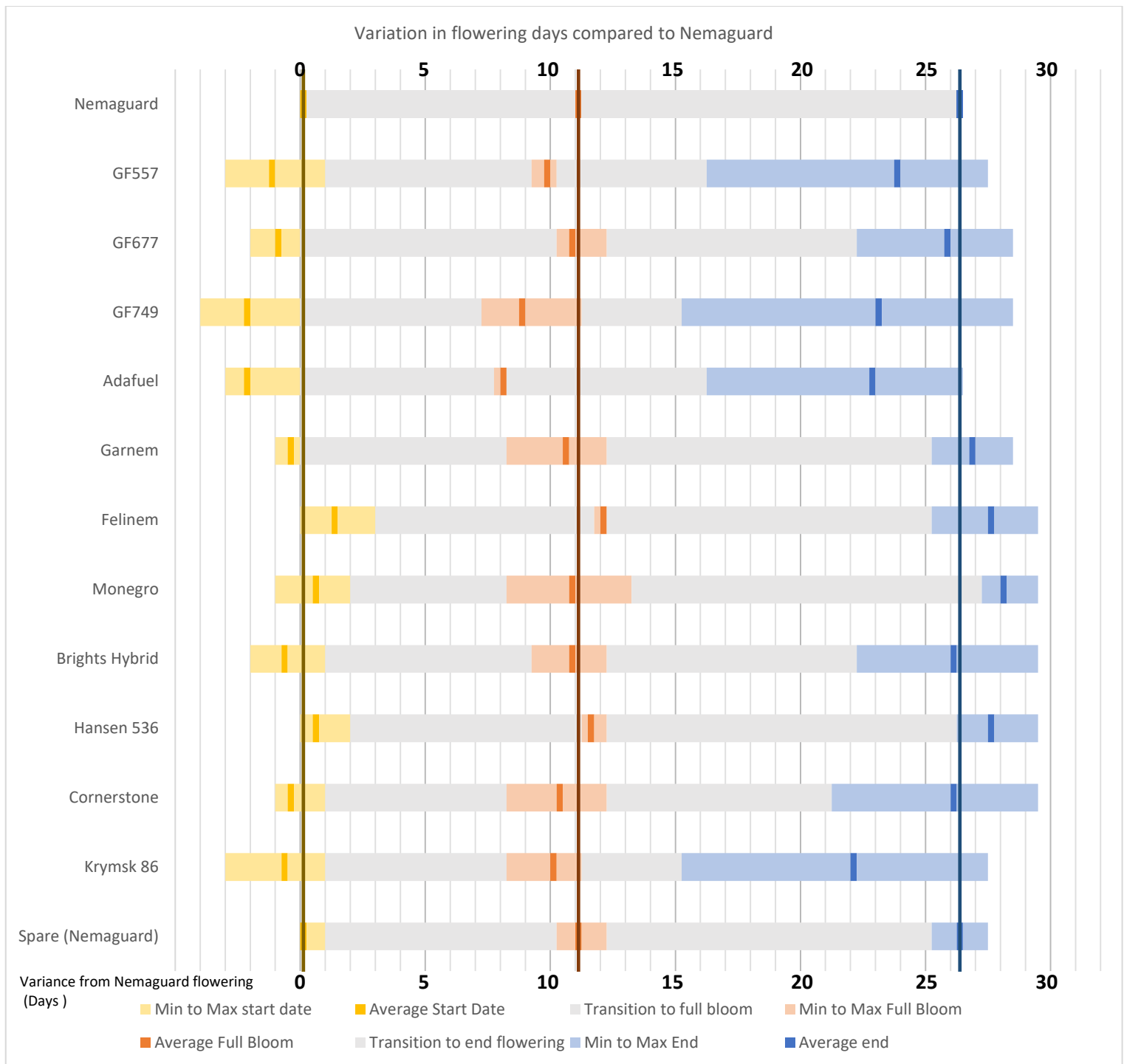


Figure E-1: Variation in flowering days for rootstocks compared to Nemaguard (2017-2020). Day 0 is the start of flowering for Nemaguard. The vertical lines indicate the average date for each stage of flowering observed for Nemaguard.

Hull split

Timing of hull split provides an indication of fruit ripening and harvest times. Stage 3: visible opening in suture less than 1 cm in width and Stage 6: completely dry (Appendix F).

Stage 3 is important as it marks the visible opening of the hull down to the shell, providing an entrance for diseases, for example hull rot, and pests to feed and lay eggs for example, carob moth and carpophilus beetle (Madge *et al.*, 2020). The timing of Stage 3 is important in preparation for appropriate pest and disease management activities. Mechanical shaking can commence with 100% of the lower interior of the tree reaching this initial Stage 3 of maturation since hulls will complete drying on the orchard floor (Carbo and Connell, 2017). Stage 6 marks the end of nut maturation.

Krymsk was the first rootstock to reach 50% of fruit at Stage 3 and Brights Hybrid reached 50% approximately 13 days later (Appendix F). Krymsk 86, Cornerstone and Nemaguard each reached 100% of Stage 3 hull split by the 25 January as did most other rootstocks except for Brights Hybrid which had only 53% of nuts reaching 100% hull split on the same day (Figure E-2 and Table E-3).

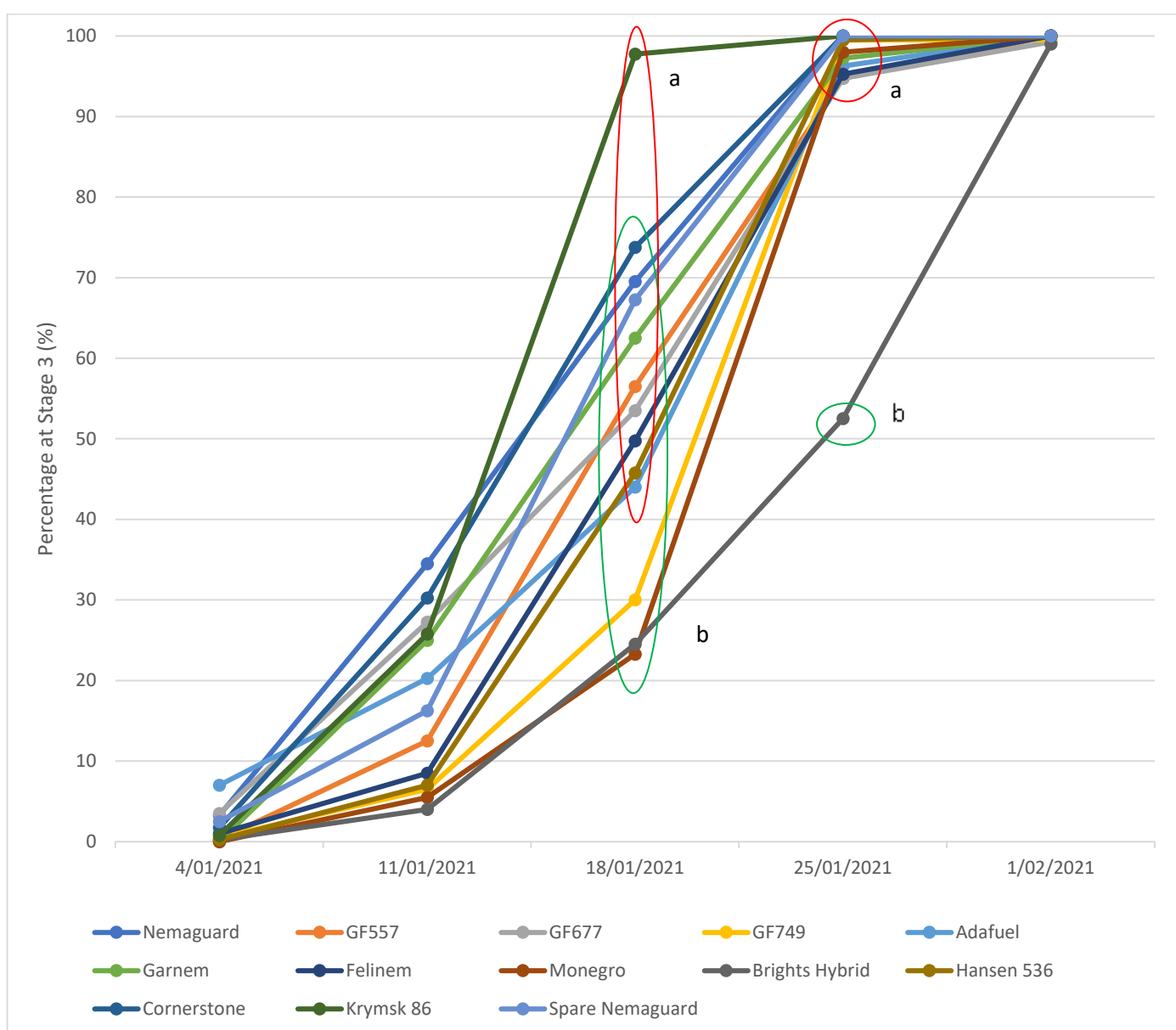


Figure E-2: Percentage of nuts at Stage 3 hull split assessed weekly.

Table E-3: Average percent of hull split to Stage 3 at each assessment date.

Rootstock	4-Jan	11-Jan	18-Jan	25-Jan	1-Feb	8-Feb	18-Feb
Nemaguard	3.25	34.5	69.5	100	100	100	100
GF557	0.25	12.5	56.5	94.75	100	100	100
GF677	3.5	27.25	53.5	94.75	99.25	100	100
GF749	0.5	6.5	30	99.5	99.5	100	100
Adafuel	7	20.25	44	96.25	100	100	100
Garnem	0	25	62.5	97.25	100	99.75	100
Felinem	1	8.5	49.75	95.25	100	100	100
Monegro	0	5.5	23.25	98	100	100	100
Brights Hybrid	0.25	4	24.5	52.5	99	99.5	100
Hansen 536	0.25	7	45.75	99.5	100	100	100
Cornerstone	1.75	30.25	73.75	100	100	100	100
Krymsk 86	0.75	25.75	97.75	100	100	100	100
Spare Nemaguard	2.5	16.25	67.25	100	100	100	100
p value	0.590	0.130	0.002	<0.001	0.638	0.544	1.000
se							
LSD							

All rootstocks reached near 100% Stage 6 hull split by the 18 February, without any significant difference between the rootstocks for this later stage of hull dehiscence (Figure E-3). The time to achieve 50% split to Stage 6 was not as clear as Stage 3. While Krymsk was first to achieve 50% there were no significant difference between the rootstocks. This may have been due to measurement variation.

Significant differences were observed between rootstocks on 1 February 2021 with Krymsk 86 significantly ($P < 0.003$) more advanced than Brights Hybrid and Felinem (Table E-4). While Krymsk appears to initiate splitting earlier this advancement to Stage 6 hull split is lost by 18 February when all rootstocks had reached 100% Stage 6.

Table E-4: Average percent of hull split to Stage 6 at each assessment date.

Rootstock	4-Jan	11-Jan	18-Jan	25-Jan	1-Feb	8-Feb	18-Feb
Nemaguard	0	0.25	0	2.25	13.5	58.25	91.75
GF557	0	0	0	4.25	25.25	72	97.75
GF677	0	0	0.25	0	1.5	42.5	96.5
GF749	0	0	0	0	3.5	50.75	97.25
Adafuel	0	1.25	0	3.25	16.25	45	95.75
Garnem	0	0	1	1	29.25	46	97.75
Felinem	0	0	0	2.25	26.75	31	95.5
Monegro	0	0	0	9.75	6.5	59.75	96.25
Brights Hybrid	0	0	0.25	0	3	26.25	90.5
Hansen 536	0	0	0	0	19.75	43	96.5
Cornerstone	0	0	0.25	1	33.5	59.75	96.5
Krymsk 86	0	0	0	0.5	42.75	89.5	98.25
Spare Nemaguard	0	0	0	0.75	10.25	57	96.25
p value	1.000	0.504	0.618	0.635	0.214	0.613	0.063
se							
LSD							

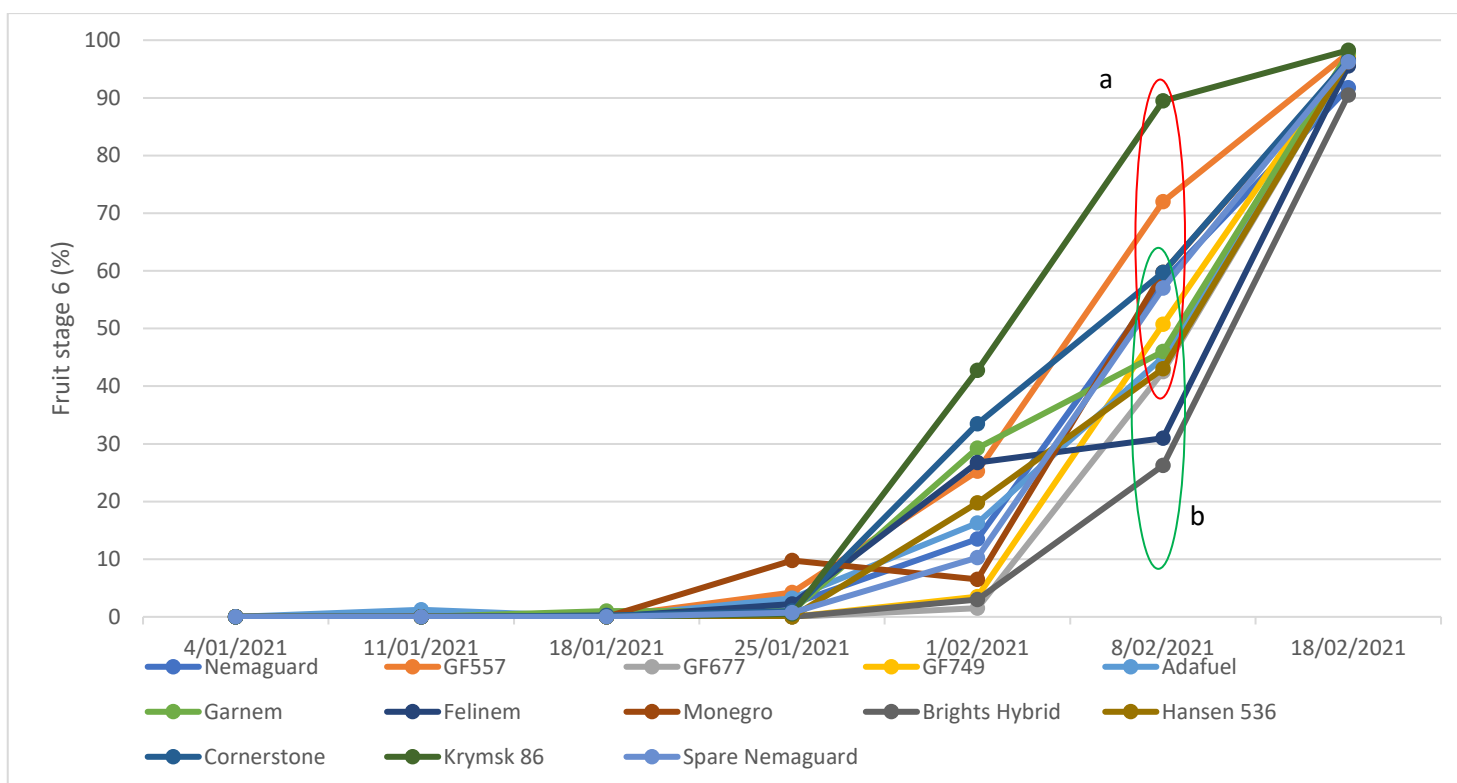


Figure E-3: Percentage of nuts at Stage 6 of hull split assessed weekly.

Variability in hull split timing was also considered in the analysis with better hull split synchronisation providing better efficacy of pest and disease control and harvest. In the advancement to Stage 3 hull split (18 January 2021), Krymsk 86 showed earlier dehiscence and significantly less variability at that stage (Table E-5). By 1 February 2021, Nemaguard had significantly lower variability than other varieties at the same stage of maturity (Table E-6).

It would be useful to repeat the hull split assessment to determine if a stronger relationship between variability and average splitting stage can be established and if the influence of Krymsk on bringing forward hull dehiscence is consistently observed in all seasons and other locations.

Table E-5: Average hull splitting stage for each rootstock ordered lowest to highest based on 1-Feb data.

Rootstock	11-Jan	18-Jan	1-Feb	Letter	8-Feb	18-Feb
GF677	2.30	3.05	4.30	a	5.46	5.97
Brights Hybrid	1.68	2.30	4.32	a	5.47	5.91
GF749	1.88	2.32	4.63	ab	5.52	5.97
Monegro	1.65	2.27	4.70	ab	5.57	5.96
Felinem	1.94	2.69	4.86	ab	5.74	5.96
Adafuel	2.14	2.71	4.88	ab	5.07	5.96
GF557	2.08	2.71	4.97	ab	5.39	5.98
Nemaguard	2.43	3.13	4.99	ab	5.23	5.92
Spare Nemaguard	2.03	3.20	4.99	ab	5.59	5.96
Hansen 536	1.88	2.65	5.00	ab	5.41	5.97
Garnem	2.06	3.06	5.16	ab	5.50	5.98
Cornerstone	2.28	3.07	5.30	ab	5.47	5.97
Krymsk 86	2.16	3.80	5.42	b	5.50	5.98
pval	0.410	0.012	0.003	NA	0.132	0.063
se	0.45	0.53	0.37	NA	0.150	0.033
LSD						

Table E-6: Variability (standard deviation) in hull splitting stage ordered lowest to highest based on 18 January 2021 data.

Rootstock	11-Jan	18-Jan	Letter	1-Feb	18-Feb
<i>Monegro</i>	0.461	0.470	a	0.607	0.181
<i>GF749</i>	0.491	0.567	a	0.686	0.139
<i>Brights Hybrid</i>	0.498	0.589	a	0.832	0.287
<i>GF677</i>	0.624	0.701	ab	0.678	0.121
<i>GF557</i>	0.402	0.708	ab	0.608	0.145
<i>Hansen 536</i>	0.569	0.729	ab	0.559	0.182
<i>Krymsk 86</i>	0.608	0.747	ab	0.466	0.064
<i>Adafuel</i>	0.719	0.762	ab	0.677	0.198
<i>Cornerstone</i>	0.536	0.765	ab	0.497	0.177
<i>Felinem</i>	0.439	0.798	ab	0.640	0.165
<i>Garnem</i>	0.648	0.802	ab	0.454	0.129
<i>Spare</i>	0.702	0.932	ab	0.446	0.160
<i>Nemaguard</i>					
<i>Nemaguard</i>	0.848	0.974	b	0.464	0.272
<i>pval</i>	0.026	0.020		0.089	0.130
<i>se</i>	0.168	0.177		0.176	0.093
<i>LSD</i>					

Production

Seasonal yield

Table E-7 and Figure E-4 presents the average annual kernel yield (kilograms per hectare) of Nonpareil harvested each year from 2016 to 2021 for each rootstock. The raw yields were adjusted using a cubic polynomial to remove row effects from the raw yield (appendix G).

Table E-7: Adjusted average annual kernel yield for Nonpareil trees on various rootstock from 2016 to 2021.

Rootstock	2016	2017	2018	2019	2020	2021
<i>Adafuel</i>	250	1110	2160	2580	3360	3440
<i>Brights Hybrid</i>	470	1190	1890	2690	3660	4120
<i>Cornerstone</i>	60	1120	1970	3160	3120	2850
<i>Felinem</i>	460	1120	1920	4150	4060	3110
<i>Garnem</i>	400	1290	1930	3880	4110	3160
<i>GF557</i>	390	820	1820	3140	3030	2190
<i>GF677</i>	560	1000	1780	3960	2920	3480
<i>GF749</i>	460	1120	1910	4420	3680	3790
<i>Hansen 536</i>	370	1080	1930	3650	3920	3340
<i>Krymsk 86</i>	440	700	1360	2310	2560	2240
<i>Monegro</i>	500	1290	1990	4500	3200	3700
<i>Nemaguard</i>	510	730	1850	2860	3590	2330
<i>Spare (Nemaguard)</i>	490	870	2100	3590	3240	2630
<i>p value</i>	0.017	0.001	0.569	0.084	0.041	0.049
<i>SE</i>	70	100	220	490	390	410
<i>LSD (Fisher's protected)</i>	142	203	NA	NA	793	834

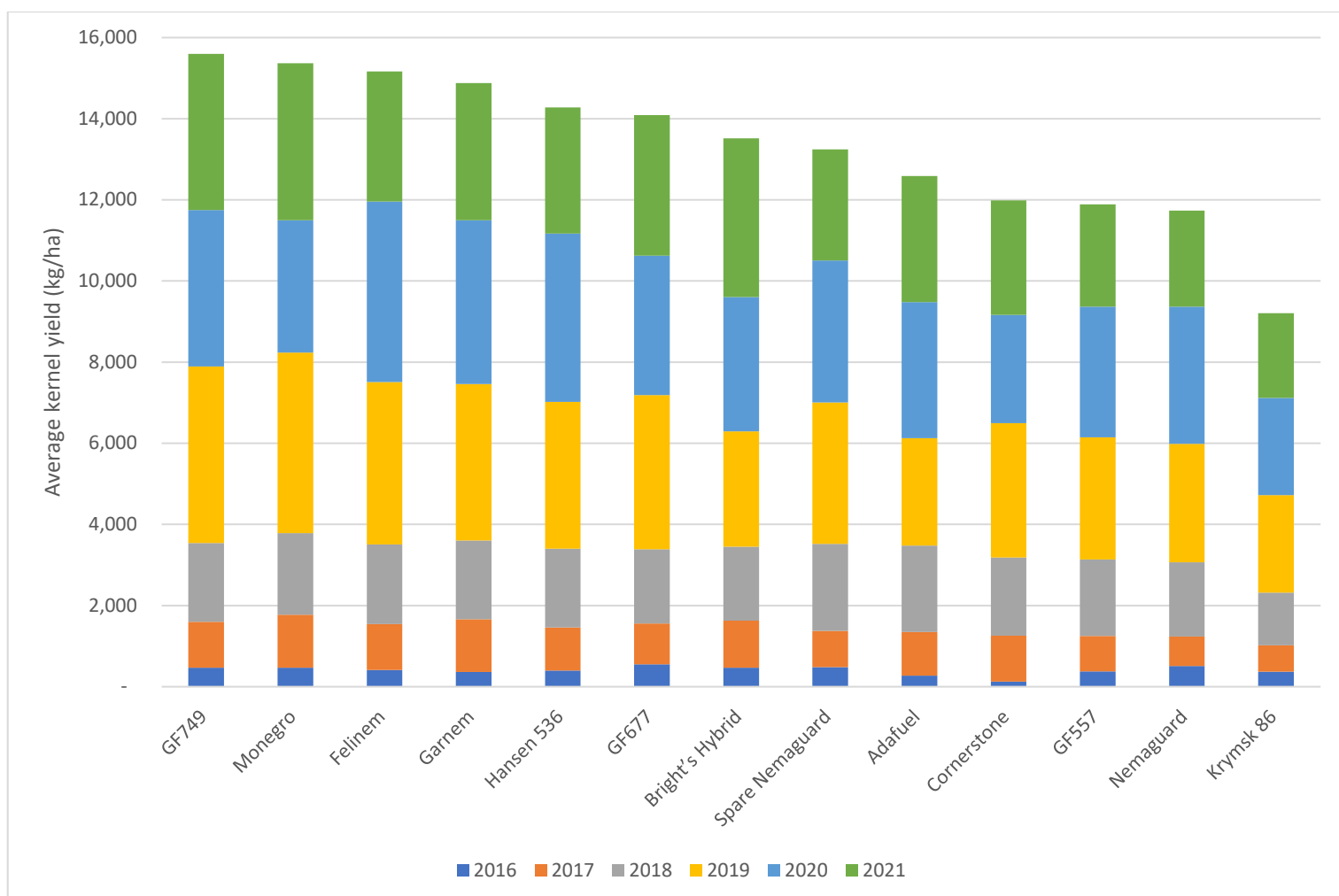


Figure E-4: Average annual kernel yield for Nonpareil trees on various rootstock (2016-2021).

Figure E-5, Figure E-6, and Figure E-7 illustrate the variability observed in annual yields for each rootstock separated into three box and whisker graphs: total average yield across six harvests (2016 to 2021); juvenile yields (2016 and 2017); and mature yields (2019 to 2021) respectively. The juvenile trees show similar yields and a lower magnitude of variability between rootstocks during the early years of establishment. As the trees have grown and a mature cropping pattern established the variability for each rootstock is more evident as illustrated in Figure E-7.

Mature yields suggest GF749 and Monegro have a similar median yield from 2019 to 2021 and both are relatively consistent. Other rootstocks for example, Cornerstone and Bright's Hybrid appear to have greater variability.

Continued monitoring of annual yield will help determine rootstock influences on yield consistency overtime.

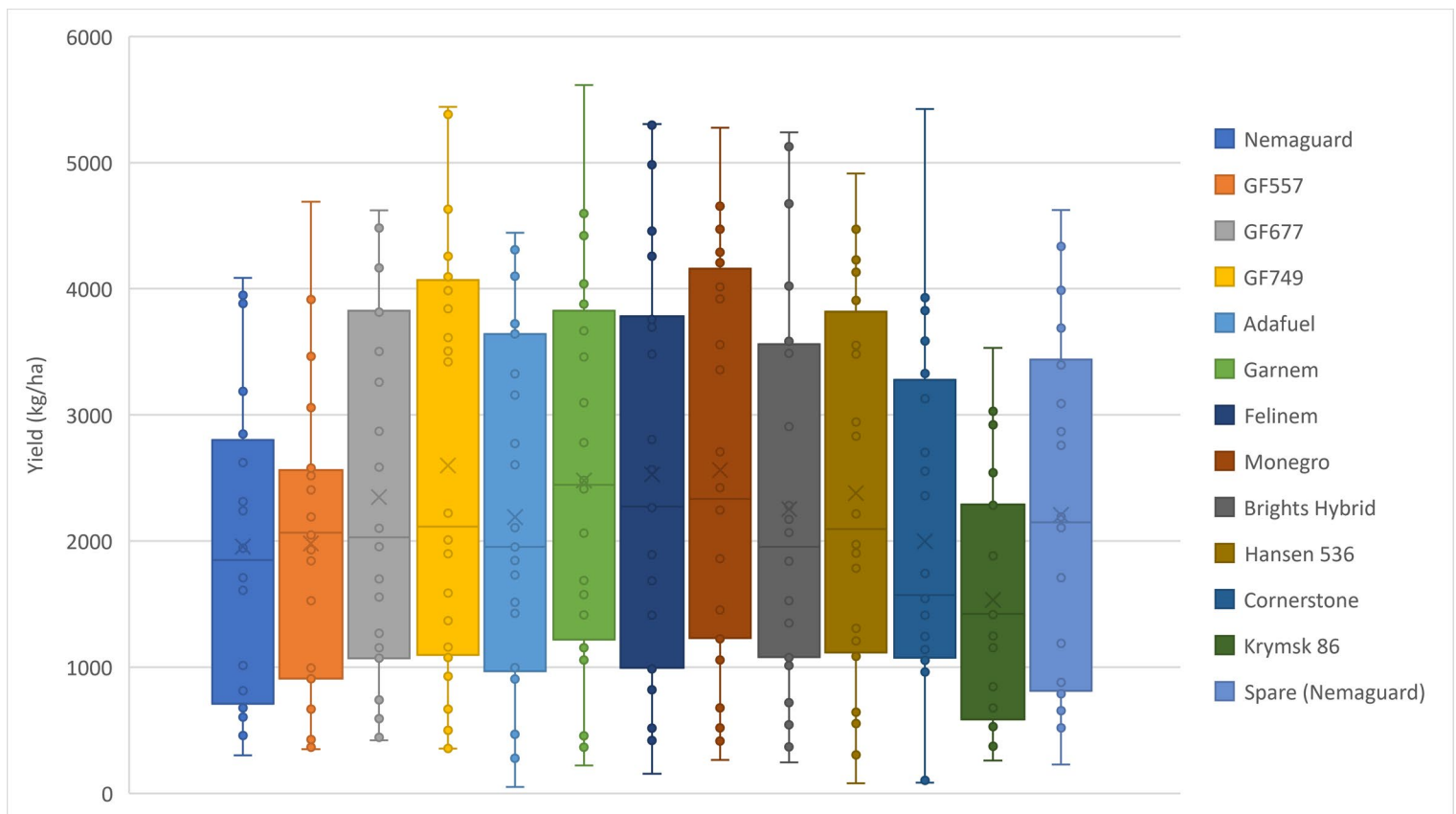


Figure E-5: Total annual kernel yield per hectare by rootstock - 2016 – 2021 (3rd to 8th leaf).

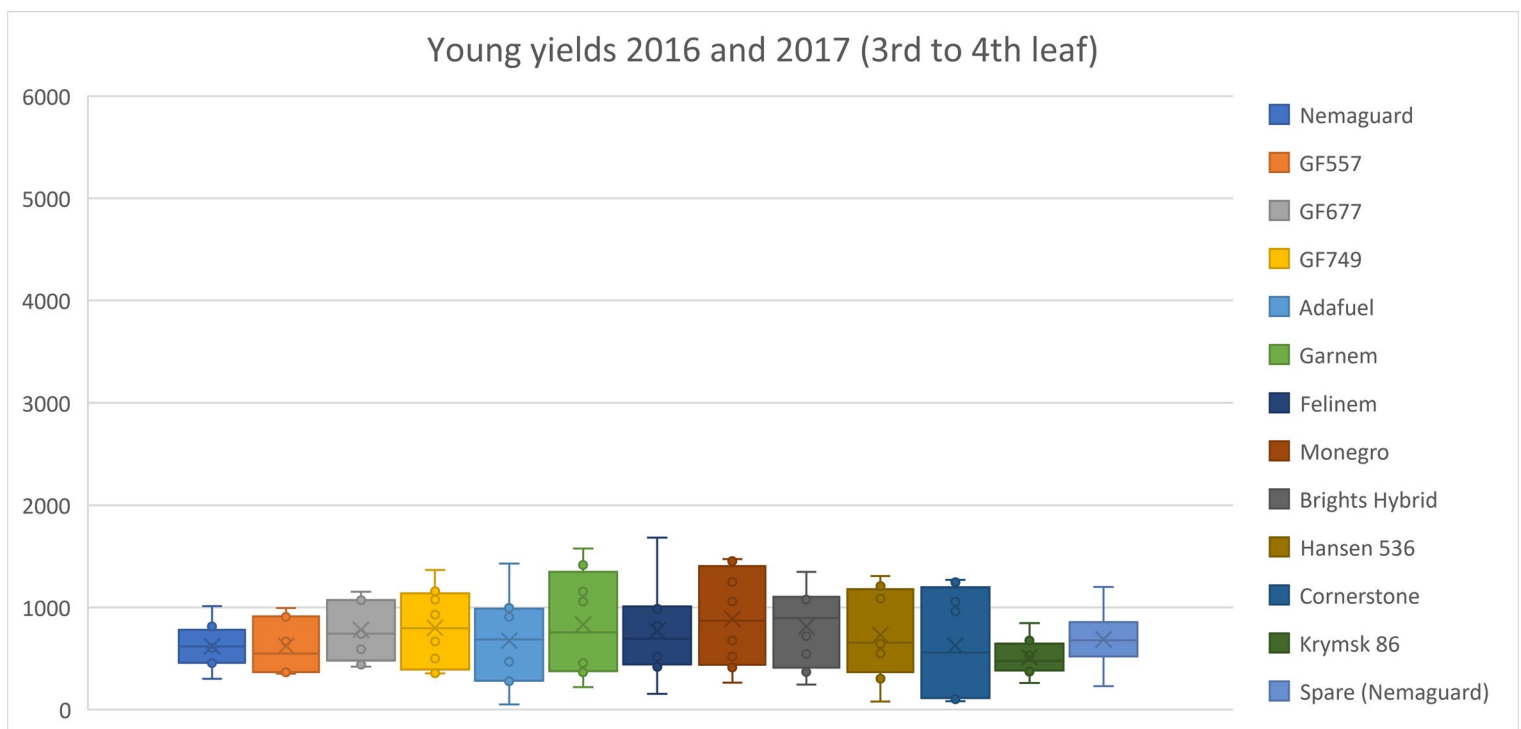


Figure E-6: Juvenile annual kernel yield per hectare by rootstock - 2016 and 2017 (3rd to 4th leaf).

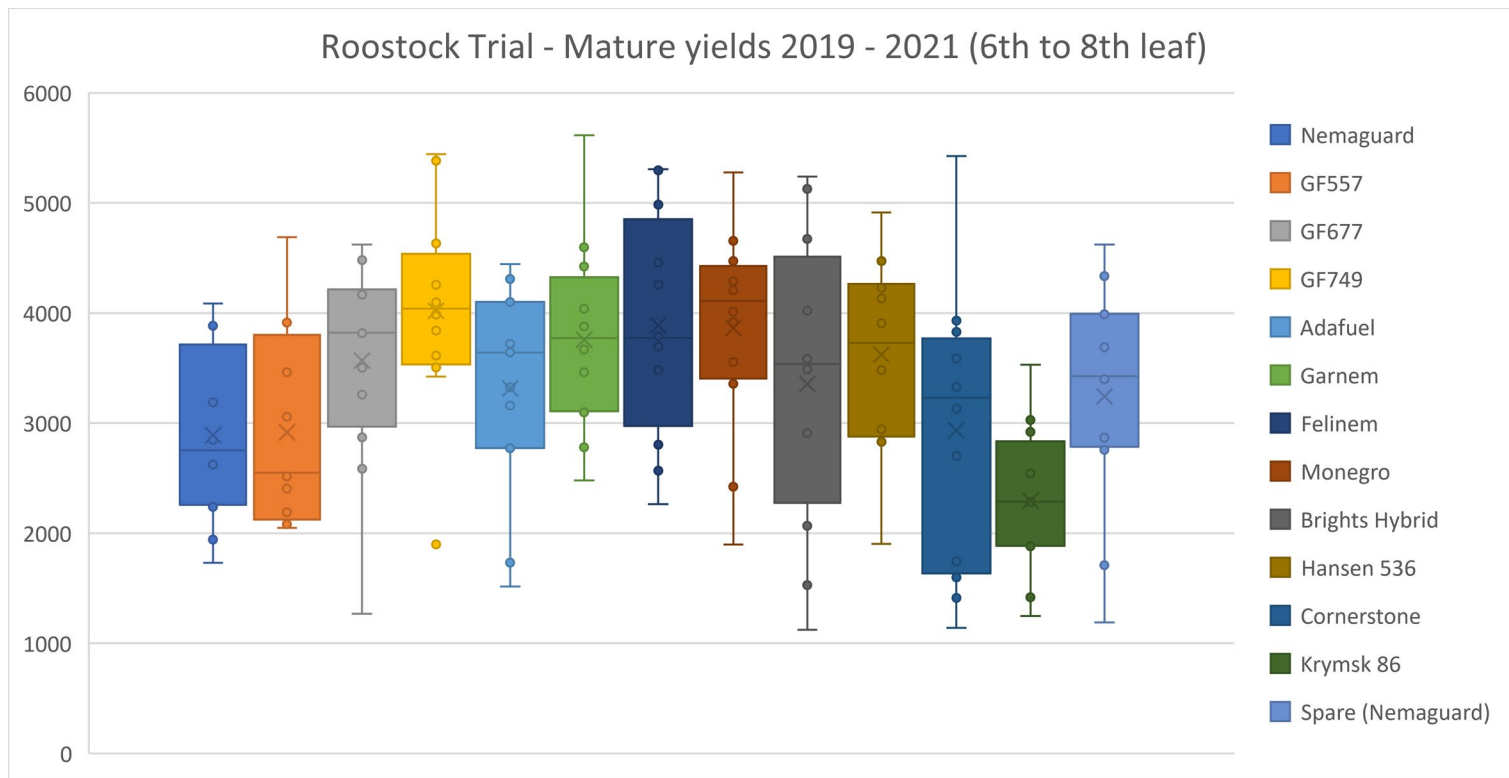
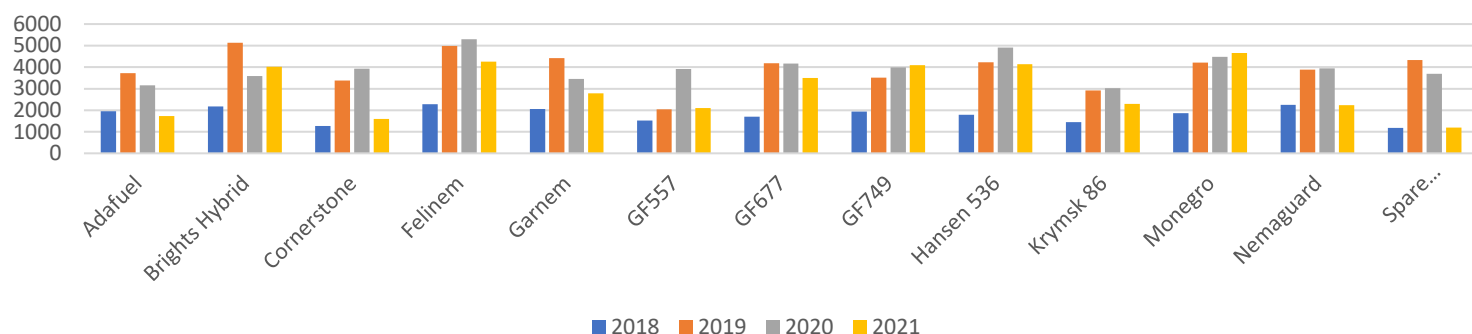


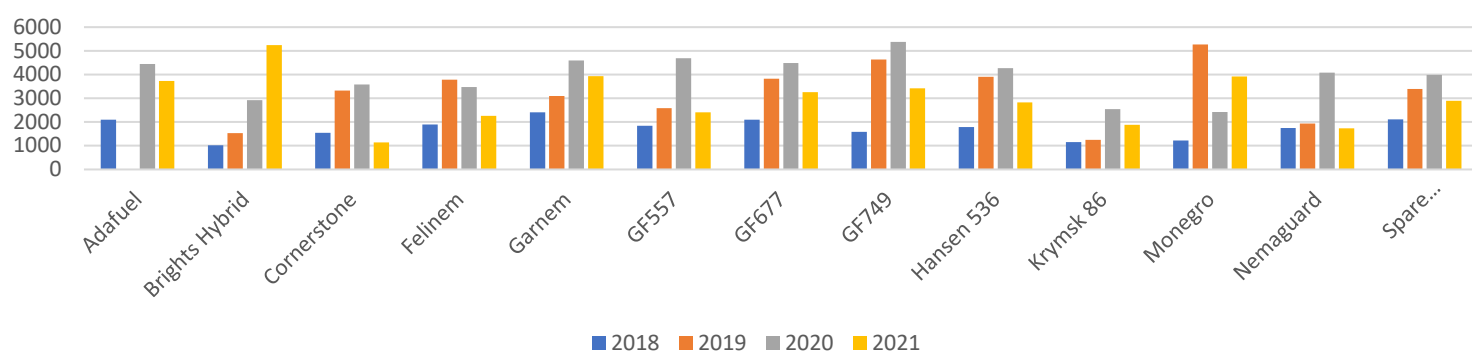
Figure E-7: Mature annual kernel yield per hectare by rootstock - 2019 to 2021 (6th to 8th leaf).

A closer investigation of the mature average annual yields to look at the variability within each replicate for each harvest from 2018 to 2021 suggested that some rootstocks were showing alternating years of higher yield followed by lower yields (Figure E-8).

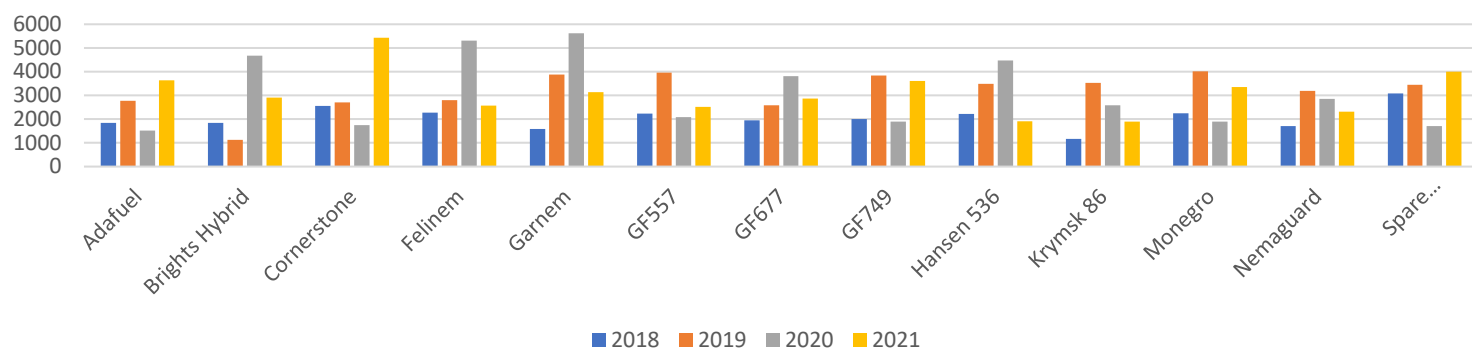
Seasonal average yield (2018 to 2021) - Replicate 1



Seasonal average yield (2018 to 2021) - Replicate 2



Seasonal average yield (2018 to 2021) - Replicate 3



Seasonal average yield (2018 to 2021) - Replicate 4

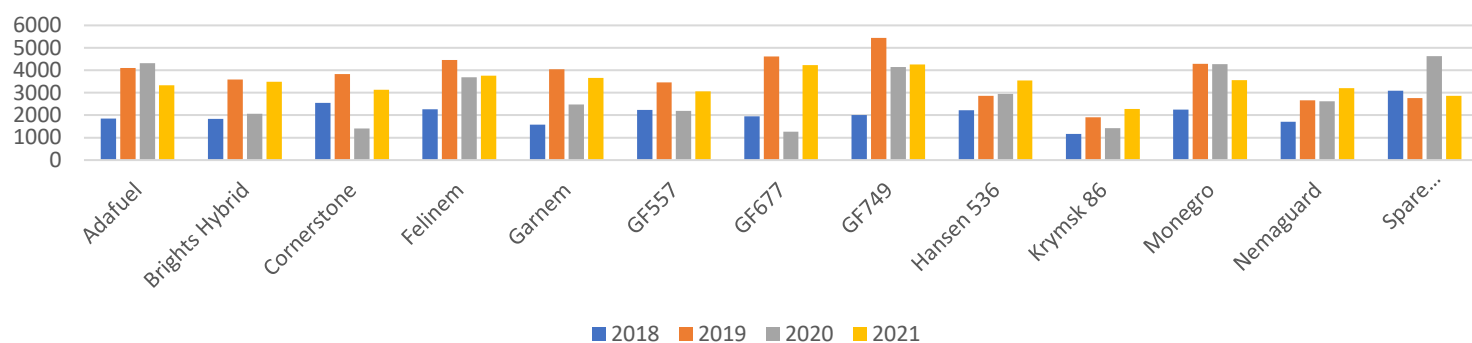


Figure E-8: Mature annual kernel yield (kg/hectare) for each rootstock in replicates 1 to 4 - 2018 to 2021.

A Biennial Bearing Index (BBI) was calculated to determine the level of biennial bearing for each rootstock using the calculation shown in Figure E-9 (Hoblyn *et al.* 1936).

$$I = \frac{\sum_{i=2}^n |y_i - y_{i-1}| / (y_i + y_{i-1})}{(n-1)}$$

Figure E-9: Biennial Bearing Index I where y_i is the yield observed in the plot, in the i th crop, in the ordered series of size n , where n is the number of harvests; $|y_i - y_{i-1}|$ is the absolute difference between the yields of two successive crops (Hoblyn *et al.* 1936).

This index was developed for apple trees where values closer to one (1), suggest a more pronounced alternation or oscillation of production, and a greater tendency for biennial bearing.

The BBI calculated for each rootstock is presented in Table 8. The BBI for each rootstock ranged from 0.24 Krymsk 86 to 0.39 for Cornerstone indicating a low tendency for biennial bearing. This is consistent with the findings of Tombesi *et al.* (2011) where studies on the relationship between spur- and orchard-level fruit bearing in almond (*Prunus dulcis*) concluded that almonds should not be considered a strictly alternate-bearing species. Tombesi *et al.* (2011) suggested that annual bearing fluctuations in almonds are probably mainly due to year-to-year variations in the conditions affecting fruit set.

Studies in apples and pears demonstrated that less vigorous cultivars could increase biennial bearing tendencies due to limitations in branch growth (Jonkers H., 1979). Yield and biennial bearing tendencies should continue to be monitored to identify if the different rootstocks influence these parameters as trees mature.

Table 8: Biennial Bearing Index for each rootstock in replicates 1 to 4 - 2016 to 2021 (Hoblyn *et al.* 1936). The closer the value is to 1 the higher the tendency towards biennial bearing.

Rootstock	Replicate 1	Replicate 2	Replicate 3	Replicate 4	BBI Average
Nemaguard	0.26	0.29	0.26	0.19	0.25
GF557	0.29	0.31	0.29	0.29	0.30
GF677	0.20	0.21	0.24	0.44	0.27
GF749	0.23	0.24	0.33	0.28	0.27
Adafuel	0.31	NC*	0.31	0.35	0.32
Garnem	0.30	0.24	0.30	0.30	0.29
Felinem	0.30	0.26	0.29	0.21	0.27
Monegro	0.25	0.35	0.30	0.22	0.28
Bright's Hybrid	0.29	0.29	0.34	0.26	0.30
Hansen 536	0.27	0.23	0.39	0.16	0.26
Cornerstone	0.36	0.38	0.41	0.43	0.39
Krymsk 86	0.26	0.21	0.26	0.22	0.24
Spare Nemaguard	0.37	0.23	0.31	0.23	0.29
Average	0.28	0.29	0.31	0.28	

*NC - not calculated due to missing data.

Cumulative yield

Cumulative yield is presented in Table E-9 in order of highest to lowest yield for all harvests from 2016 to 2021. In Figure E-10 the four trial replicates are illustrated by a different colour (red, green, yellow, blue) and seasonal yields depicted by six different shades (increasing darkness with each season).

By 2021 (8th leaf), the highest cumulative yields were observed for seven rootstocks, GF749 (15,597 kg/ha), Monegro (15,369 kernel kg/ha), Felinem (15,169 kernel kg/ha), Garnem (14,877 kernel kg/ha), Hansen 536 (14,276 kernel kg/ha), GF677 (14,089 kernel kg/ha) and Brights Hybrid (13,519 kernel kg/ha). The cumulative yields for the top seven rootstocks were not statistically different from each other. Of the top seven all but Brights Hybrid had significantly higher cumulative yields than Nemaguard (11,737.62 kg/ha). GF749 was significantly higher than both Nemaguard and spare Nemaguard (13,243.15 kg/ha). Nemaguard, Adafuel, Cornerstone (see note) and GF557 showed some differences between the high yielding seven but not for all rootstocks. All rootstocks produced yields significantly higher than Krymsk 86 for this site.

Krymsk 86 produced the lowest cumulative yield of 9,205 kernel kilograms per hectare and was the only rootstock with a cumulative yield significantly lower than both Nemaguard and all other rootstocks.

Of note, Cornerstone was planted 12 months later, and younger trees received higher fertiliser and water. These differences in treatment made it difficult to directly compare Cornerstone performance against other rootstocks in this trial. However, after 7 years growth Cornerstone was to achieve a similar cumulative yield to Nemaguard that had 8 years growth.

Table E-9: Cumulative average kernel yield (kg/ha) for each rootstock - 2016 to 2021. Rootstocks are ranked from highest to lowest kernel cumulative yield. Rootstocks sharing a common letter do not differ by Fisher's protected LSD.

Rootstock	Replicate 1	Replicate 2	Replicate 3	Replicate 4	Cumulative average kernel yield (kg/ha)	Fisher Letter
GF749	15,038.81	17,057.45	12,790.60	17,501.97	15,597.21	a
Monegro	16,912.18	14,507.54	13,248.29	16,809.29	15,369.32	ab
Felinem	18,651.71	12,832.63	14,284.86	14,905.28	15,168.62	ab
Garnem	14,359.20	15,606.69	15,725.71	13,815.79	14,876.85	abc
Hansen 536	16,575.60	13,991.49	13,236.84	13,300.67	14,276.15	abcd
GF677	15,292.41	15,484.39	12,391.08	13,186.17	14,088.51	abcde
Brights Hybrid	16,367.14	12,027.76	12,195.07	13,487.59	13,519.39	abcdef
Spare Nemaguard	11,833.37	13,783.53	13,470.67	13,885.03	13,243.15	bcdef
Adafuel	11,773.61	11,981.73	11,209.56	15,386.16	12,587.77	cdef
Cornerstone	11,291.05	10,946.78	13,564.57	12,147.21	11,987.40	def
GF557	10,631.46	12,789.43	12,137.15	11,985.80	11,885.96	ef
Nemaguard	13,458.75	10,932.64	10,990.74	11,568.35	11,737.62	f
Krymsk 86	10,790.59	7,726.74	10,163.18	8,137.35	9,204.468	g
pval						
se					1147	
LSD					2321	

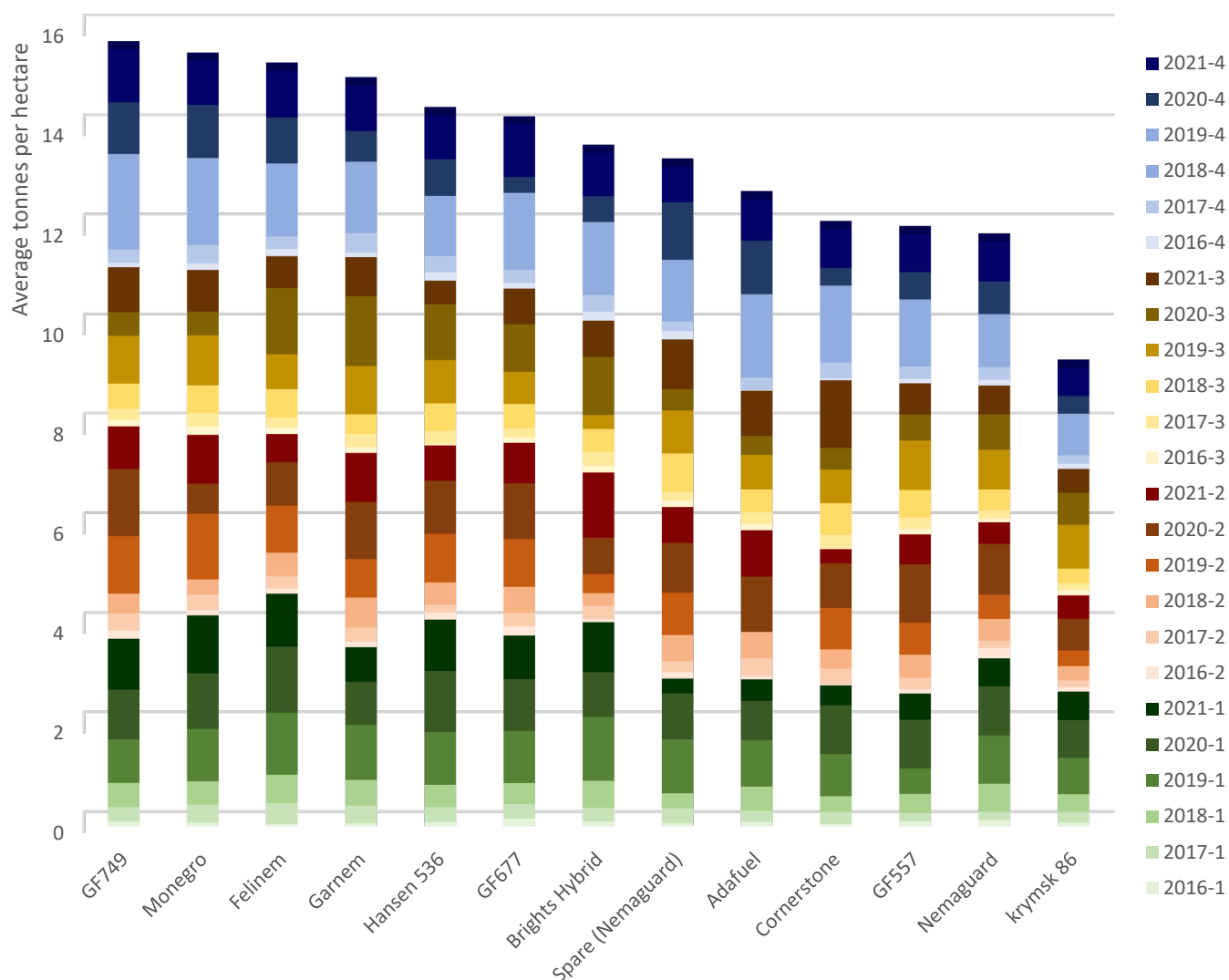


Figure E-10: Cumulative average kernel yield (tonnes/ha) for each rootstock and replicates 1 to 4 - 2016 to 2021.

Vigour

Trunk cross sectional area

Table E-10 presents the average butt circumference and statistical analysis for each rootstock measured in 2016, 2018 and 2020 (Appendix G).

Felinem, Hansen 536 and Monegro had the largest butt circumferences both initially in 2016 and in 2020. Adafuel increased its relative size during the trial period. Cornerstone and Nemaguard were relatively small both in 2016 and 2020. The ranking of rootstocks for 2018 was similar to those of 2020 and so it is assumed therefore tree size was a product of the initial planting size and genetic vigour of the rootstock.

Figure E-11 illustrates the cross-sectional area (cm²) calculated from the butt circumference in 2020 measured for each rootstock. This information is also presented in a stacked cumulative graph in Figure E-12.

Table E-10: Average butt circumference (mm) by rootstock.

Rootstock 2016			Rootstock 2018			Rootstock 2020		
Cornerstone	302.1	a	Cornerstone	442.2	ab	Cornerstone	540.4	a
Nemaguard	320.9	b	Nemaguard	442.8	ab	Nemaguard	549.8	a
Krymsk 86	321.3	b	Krymsk 86	450.0	abc	Spare	556.3	a
Adafuel	326.7	bc	Spare	450.2	abc	Brights Hybrid	560.4	ab
Spare	328.3	bc	Brights Hybrid	450.3	abc	GF557	564.6	ab
GF557	329.0	bc	GF557	459.9	abcd	Krymsk 86	568.8	abc
Brights Hybrid	335.9	bcd	GF749	464.6	bcd	GF677	569.5	abc
GF749	338.0	bcd	Garnem	468.5	bcd	Garnem	572.1	abc
GF677	344.5	cde	GF677	473.0	bcd	GF749	572.3	abc
Garnem	353.0	de	Adafuel	479.7	de	Adafuel	600.2	bcd
Felinem	355.9	de	Felinem	490.2	de	Felinem	605.4	cd
Hansen 536	358.5	de	Monegro	492.3	de	Monegro	608.8	cd
Monegro	362.7	e	Hansen 536	511.7	e	Hansen 536	619.6	d
p value	<0.001		p value	<0.01		p value	<0.01	
se	8.0		se	11.7		se	14.0	
lsd Fisher	22.9		lsd Fisher	33.6		lsd Fisher	40.2	
lsd Tukey	42.2		lsd Tukey	62.0		lsd Tukey	74.1	

Note: Units of measure are mm of circumference. Rootstocks that share the same letter do not differ at the 5% levels using Fisher's protected LSD.

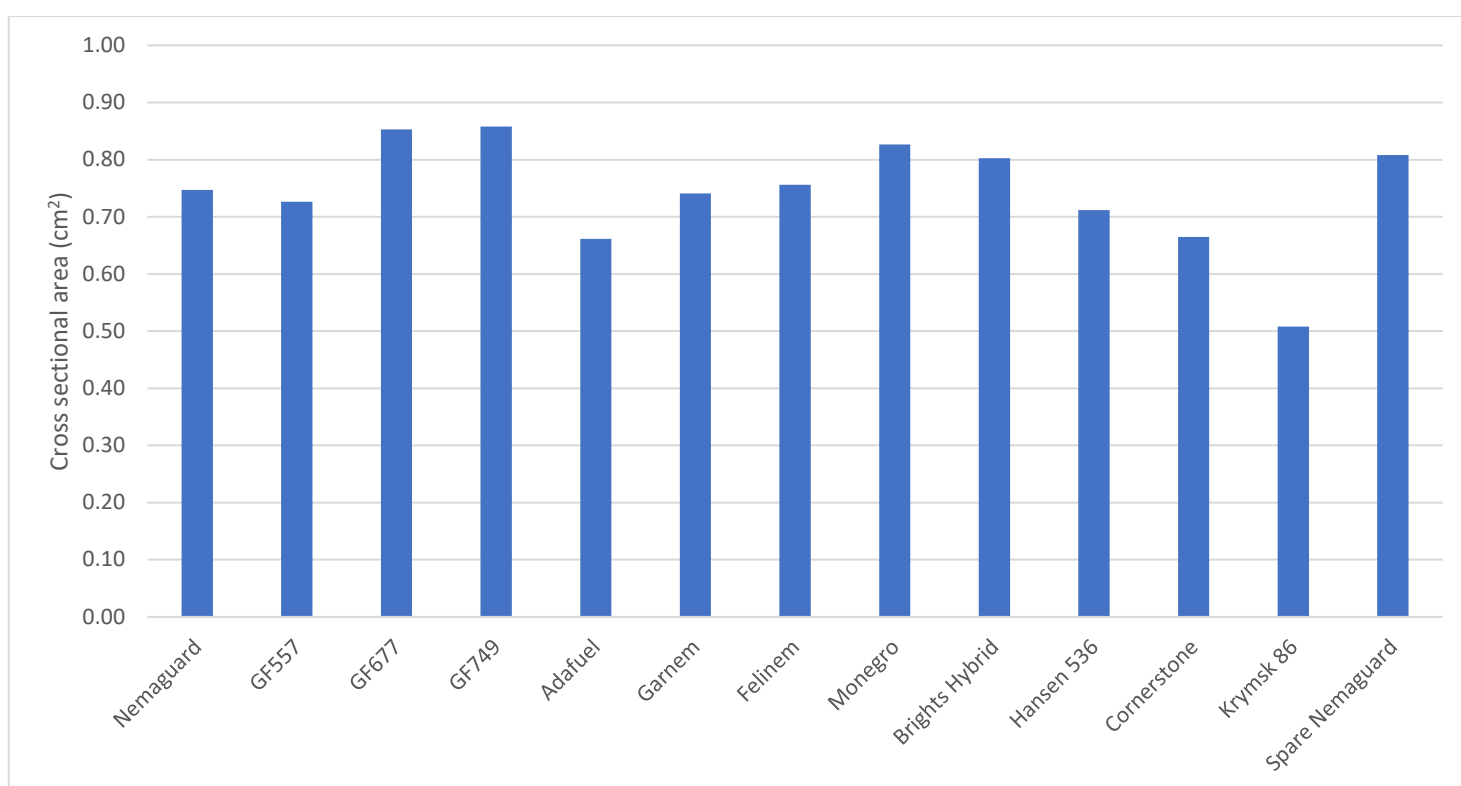


Figure E-11: Average cross-sectional area (cm²) for each rootstock in 2020.

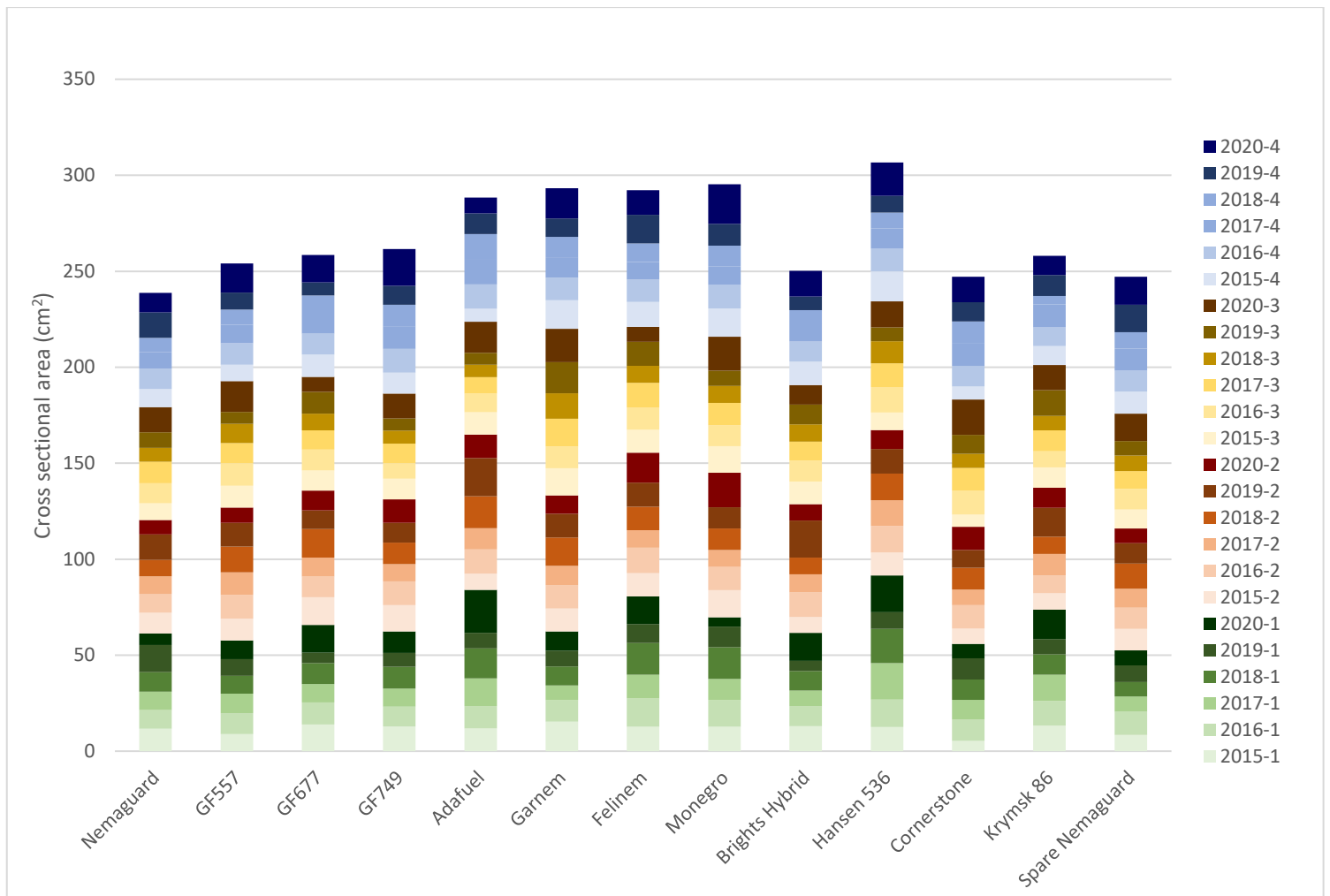


Figure E-12: Tree trunk cross sectional area (cm²) by rootstock for each replicate – 2015 to 2020.

Index of production efficiency

Production efficiency (kg/cm^2) was calculated using the annual kernel yield (kg/tree) divided by the increase in trunk cross-sectional area as illustrated in Table E-11 and Figure E-13.

In 2017 Adafuel, Cornerstone and GF557 had significantly higher production efficiencies (yield / trunk cross sectional area) compared to Garnem, Brights Hybrid, Nemaguard, Hansen 536 and Krymsk 86 rootstocks. However, the significance of these differences between rootstocks was lost after 2017 meaning trees with larger trunks were no more, or less, productive than trees with smaller trunks after their 4th leaf.

Table E-11. Analysis of production efficiency (kg/cm^2) for each year. Listed from highest to lowest production efficiency for 2020.

Rootstock	2016	2017	2018	2019	2020
Nemaguard	0.037	0.057	0.161	0.186	0.307
Felinem	0.025	0.077	0.126	0.243	0.286
Spare Nemaguard	0.032	0.07	0.175	0.269	0.262
Monegro	0.029	0.095	0.133	0.32	0.251
Garnem	0.023	0.095	0.119	0.265	0.238
GF677	0.036	0.077	0.122	0.381	0.237
GF557	0.024	0.061	0.141	0.27	0.231
Brights Hybrid	0.032	0.092	0.157	0.301	0.22
Hansen 536	0.023	0.059	0.12	0.292	0.218
GF749	0.033	0.084	0.147	0.383	0.212
Adafuel	0.018	0.069	0.135	0.235	0.204
Cornerstone	0.008	0.08	0.148	0.242	0.186
Krymsk 86	0.028	0.04	0.135	0.162	0.143
p value	0.056	0.008	0.665	0.315	0.949
SE	0.006	0.01	0.019	0.059	0.066
LSD	NA	0.028	NA	NA	NA

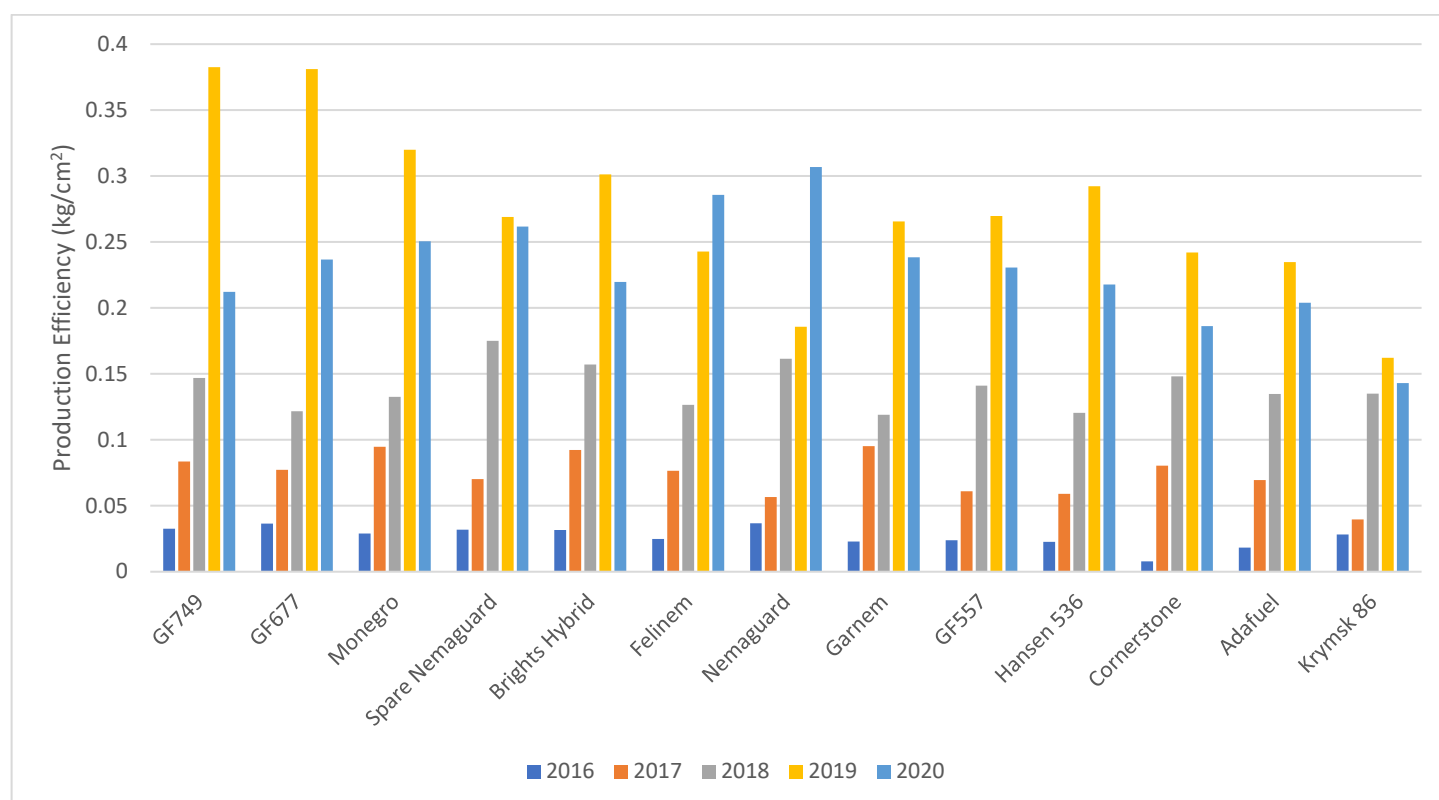


Figure E-13: Average production efficiency (kg/cm^2) for each rootstock– 2016 to 2020.

Fruit

Crack-out

For each monitoring plot a random sample of 100 nuts were weighed and sorted into kernel, shell and hull and each portion weighed to determine the “crack-out” as a percentage of the sample weight.

In 2021 crack-out's were significantly different between rootstocks ($p < 0.1$) with 5% difference between the highest crack-out, observed for Brights hybrid and Monegro (33% each), and the lowest crack-out observed for Krymsk (28%) Table E-12.

When crack-outs were averaged out across the six years the differential was only 3% from lowest (28) to (31) Table E-12.

Table E-12: Average annual crack-out (%) for each rootstock. Listed from smallest to largest average crack-out (2016 to 2021).

Rootstock	2016	2017	2018	2019	2020	2021	Average crack-out	Mature Average (2019 – 2021)
Krymsk 86	31	25	25	27	31	28	28	30
Adafuel	31	29	30	23	33	32	30	32
GF557	32	26	29	27	34	30	30	32
Nemaguard	32	26	28	30	35	29	30	32
Cornerstone	30	29	28	31	35	29	30	32
GF749	31	26	27	32	32	32	30	32
Garnem	30	27	29	31	34	31	30	33
GF677	32	27	29	30	34	32	30	33
Spare Nemaguard	31	30	28	31	35	30	31	32
Felinem	32	27	29	31	34	30	31	32
Brights Hybrid	33	28	26	29	34	33	31	34
Hansen 536	33	28	28	29	35	31	31	33
Monegro	30	27	28	34	34	33	31	33

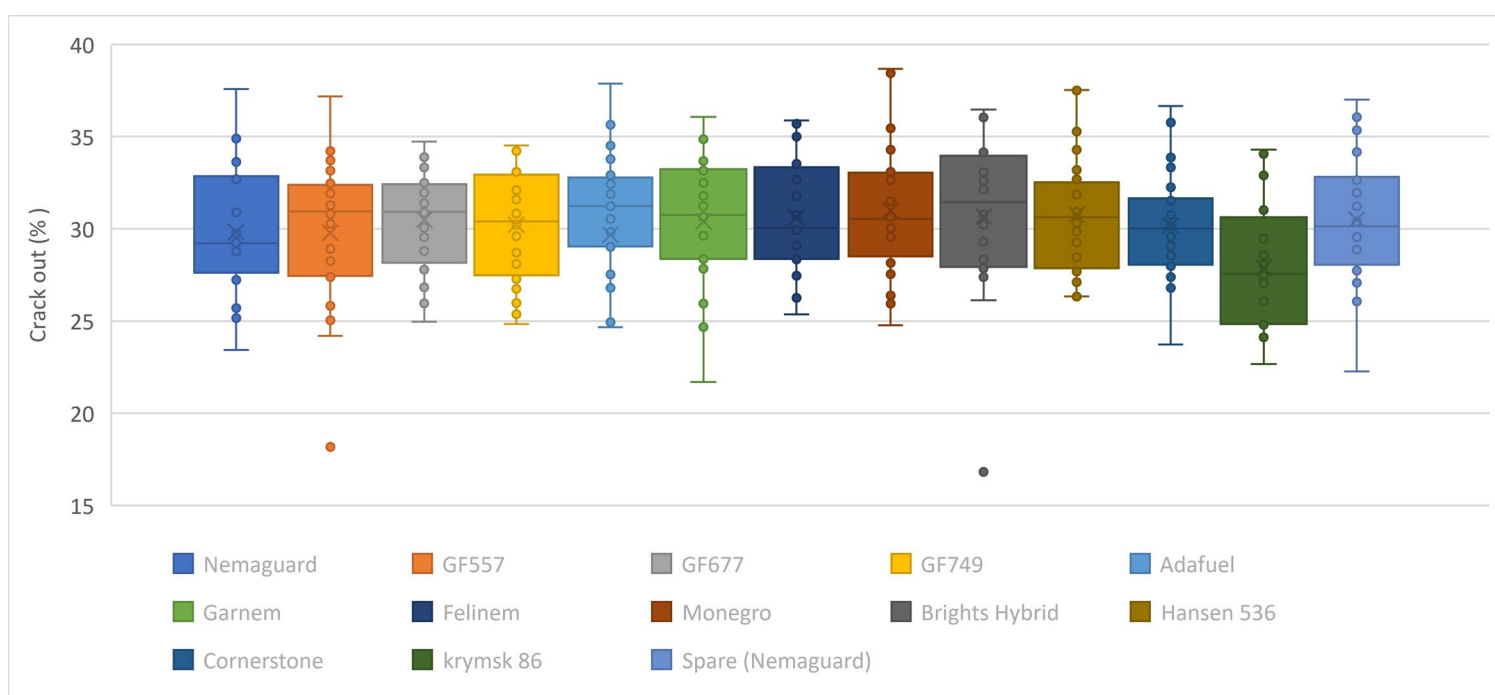


Figure E-14: Average annual crack-out (%) for each rootstocks from 2016 to 2021.

Fruit size and weight

The weight of each 100 nut subsample was used to calculate the average fruit weight and the 100 kernel sample was used to calculate the average kernel weight in Table E-13 and Figure E-15. The variability in fruit weight is illustrated in Figure E-16. Kernel weight increased as the trees matured. A strong ($p < 0.001$) negative correlation between yield and kernel weight was observed in 2021 i.e. where there was a high yield the kernel weight tended to be small (Appendix G).

Table E-14 describes the grams equivalent for almonds grades as sold by almond marketers.

In 2021 there were no significant differences in kernel weight between rootstocks ranging from the smallest 1.35 grams for GF749 (Size grade 20/22) to 1.55 grams for Nemaguard (Size grade 18/20).

Other correlations with 2021 kernel weight included:

- A very strong ($p < 0.001$) negative correlation with Calcium i.e. high levels of calcium have small kernel weight.
- A strong ($p < 0.01$) negative correlation with tree height i.e. larger trees have smaller kernel weights.
- A strong ($p < 0.01$) negative correlation with leaf magnesium i.e. higher levels of magnesium have smaller kernel weights.
- A strong ($p < 0.01$) positive correlation with leaf potassium i.e. higher levels of potassium have higher kernel weights.

Table E-13: Average kernel weight from 2016 – 2021.

Rootstock	2016	2017	2018	2019	2020	2021	Average	Average Mature (2019-2021)
GF557	1.27	1.28	1.11	1.39	1.26	1.54	1.31	1.40
Nemaguard	1.24	1.27	1.10	1.34	1.26	1.55	1.29	1.38
Cornerstone Spare (Nemaguard)	1.33	1.20	1.08	1.28	1.22	1.53	1.27	1.34
Krymsk 86	1.28	1.42	1.15	1.28	1.19	1.51	1.31	1.33
Brights Hybrid	1.29	1.20	1.12	1.23	1.26	1.49	1.26	1.32
GF677	1.28	1.27	1.04	1.15	1.30	1.51	1.26	1.32
Hansen 536	1.26	1.30	1.10	1.19	1.20	1.51	1.26	1.30
Garnem	1.33	1.25	1.07	1.21	1.21	1.46	1.26	1.30
Felinem	1.37	1.21	1.06	1.16	1.25	1.44	1.25	1.28
Monegro	1.28	1.20	1.06	1.18	1.19	1.46	1.23	1.28
GF749	1.29	1.17	1.08	1.24	1.18	1.36	1.22	1.26
Adafuel	1.28	1.15	1.08	1.21	1.20	1.35	1.21	1.25
	1.25	1.19	1.08	0.92	1.26	1.51	1.20	1.23

Table E-14: Gram equivalent to almond grading sizes – kernels per ounce.

Grade size	14/16	16/18	18/20	20/22	23/25	25/27	27/30	30/32
Gram's equivalent	1.77 – 2.02	1.57 – 1.76	1.42 – 1.57	1.29 – 1.42	1.13 – 1.29	1.05 – 1.13	0.94 – 1.05	0.89 – 0.94

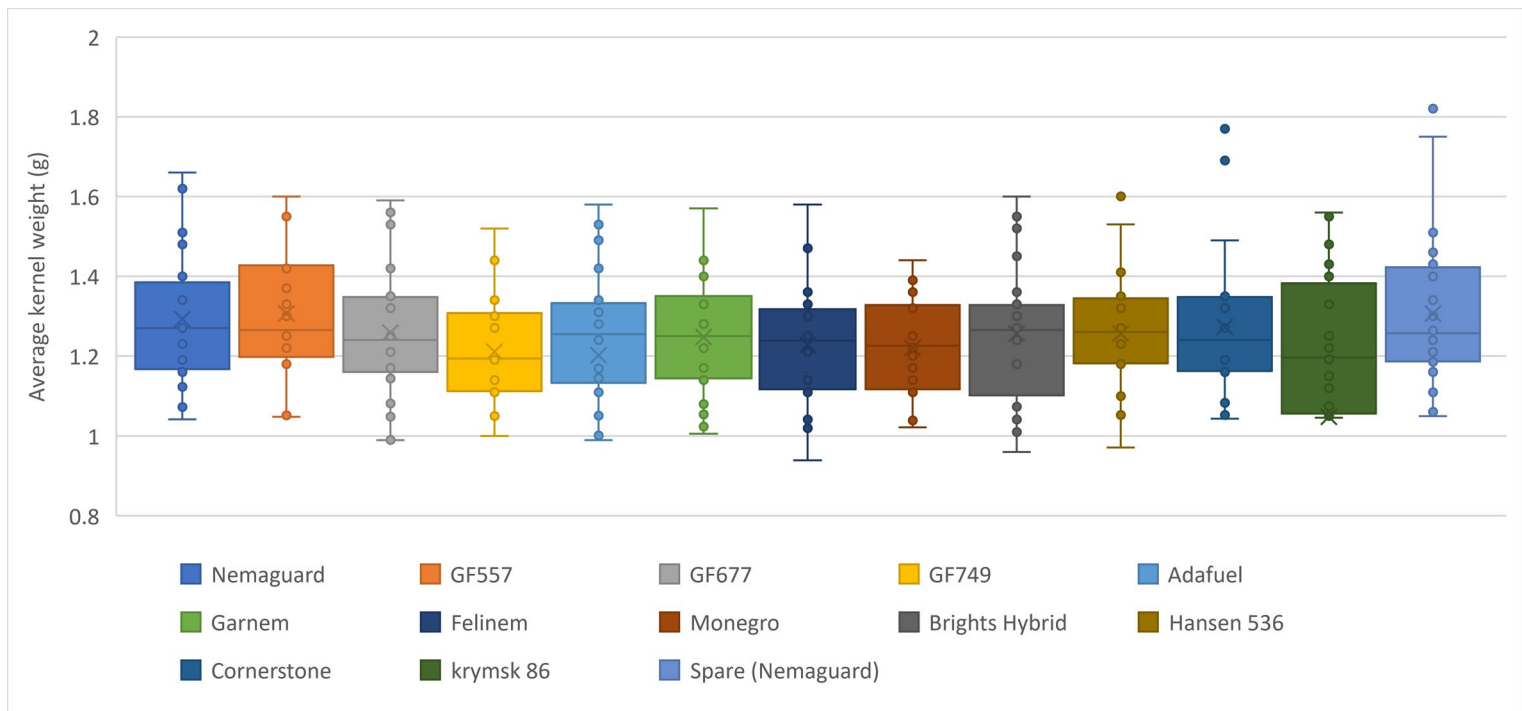


Figure E-15: Average kernel weight (g) from 2016 to 2021.

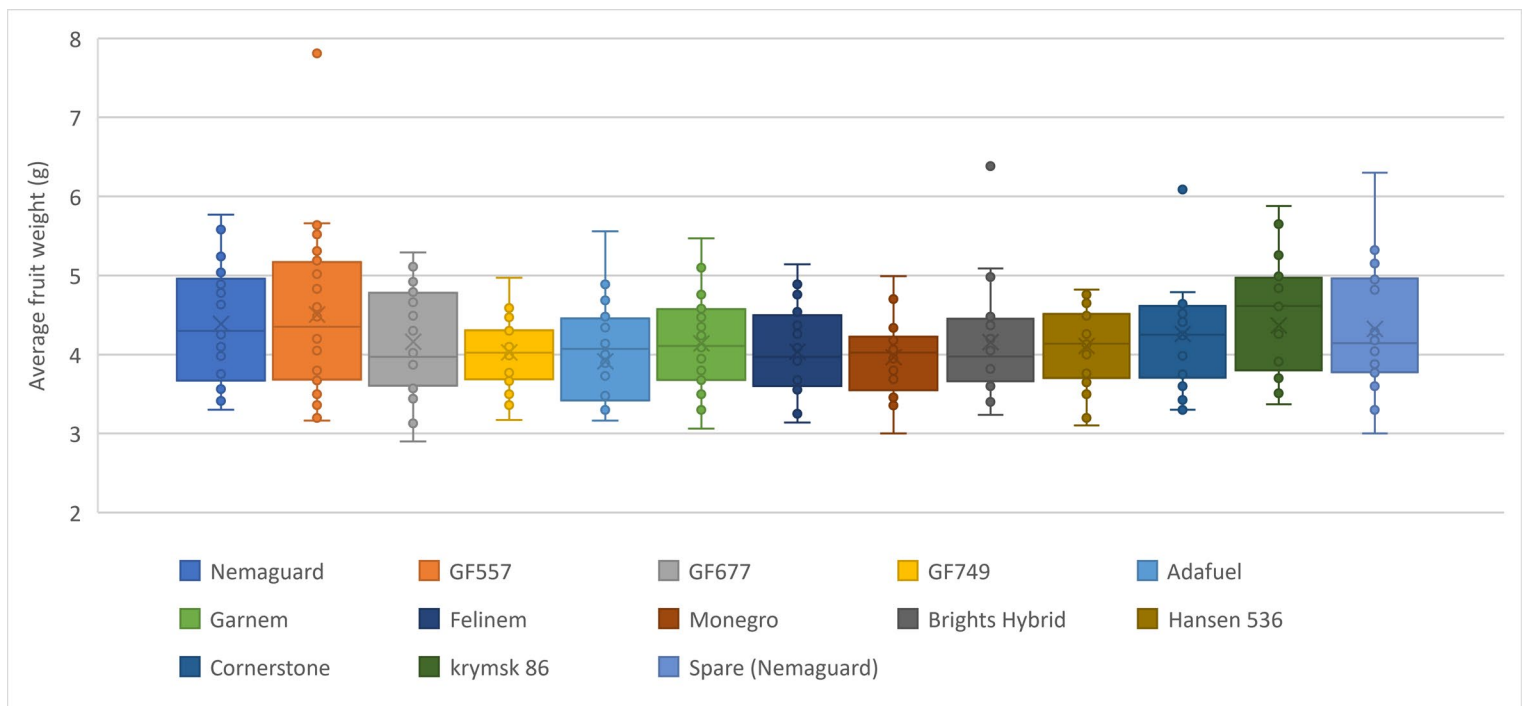


Figure E-16: Average fruit weight (g) from 2016 to 2021.

Stick tights

Stick tights were recorded in 2017 and 2018 for each rootstock and replicate (Figure E--30). Figure E--31 illustrates the number of stick tights for rootstock compared with Nemaguard. Post 2018 it was increasingly difficult to accurately count the number of stick tights due to the height of the trees and quantum of stick tights.

Table E-15: Average number of stick tights in 2017 and 2018 per tree.

	2017	2018	Average
Monegro	279	834	556
Cornerstone	409	624	517
Spare (Nemaguard)	487	508	498
Garnem	260	730	495
Felinem	191	792	492
Nemaguard	469	459	464
Hansen 536	247	617	432
GF557	336	458	397
krymsk 86	432	311	371
GF677	217	460	338
Brights Hybrid	159	408	283
Adafuel	198	182	190
GF749	75	134	105

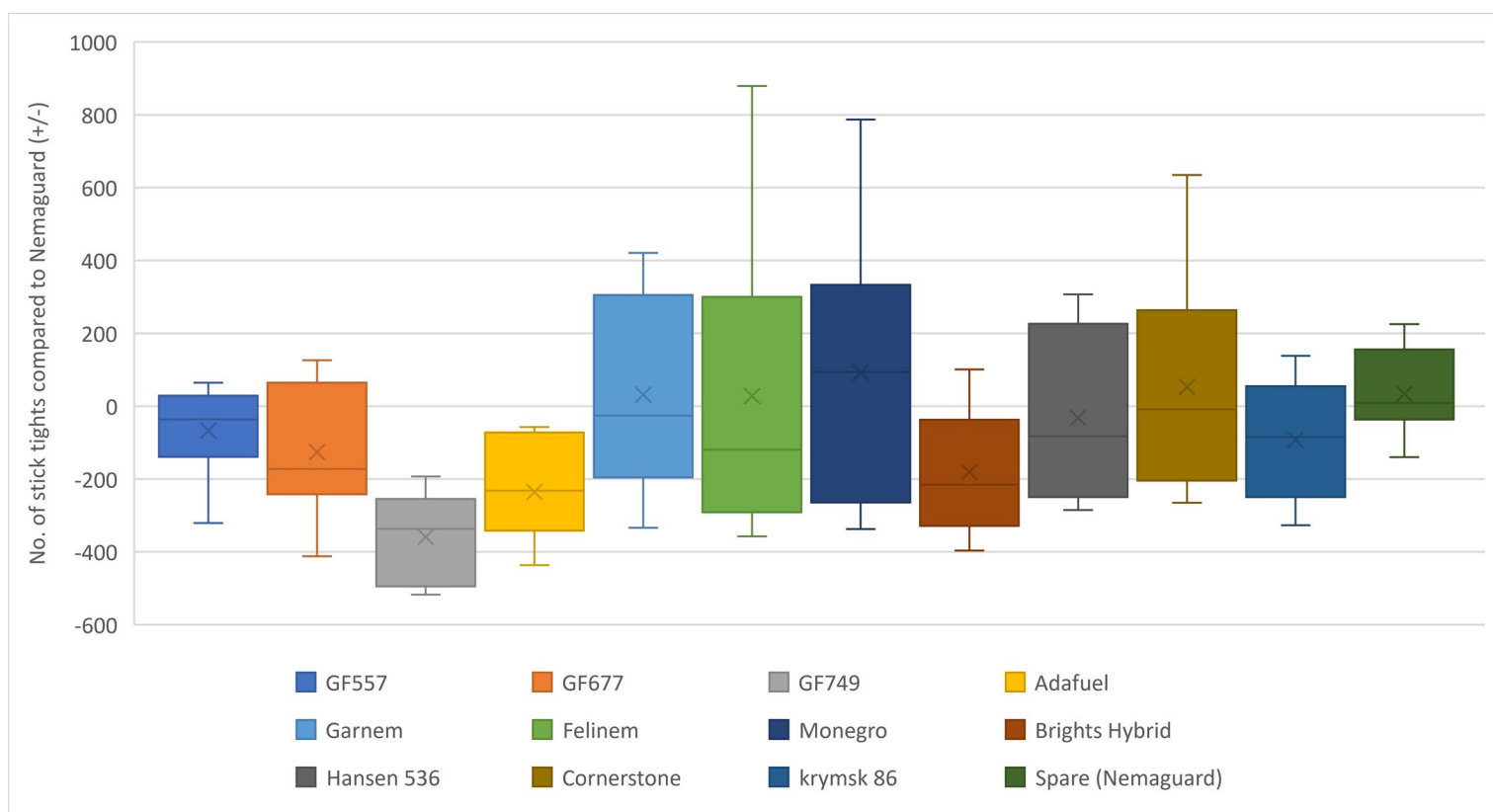


Figure E-17: Stick tights compared with Nemaguard (number).

Tree habit

Tree height

The mean heights of each tree grown on different rootstock are shown in Table E-16.

Table E-16: Annual tree heights (m) on each rootstock ranked from smallest to highest 2020 height.

	2017	2018	2019	2020
Krymsk 86	4.45	4.33	4.65	4.70
Nemaguard	4.28	4.27	4.63	4.78
Cornerstone	4.30	4.39	4.68	4.78
Adafuel	4.55	4.51	4.60	4.88
Monegro	4.75	4.55	4.78	4.88
GF557	4.63	4.40	4.75	4.90
Hansen 536	4.68	4.80	4.88	4.90
Spare (Nemaguard)	4.55	4.36	4.80	4.90
Brights Hybrid	4.45	4.54	4.85	4.93
GF677	4.58	4.44	4.68	4.95
GF749	4.70	4.73	4.95	4.98
Garnem	4.38	4.38	4.78	4.98
Felinem	4.83	4.59	5.00	5.00

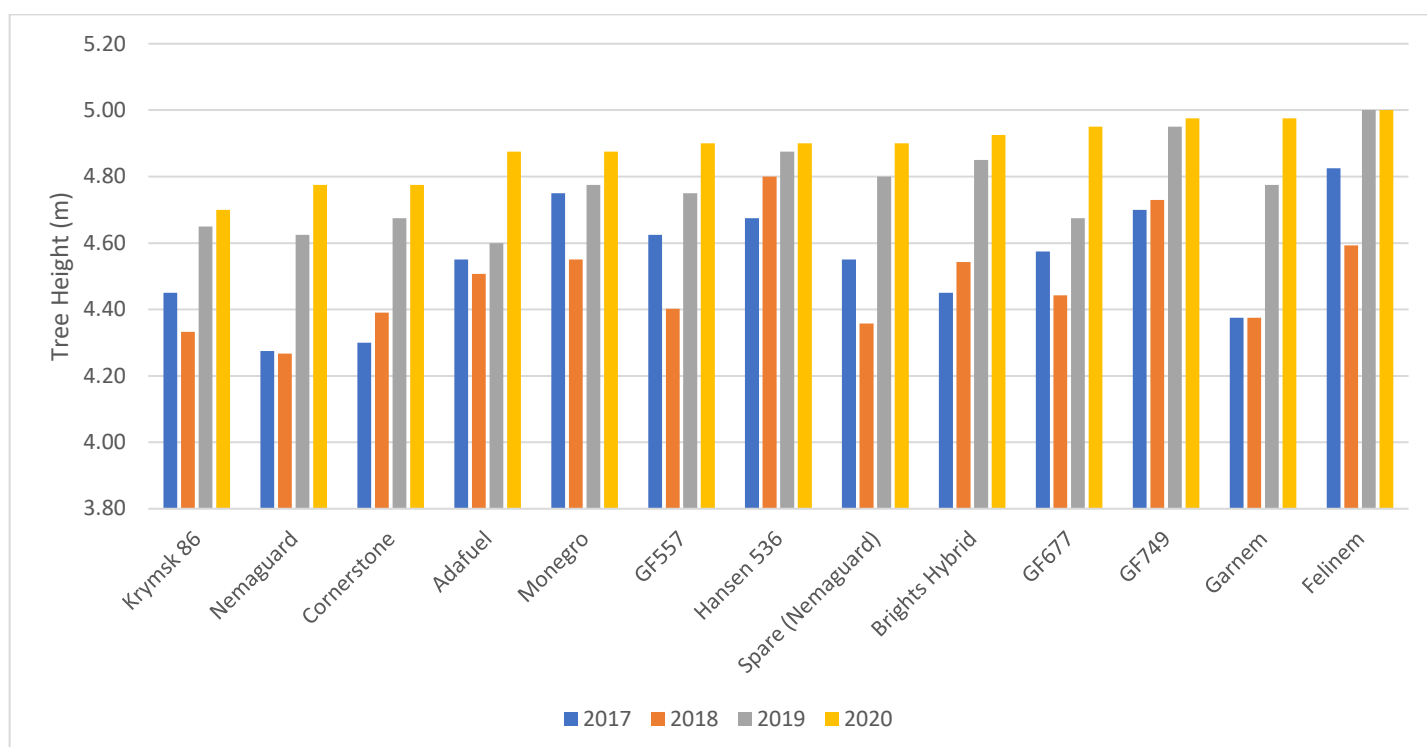


Figure E-18: Annual tree heights (m) on each rootstock from 2017 to 2020 by replicate.

A quadratic trend was used to adjusted for tree growth (butt diameter and tree height) and presented as ‘adjusted mean’ heights. It differed from ‘Spare’ Nemaguard according to Fisher’s protected LSD of 0.165 but not by Tukey’s HSD of 0.30. Cornerstone and Krymsk 86 were similar in height to Nemaguard (Table E-17). Garnem and GF749 had significantly higher tree height than Nemaguard and Cornerstone (Appendix G).

A positive correlation ($p < 0.01$) was observed between tree heights 2020 and yield in 2021 indicating that taller trees had higher yields (Appendix G).

Table E-17: Adjusted annual tree heights (m) on each rootstock ranked from smallest to highest 2020 height.

Rootstock	Height	Letters
Nemaguard	4.65	a
Cornerstone	4.78	a
Krymsk 86	4.78	ab
Spare Nemaguard	4.83	bc
GF557	4.88	bc
Monegro	4.88	bc
Hansen 536	4.90	bc
Adafuel	4.93	bc
Brights Hybrid	4.93	bc
Felinem	4.93	bc
GF677	4.93	bc
Garnem	4.98	c
GF749	4.98	c
P value	0.01	
Fisher’s LSD	0.165	

Note: Rootstocks that share the same letter do not differ at the 5% levels using Fishers protected LSD.

Canopy area

Canopy area (m²) was recorded, and results analysed by the South Australian Research Development Institute (SARDI, Appendix F). There was a reduction in the tree areas measured between 27 October 2017 and 28 February 2018. This is thought to be due to the different timing in that 2017 was relatively early in the growing season with an upright canopy and 2018 was when the tree was carrying a full crop ready for harvest and pulling the tree branches down hence a reduced area in canopy ground cover.

The measurements taken in the first week of May in 2020 and 2021 post-harvest and show the effect of two- and three-years tree growth after the initial readings (Figure E-19). In 2020, trees grown on Krymsk were significantly smaller in canopy area than most rootstocks but not significantly different in area when compared with Nemaguard, GF557, and Felinem (Table E-18).

The increase in canopy area over three years indicates the trees are still actively growing, with only minor slowing of their growth rate evident. However, by May 2021 there were no significant differences between rootstocks (Table 3). This may be because the trees are beginning to fill their allocated space, with competition and shading from adjacent trees slowing the growth rate for the larger trees and allowing the smaller trees to catch up.

Consistent timing in measuring canopy area for newly established trial sites in Loxton may identify differences in the rate of each rootstock reaching full canopy area however any significant differences were alleviated by 8th leaf.

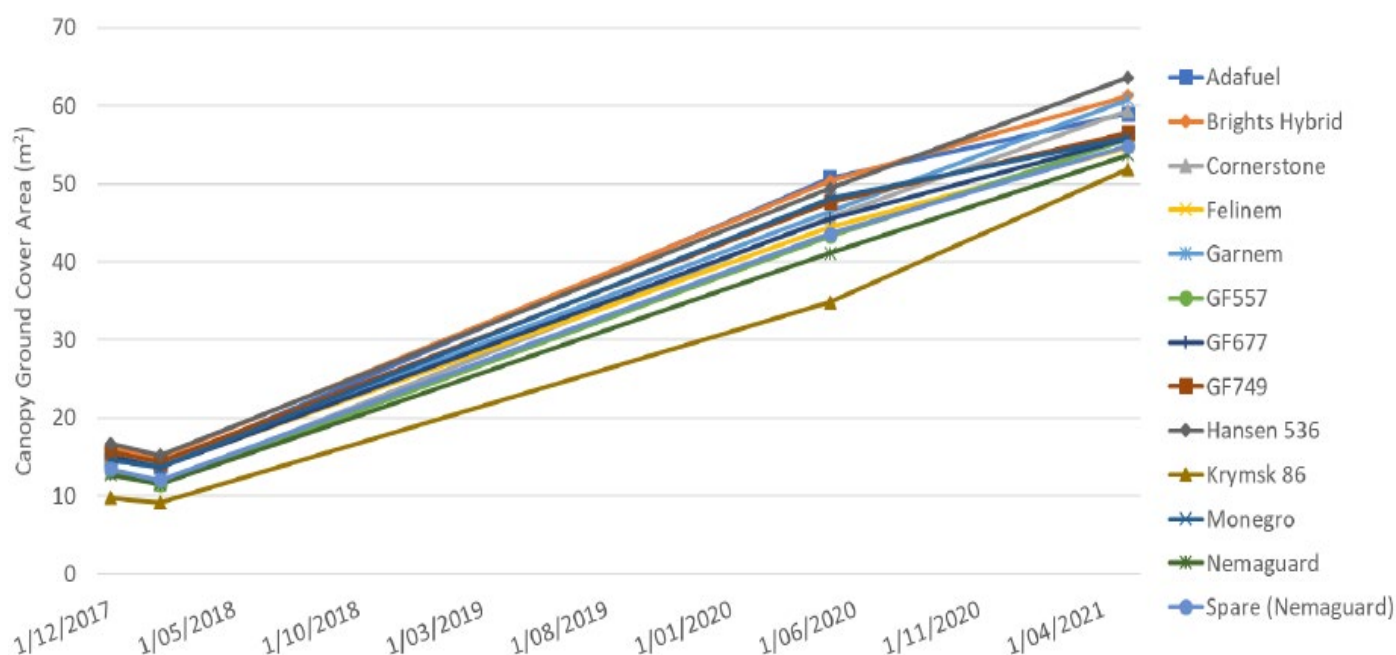


Figure E-19. Average canopy ground cover area measured on four dates (SARDI 2021).

Table E-18: Average canopy ground cover area by rootstock in 2017, 2018, 2020 and 2021 (SARDI 2021).

	27/10/2017		28/02/2018		4/05/2020		6/05/2021	
Hansen 536	16.70	a	15.19	a	49.40	a	63.60	a
Brights Hybrid	15.93	ab	14.77	ab	48.75	a	60.83	a
GF749	15.69	abc	14.42	abc	46.82	a	56.64	a
Garnem	14.94	abcd	13.52	abcd	45.81	a	59.87	a
GF677	15.01	abcd	13.65	abcd	45.54	a	55.80	a
Monegro	14.57	abcd	13.57	abcd	48.14	a	55.88	a
Adafuel	14.73	abcd	14.05	abcd	50.09	a	58.57	a
Felinem	14.82	abcd	13.74	abcd	44.45	ab	54.64	a
Spare Nemaguard	13.45	bcd	12.02	bcd	43.55	ab	54.83	a
Cornerstone	12.79	cd	11.22	cde	44.77	a	58.79	a
GF557	13.19	cd	11.49	de	43.27	ab	55.74	a
Nemaguard	12.71	d	11.51	de	41.11	ab	53.71	a
Krymsk 86	9.76	e	9.16	e	34.84	b	51.85	a

Light interception

Leaf area index (LAI) was calculated by SARDI on 22 February 2018 using the Plant Canopy Analyser to assess light interception and assign a value to each reading (Appendix F). Higher LAIs indicate larger and/or more dense canopies. These readings were taken close to the time when canopy ground cover readings were taken (28 February 2018) allowing comparison.

Krymsk 86 had the lowest LAI which was significantly lower than rootstock varieties with higher LAIs including Hansen, GF677, Felinem, Brights Hybrid, GF749 and Monegro (Figure E-20). This aligns with the high average ground covers observed for Hansen, Brights Hybrid and GF749 (although not significantly different from other rootstocks) as LAI respond to the interception of sunlight by the canopy, a direct function of the size of canopy. Canopy density also influences LAI and may account for the slight differences in the order of rootstocks under the two measures. Nemaguard rootstocks resulted in similar LAIs as Garnem, GF557, Adafuel and Cornerstone.

Light interception promotes bud numbers and bud health, and a positive correlation ($p < 0.01$) was observed between LAI (2018) and yield (2021) Appendix G. It may be interesting to repeat the LAI to determine if canopy density has reached the light interception threshold after which bud health and canopy productivity declines.

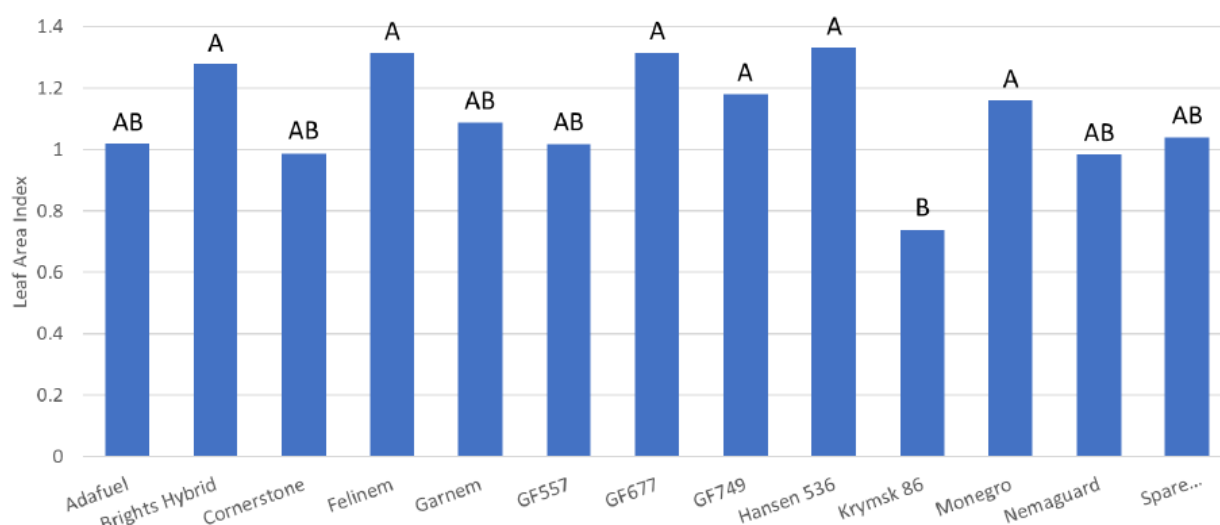


Figure E-20. Average canopy ground cover area measured on four dates

Canopy temperature assessment

SARDI collected fortnightly drone image recordings of canopy temperatures for each rootstock between late October 2017 and late February 2018 (Appendix F). Relative canopy temperature can be correlated with the rate of transpiration. Evaporative cooling of the leaves is driven by the rate of transpiration, so relatively higher canopy temperature indicates relatively lower transpiration rate. In turn, reduced transpiration rate may indicate greater water stress in the tree (Jones *et al.*, 2009). The data collected represented relative water stress under fully irrigated conditions, whereby higher relative canopy temperature is associated with lower transpiration rates, despite adequate water availability.

The canopy temperatures were extremely variable and driven primarily by the climatic conditions at the time of measurement (air temperature, cloud cover, humidity and wind). Differences between rootstocks on any given day are very small in comparison to the differences between readings taken on different days.

Relative canopy temperature was calculated as the difference in actual temperature from a standard temperature also measured at the same time as canopy temperature readings are collected. Spare Nemaguard trees were used as a control against which all other rootstocks were compared. Relative canopy temperature difference reflects how much warmer (+) or cooler (-) trees on the given rootstock were than trees in the Spare (Nemaguard) treatment within the same replicate.

Data in Figure E-21 shows the relative canopy temperature of the other rootstocks, averaged across 12 trees (3 trees x 4 replicates) and all 10 measurement dates. Bars with the same letter are not significantly different.

Trees on Krymsk 86, Adafuel, Cornerstone and Nemaguard were significantly warmer on average than trees on most other rootstocks, indicating that they were generally more stressed. It is interesting to note that Krymsk 86 also had the smallest canopy area (Figure E-19 & Table E-18), and Cornerstone and Nemaguard trees were also among the smaller trees.

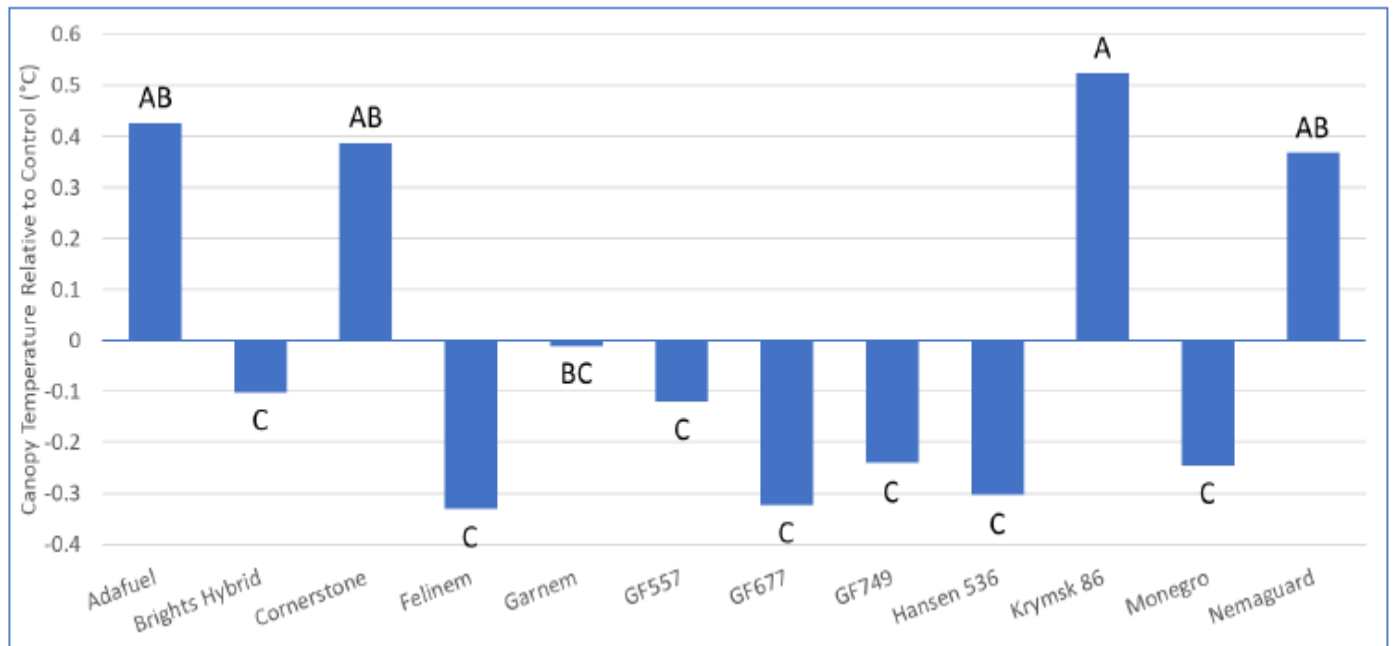


Figure E-21: Average canopy temperature for each rootstock relative to Spare Nemaguard treatment across multiple dates (bars with the same letter are not significantly different)

Nutrition

Leaf Analysis

A summary of 2021 leaf nutrient analysis is provided in Table E-19 and further leaf nutrient results for each rootstock, year and replicate is provided in Appendix H. Variability in samples may have been due to timing or sampling technique.

An analysis of correlations between yield and kernel weight for 2021 against various leaf nutrients 2021 was undertaken (Appendix G). Observations from this analysis are provided below.

Nitrogen

While a significant correlation was shown for leaf Nitrate and yield ($p < 0.1$) there was no significant difference in leaf Nitrate between rootstocks (Table E-19).

Leaf Nitrogen however did show a significant difference ($p < 0.01$) between rootstocks in 2021 although the difference was not great, Brights Hybrid and Krymsk 86 had slightly higher Nitrogen levels being 2.463% and 2.42% respectively. All rootstocks' readings were below 2.388% and within the Australian standard range 2.2 to 2.5% (Rosenzweig 2012).

Potassium

There was a highly significant but opposite correlation when comparing yield ($p < 0.001$) versus kernel weight ($p = 0.002$) with potassium levels in 2021. High potassium levels correlated with low yields, and high kernel weights.

There was no significant effect of rootstock on leaf potassium levels. All rootstocks had readings of potassium greater than the Australian standard range 1.4 to 1.7% and most were higher than the proposed Australian standards (Rosenzweig 2012) of 2.2 to 2.5%.

Table E-19 shows high variability in potassium leaf tissue readings between years and may be due to the timing of the sampling and the high mobility of this element resulting in variable and inconsistent results.

Calcium

There was a highly significant effect of rootstock on leaf calcium levels measured in 2021 with Hansen having the highest average of 3.2%, closely followed by GF749 (2.96%), GF677 (2.88%), Garnem (2.83%) and Monegro (2.82%). These rootstocks are within the top six highest yielding (cumulative yields) rootstocks. The lowest levels were observed for the two Nemaguard rootstocks and Krymsk. All rootstocks had calcium levels higher than 2.0% in line with the Australian standards (Rosenzweig 2012).

Table E-19 shows high variability in calcium leaf tissue readings between replicates and years and may be due to the timing or sampling resulting in variable and inconsistent results.

Magnesium

Similar to calcium, magnesium levels showed a significant correlation (not as strong as calcium) when comparing yield ($p = 0.003$) versus kernel weight ($p = 0.003$) with magnesium levels in 2021. There was a positive correlation, with high magnesium levels having high yields, but conversely low kernel weights.

Leaf magnesium followed a similar pattern to leaf calcium with highly significant effect of rootstock on leaf magnesium levels measured in 2021. The highest level in 2021 were observed for Hansen, Garnem and Monegro (with average readings of 0.59%, 0.52% and 0.52% respectively). GF749 uptake of Magnesium was 0.47%. The lowest levels were observed for the two Nemaguard rootstocks and Krymsk 86 (0.4%, 0.41%, and 0.43% respectively).

For all rootstock leaf Magnesium levels were above the Australian standard ($> 0.25\%$) and the proposed new Australian standards (> 0.4) (Rosenzweig, 2012).

Sodium

Like potassium there was a significant but negative correlation when comparing yield ($p = 0.02$) with leaf sodium levels but no correlation with kernel weight in 2021 (Appendix G). High sodium levels correlated with low yields.

In 2021 there were significant differences ($p < 0.01$) of leaf sodium among the rootstock with the lowest levels of leaf sodium observed for GF557, Monegro and GF749, (0.0083%, 0.0084% and 0.0085% respectively). The highest levels of leaf sodium were found in Krymsk, and Nemaguard (0.013%, 0.0115% and 0.0123% respectively). Krymsk also recorded sodium readings higher than 0.25% in 2018 and 2019. These levels were much lower in 2020 and

2021 but remain significantly higher than other rootstock varieties. Both Krymsk and Nemguard have been found to be poor excluders of sodium and chloride (Walker *et al.*, 2017) which is consistent with this rootstock trial observations even when soil salinities were below the level of 1.5dS/m where yield may be affected (Walker *et al.*, 2017) and similar to other rootstocks. This may be a contributing factor towards the low yield performance particularly for Krymsk.

Leaf sodium levels in 2018 and 2019 were greater than 2020 and 2021 for all rootstocks (Figure H-14). Other than Krymsk, all rootstock leaf sodium levels were below the Australian standard <0.25% (Rosenzweig 2012).

Chloride

There was a very high significant difference ($P < 0.001$) in the levels of chloride between rootstocks. Both Nemaguard and Krymsk showed high readings of chloride with an average value of (0.56 and 0.4 respectively). Both Nemaguard and Krymsk have been found to be poor excluders of sodium and chloride (Walker *et al.*, 2017).

Sulfur

There was a significant but opposite correlation when comparing yield ($p = 0.005$) with leaf sulfur levels but no correlation with kernel weight in 2021 (Appendix G). High sulfur levels correlated with low yields in 2021.

There were significant differences ($p < 0.01$) of leaf sulfur among the rootstock with the highest levels found in Krymsk, Hansen and GF557 (0.208%, 0.205% and 0.200% respectively). The lowest levels were observed for sparc Nemaguard, GF749, Monegro, and GF677 (0.178%, 0.178%, 0.183% and 0.183% respectively).

There is no current standard in Australia but the proposed new Australian standard for sulfur is >0.15 (Rosenzweig 2012). All rootstock leaf sulfur levels were above the minimum except in 2020 for Nemaguard where some readings were just below.

Table E-19: Leaf petiole nutritional values and statistical significance for each rootstock 2021.

Rootstock	Nitrate mg/kg	Nitrogen %	Phosphorus %	Potassium %	Calcium %	Magnesium %	Sodium %	Sulfur %
Adafuel	173	2.380	0.125	2.97	2.800	0.46	0.0090	0.1875
Brights Hybrid	225	2.463	0.123	2.95	2.600	0.48	0.0107	0.1950
Cornerstone	95	2.368	0.120	3.17	2.495	0.48	0.0099	0.1950
Felinem	202	2.340	0.115	3.21	2.768	0.47	0.0102	0.1900
Garnem	161	2.343	0.120	2.94	2.833	0.52	0.0088	0.1850
GF557	132	2.358	0.125	3.11	2.558	0.44	0.0083	0.2000
GF677	141	2.325	0.123	2.93	2.878	0.43	0.0094	0.1825
GF749	111	2.300	0.125	2.82	2.963	0.47	0.0085	0.1775
Hansen	177	2.258	0.123	2.93	3.208	0.59	0.0100	0.2050
Krymsk 86	133	2.420	0.115	3.42	2.235	0.43	0.0130	0.2075
Monegro	239	2.388	0.125	2.90	2.823	0.51	0.0084	0.1825
Nemaguard	134	2.360	0.118	3.08	2.218	0.40	0.0115	0.1850
Spare Nemaguard	129	2.340	0.123	3.03	2.263	0.41	0.0123	0.1775
pvalue	0.549	0.009	0.391	0.228	0.0000	0.0000	0.0049	0.0022
se	46	0.031	0.0035	0.14	0.099	0.018	0.00087	0.0053
LSD								
Rootstock	Boron mg/kg	Copper mg/kg	Zinc mg/kg	Manganese mg/kg	Iron mg/kg	Aluminium mg/kg	Molybdenum mg/kg	Chloride %
Adafuel	29.75	7.28	78.0	418	120.0	135.0	0.0475	0.105
Brights Hybrid	28.75	7.73	71.5	420	125.0	137.5	0.0483	0.115
Cornerstone	28.75	7.98	82.0	395	120.0	130.0	0.0458	0.105
Felinem	30.75	8.30	81.0	453	122.5	132.5	0.0420	0.148
Garnem	30.25	7.18	70.0	428	117.5	130.0	0.0450	0.188
GF557	29.50	8.08	75.0	350	120.0	132.5	0.0298	0.095
GF677	29.50	9.45	95.5	418	117.5	127.5	0.0388	0.078
GF749	29.00	8.75	80.3	405	117.5	125.0	0.0438	0.068
Hansen	32.25	7.75	86.0	518	122.5	135.0	0.0360	0.130
Krymsk 86	35.25	7.05	58.8	303	120.0	127.5	0.0875	0.400
Monegro	30.25	7.90	72.5	435	117.5	127.5	0.0410	0.118
Nemaguard	30.75	7.45	80.0	363	120.0	142.5	0.0435	0.580
Spare Nemaguard	30.50	7.40	75.0	375	111.5	130.0	0.0458	0.543
pvalue	0.0000	0.18	0.051	0.0005	0.809	0.861	0.00000	0.00000
se	0.72	0.553	6.2	26	4.2	6.5	0.0025	0.039
LSD								

Note: Red and orange indicates p values of <0.001 and < 0.01 respectively.

Soil Analysis

A summary of soil nutrient analysis is provided in Table E-20 and further soil nutrient results for each rootstock, year and replicate is provided in Appendix H.

No large differences were expected in the nutrient levels of soil for different rootstocks as each received the same fertiliser treatment.

Some correlations were observed between leaf nutrient and soil properties (Appendix G) in particular:

- Soil pH (CaCl₂) had a positive correlation with the uptake of minerals calcium ($p < 0.01$), copper ($p < 0.1$) and chloride ($p < 0.01$) (low pH = low uptake) and a negative correlation with sodium ($p < 0.01$) (i.e. low pH had high uptake).
- Soil potassium has a negative correlation with the uptake of sodium and a positive correlation with copper uptake.
- There was a very strong correlation ($p < 0.001$) between the uptake of copper and soil sulfur, soil salinity and TDS.
- Zinc uptake was positively correlated ($p < 0.1$) with soil EC and TDS (i.e. low EC and TDS had low uptake).

There were highly significant differences ($p < 0.001$) in the soil pH (CaCl₂) measured in 2021 for each of the rootstocks (Figure E--36) with four rootstocks having a pH less than 4.5 including GF557, GF749, Adafuel and Cornerstone.

Table E-20 highlights the decrease in pH from 2018 to 2021 however they consistently remain below the ideal pH range for almond production between 6.5 and 7.5 (Micke 1996). Levels below six may result in deficiency symptoms in calcium, magnesium, phosphorus or molybdenum. Very low pH (less than 4.5) may affect the availability of some nutrients including Ca, Mg, P and Mo (Micke 1996). In 2021, there was a significant correlation shown between leaf nutrients and soil pH (CaCl₂) ($p < 0.01$) where low pH soils correlated with lower levels of calcium uptake (Appendix G). In 2021 the average soil pH (CaCl₂) for GF749 was very low, around 4.24, however, this has not yet influenced the availability and uptake of calcium, and GF749 currently having the highest cumulative yield. Ongoing monitoring will determine if GF749 continues to have high yields. Garnem pH was within the adequate range, above 6, however Hansen, GF667 and Monegro were below between 5.17 and 5.28.

And very low pH, below 4.5, may result in excessive toxicity of Manganese, Iron and Aluminium, however these toxicities have not yet been observed in this trial.

Soil salinity provided variable results between years and rootstocks. Many rootstocks had soil salinity readings in one or more years above the 1.5dS/m where yield may be affected (Walker *et al.*, 2017) (Figure H-25). These levels were not consistent each year and high levels were followed by years of levels less than 1.5dS/m and vice versa. In 2021, EC readings were significantly different amongst rootstocks with mean soil EC for Felinem and Garnem reaching high levels of 2.9dS/m and 1.6dS/m respectively. All other readings were below 1.5dS/m which is the level at which there may be an effect on yield (Walker *et al.*, 2017).

Table T20: Mean soil nutrient levels for each rootstock 2021.

Rootstock	pH.H₂O	pH.CaCl₂	OC	Nitrate N	Ammonia N	Col.P	Tot.P	K	S	EC_{1:5}	TDS
<i>Adafuel</i>	5.32	4.18	0.58	2.63	3.65	63.0	55.5	280	15.8	0.06	37.3
<i>Brights Hybrid</i>	6.02	4.83	0.61	1.53	14.95	57.5	49.0	348	18.5	0.07	42.5
<i>Cornerstone</i>	5.35	4.21	0.52	1.70	9.45	57.3	58.3	273	17.8	0.06	35.8
<i>Felinem</i>	6.69	6.23	1.43	4.25	9.88	75.8	42.3	425	103.8	0.29	186.5
<i>Garnem</i>	7.16	6.63	0.90	5.98	4.55	56.8	45.5	450	29.0	0.16	102.0
<i>GF557</i>	5.18	4.06	0.69	3.67	6.13	47.3	52.8	300	21.2	0.07	41.5
<i>GF677</i>	6.23	5.28	0.77	1.75	6.05	25.0	44.8	408	13.9	0.10	65.8
<i>GF749</i>	5.32	4.24	0.55	18.23	5.75	60.3	58.8	333	33.9	0.09	59.0
<i>Hansen</i>	6.21	5.25	0.63	1.31	4.95	44.8	50.8	345	22.7	0.11	70.5
<i>Krymsk</i>	5.97	5.20	0.64	3.58	2.95	96.0	66.5	373	16.3	0.11	64.8
<i>Mongero</i>	5.91	5.17	0.86	2.65	6.10	80.0	49.5	415	30.5	0.13	81.0
<i>Nemaguard</i>	6.25	5.28	0.93	2.60	5.45	29.8	43.0	320	24.8	0.09	58.8
<i>Spare</i>	5.75	4.80	0.99	3.30	5.43	43.3	45.0	345	27.8	0.10	65.5
<i>pval</i>	0.001	0.001	0.006	0.010	0.439	0.003	0.345	0.270	0.032	0.009	0.007
<i>se</i>	0.30	0.40	0.15	2.21	3.16	10.8	6.71	50	16	0.04	23.5
<i>LSD</i>											

Nematodes

There were eight different nematode species observed over four years (Table E-21).

Table E-21: Nematode species observation percentage of total sum of nematodes.

Species	Scientific Name
Root Knot Nematode	Meloidogyne
Ring Nematode	Criconemella
Root Lesion Nematode	Pratylenchus
Pin Nematode	Paratylenchus
Stubby Root Nematode	Paratrichodorus
Citrus Nematode	Tylenchulus
Stunt Nematode	Merlinius
Cyst Nematode Males	Heterodera

Three of these nematodes are of particular interest due to their effect on almonds being:

- Root Knot Nematode (*Meloidogyne*) – may affect root growth and the plant’s ability to absorb water and nutrients, exacerbating tree stress and can reduce crop yields. Symptoms can be extreme (Brown *et al.* 2015).
- Ring Nematode (*Criconemella*) - high populations in porous soils has been associated with bacterial canker complexes. Most problematic in replant scenarios (Socias i Company and Gradziel 2017).
- Root Lesion Nematode (*Pratylenchus*) - may require control if levels are high enough.

Root knot nematode

Nemaguard is resistant to all common root knot nematode species and neither Nemaguard or Spare Nemaguard recorded presence of root knot nematodes (Brown *et al.* 2015). Hansen is even more resistant to root knot and had no root knot nematode detected during the course of the trial.

Root knot was detected in rootstock varieties GF677 and GF557 at low levels and GF749 at moderate levels (Figure E-22). GF677 rootstock is considered to have medium to high susceptibility and GF557 is susceptible to root knot nematode (Brown *et al.* 2015). GF749 and GF677 are within the top six highest cumulative yielding rootstocks however the susceptibility of GF749 to root knot nematode is unknown.

Root Knot was detected on Adafuel rootstock in moderate levels which has low to medium susceptibility.

Future assessments will need to monitor if these populations increase with time and note their impact on crop yields.

Ring nematode

Ring nematodes were observed at very low to low levels for all rootstocks except Krymsk which recorded low – moderate detections in 2021. Seven of the rootstocks are susceptible to ring nematode (including Krymsk) and Nemaguard has medium resistance (Brown *et al.* 2015). Future monitoring is required to determine if there is an increase in ring nematode population and / or if bacterial canker complexes develop as a result.

Root lesion nematode

Root lesion nematodes were observed for four rootstocks at very low levels e.g. Nemaguard and Krymsk, GF677 and at moderate levels, e.g. Bright’s Hybrid. Nemaguard and Krymsk have medium resistance to root lesion nematode and Brights Hybrid is even more tolerant than Nemaguard, while GF677 is susceptible. Continued monitoring will determine if numbers increase over time and their relative impact on tree growth and crop yield.

While Pin nematode and Stubby root nematode are thought not to effect tree growth or yield (Brown *et al.* 2015) it is less clear the influence of the Citrus, Stunt and Cyst (male) nematodes on almonds. Continued monitoring for nematodes will determine if these species continue to increase in number over time and their relative impact on tree growth and crop yield.

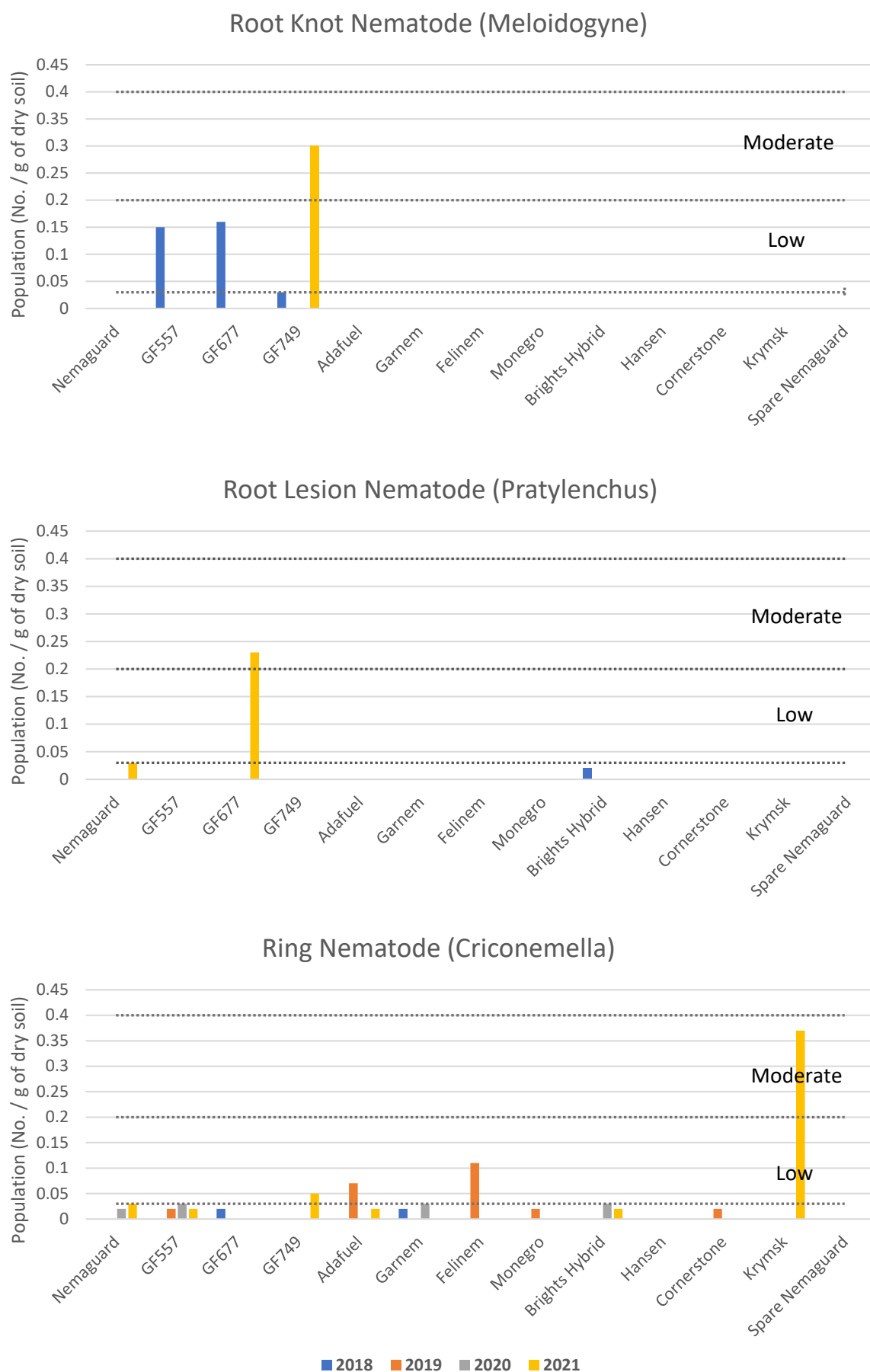


Figure E-20: Nematodes population (number / g of dry soil) by rootstock from 2018 to 2021.

Table E-22: Observed nematodes incidences of Root Knot Nematode, Ring Nematode and Root Lesion Nematode. Replicate 1 from 2018 to 2021 by replicate.

Year	Rootstock	Replicate	Nematode	Level	Threshold Classification
2018	GF557	1	Root Knot Nematode (Meloidogyne)	0.15	Low
	GF677		Root Knot Nematode (Meloidogyne)	0.16	Low
	GF749		Ring Nematode (Criconemella)	0.02	Very low
	Garnem		Root Knot Nematode (Meloidogyne)	0.03	Very low
	Brights Hybrid		Ring Nematode (Criconemella)	0.02	Very low
	Spare Nemaguard		Root Lesion Nematode (Pratylenchus)	0.02	Very low
			Ring Nematode (Criconemella)	0.02	Very low
2019	GF557	1	Ring Nematode (Criconemella)	0.02	Very low
	Adafuel		Ring Nematode (Criconemella)	0.07	Low
	Felinem		Ring Nematode (Criconemella)	0.11	low
	Monegro		Ring Nematode (Criconemella)	0.02	Very low
	Cornerstone		Ring Nematode (Criconemella)	0.02	Very low
2020	Nemaguard	1	Ring Nematode (Criconemella)	0.02	Very Low
	GF557		Ring Nematode (Criconemella)	0.03	Very Low
	Garnem		Ring Nematode (Criconemella)	0.03	Very Low
	Brights Hybrid		Ring Nematode (Criconemella)	0.03	Very Low
2021	Nemaguard	1	Ring Nematode (Criconemella)	0.03	Very Low
			Root Lesion Nematode (Pratylenchus)	0.03	Very Low
	GF557		Ring Nematode (Criconemella)	0.02	Very Low
	GF677		Root Lesion Nematode (Pratylenchus)	0.23	Moderate
	GF749		Root Knot Nematode (Meloidogyne)	0.3	Moderate
			Ring Nematode (Criconemella)	0.05	Low
	Adafuel		Ring Nematode (Criconemella)	0.02	Very Low
	Brights Hybrid		Ring Nematode (Criconemella)	0.02	Very Low
	Krymsk		Ring Nematode (Criconemella)	0.37	Moderate
	Spare Nemaguard		Ring Nematode (Criconemella)	0.08	Low
	Nemaguard	2	Ring Nematode (Criconemella)	0.2	Moderate
	GF677		Ring Nematode (Criconemella)	0.07	Low
	GF749		Ring Nematode (Criconemella)	0.02	Very Low
	Garnem		Ring Nematode (Criconemella)	0.12	Low
	Felinem		Ring Nematode (Criconemella)	0.02	Very Low
	Monegro		Ring Nematode (Criconemella)	0.02	Very Low
	Brights Hybrid		Ring Nematode (Criconemella)	0.07	Low
	Cornerstone		Ring Nematode (Criconemella)	0.02	Very Low
	Krymsk		Ring Nematode (Criconemella)	0.08	Low
	Spare Nemaguard		Ring Nematode (Criconemella)	0.1	Low
	GF557	3	Ring Nematode (Criconemella)	0.04	Low
	GF677		Ring Nematode (Criconemella)	0.04	Low
			Root Lesion Nematode (Pratylenchus)	0.18	Low
	GF749		Ring Nematode (Criconemella)	0.02	Very Low
	Adafuel		Root Knot Nematode (Meloidogyne)	0.37	Moderate
			Ring Nematode (Criconemella)	0.09	Low
	Garnem		Ring Nematode (Criconemella)	0.02	Very Low
	Monegro		Ring Nematode (Criconemella)	0.02	Very Low
	Brights Hybrid		Root Lesion Nematode (Pratylenchus)	1.18	Moderate
			Ring Nematode (Criconemella)	0.04	Low
	Krymsk	4	Ring Nematode (Criconemella)	0.06	Low
	Spare Nemaguard		Ring Nematode (Criconemella)	0.02	Very Low
	Nemaguard		Ring Nematode (Criconemella)	0.02	Very Low
	GF557		Ring Nematode (Criconemella)	0.12	Low
	GF749		Ring Nematode (Criconemella)	0.02	Very Low

Adafuel	Ring Nematode (Criconemella)	0.03	Low
Felinem	Ring Nematode (Criconemella)	0.07	Low
Monegro	Ring Nematode (Criconemella)	0.1	Low
Hansen	Ring Nematode (Criconemella)	0.02	Very Low
Cornerstone	Ring Nematode (Criconemella)	0.05	Low
Krymsk	Ring Nematode (Criconemella)	0.03	Low
Spare Nemaguard	Root Lesion Nematode (Pratylenchus)	0.02	Very Low
	Root Lesion Nematode (Pratylenchus)	0.02	Very Low

Other growing factors

Graft compatibility

Field observations from 2018 to 2021 did not identify any incompatibilities or over-growth of scion for any of the rootstocks.

Suckering

No suckering was observed for any rootstocks.

Iron chlorosis

No iron chlorosis was observed for any rootstocks as four applications of liquid iron are applied as standard management practice throughout the growing season to prevent symptoms.

Lacton Rootstock Trial

Assessment of Canopy Characteristics



Lacton Rootstock Trial – Assessment of Canopy Characteristics

Information current as of 30 June 2021

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Background

In 2017, ABA contracted SARDI under Project AL16006 to assist with ongoing data collection from its Lacton Farm rootstock trial at Lyndsay Point. SARDI initially provided technical services to the ABA using drone-based collection of RGB and Infrared Thermal images for the calculation of water stress and canopy area, as well as ground-based measurements of Leaf Area Index.

The project was reviewed in 2020, and subsequently data was collected and analysed to evaluate the impact of rootstock on the progress of nut maturity throughout the preharvest period of the 2020/21 growing season.

The data collected and analysed here is intended as supplementary to other data collected by the ABA. Some analysis has been undertaken here in isolation, but it is recommended that this data be further analysed alongside other data, such as the multi-year yield data collected by the ABA.

Methodology

The Almond Board of Australia Incorporated (ABA) planted a trial block of almond trees of three varieties (Nonpareil, Carmel and Peerless) budded to 17 rootstocks at the Lyndsay Point property of Lacton Pty Ltd in 2013, under project AL11012. Three rootstocks suffered from very poor establishment, and these were removed from further evaluation. Also, trees on Cornerstone were planted in 2014, and are therefore one year younger than trees on the other rootstocks. The 14 rootstocks which are still monitored are listed in Table 1, and the trial site map is shown in Figure 1.

Note that there are two treatments budded to Nemaguard rootstock, one labelled Nemaguard and another labelled Spare Nemaguard. This Spare treatment may have been included in order to fill a space in the trial design, due to the unavailability of another rootstock. Differences have been noted in performance of the two Nemaguard treatments, both in this project and throughout the life of this trial. The reasons for these differences are not clear.

Table 1 Rootstocks planted in the Lacton rootstock trial

Colour code in trial site map	Rootstock
	Nemaguard
	GF557
	GF677
	GF749
	Adafuel
	Garnem
	Felinem
	Monegro
	Brights Hybrid
	Hansen 536
	Cornerstone
	Nickels
	Krymsk 86
	Spare (Nemaguard)
	Non-measurement

Canopy Size Assessment

SARDI collected RGB imagery from the trial planting in the 2017/18 growing season using an Unmanned Aerial Vehicle (UAV). Imagery was collected using the built-in RGB camera on SARDI's DJI Phantom 3 drone. Each replicate of the trial was captured in a single image, which was auto rectified to minimise distortion of objects around the edges of the image. An example of the imagery is shown in Figure 2.

SARDI collected RGB imagery on two dates, early and late in the 2017/18 growing season (27 October 2017 & 28 February 2018). ABA collected analogous UAV imagery late in the 2019/20 and 2020/21 growing seasons (4 May 2020 & 6 May 2021). The combined imagery provides an in-season comparison during 2017/18, as well as an assessment of canopy growth across a three-and-a-half-year period.



Figure 2 Example of an RGB image of the Lacton rootstock trial

For each image the number of pixels contained in a square meter of ground surface was estimated using objects of known size in the image. The number of pixels in a tree canopy was then measured from the image. In 2017/18 this was accomplished by identifying the number of "green" pixels in each tree canopy, using Adobe Photoshop CC (2017). In the later images area was estimated by manually delineating the main area of each tree canopy in GNU Image Manipulation Program GIMP v2.10.24 software and calculating the number of pixels from the reported height and width of the selected area in pixels. Dividing the reported or calculated

number of pixels by the calibration (pixels/m²) for the given image returned an estimate of canopy area in m² for each tree.

The central three Nonpareil trees in each measurement row of the trial were measured, resulting in 12 measurements per rootstock (3 trees x 4 replicates). Analysis of variance of the raw data was conducted to identify significant differences between rootstocks at the 5% significance level.

Leaf area index (LAI) is a measure of the total area of leaf surface in a tree (Strachan et al., 2005). LAI was assessed on one occasion (22/2/2018), using a Li-Cor LAI-2000 Plant Canopy Analyser. This device uses a hemispherical sensor to assess light interception by the canopy and assign a value of Leaf Area Index to each reading, with larger numbers indicating larger and/or more dense canopies.

LAI is assessed from a series of readings across the orchard floor, with data collected from the mid row, directly under the tree row, and at intervals in between. The final reading uses the data from all readings to assign a figure to LAI for the section of the orchard represented in the readings.

One LAI number was generated for each trial plot in the Lacton Rootstock Trial, resulting in four values per rootstock (one per replicate). Analysis of variance (5% significance) was used to compare LAI across rootstocks.

Canopy Temperature Assessment

SARDI evaluated relative canopy temperature of trees on different rootstocks using a Flir Tau 2 Thermal Camera mounted on the DJI Phantom 3 drone, at fortnightly intervals between late October 2017 and late February 2018. An example thermal image is shown in Figure 3. The average temperature of individual tree canopies was measured from the thermal imagery, which contained temperature readings for every pixel recorded in each image. Each canopy of interest was manually delineated in the software, which reported the average pixel temperature for the selected area.

Relative canopy temperature can be correlated with the rate of transpiration. Evaporative cooling of the leaves is driven by the rate of transpiration, so relatively higher canopy temperature indicates relatively lower transpiration rate. In turn, reduced transpiration rate may indicate greater water stress in the tree (Jones et al., 2009).

The original aim of this data collection was to assess the relative water uptake efficiency of different rootstocks under water deficit conditions, on the assumption that more water efficient trees would suffer less stress under water deficit. However, the irrigation system in the trial area did not allow application of water deficit to the trial without also applying the same water deficit to large plantings on either side of the trial planting. The property owner was not willing for water stress to be applied to the adjoining plantings, so application of water deficit to the trial trees was not possible.

As a result, the data collected represents relative water stress under fully irrigated conditions, whereby higher relative canopy temperature is associated with lower transpiration rates, despite adequate water availability.

Actual canopy temperature is affected by ambient temperature, and some calibration to either ambient conditions or a standard temperature measurement is required to evaluate canopy

temperature readings. For this study the Spare (Nemaguard) treatment was used as the standard against which to compare all other rootstocks. Data is therefore presented as Temperature Difference from the standard.

In addition, each replicate of the trial was captured in a single image, ensuring there was no change in ambient conditions between measurements. Temperature difference was calculated relative to the Spare (Nemaguard) trees within the same replicate, providing good comparability between individual measurement dates as well as between different rootstocks on the same date.

Analysis of variance was carried out on the data to identify significant differences at the 5% significance level, in canopy temperature difference between rootstocks and across dates.

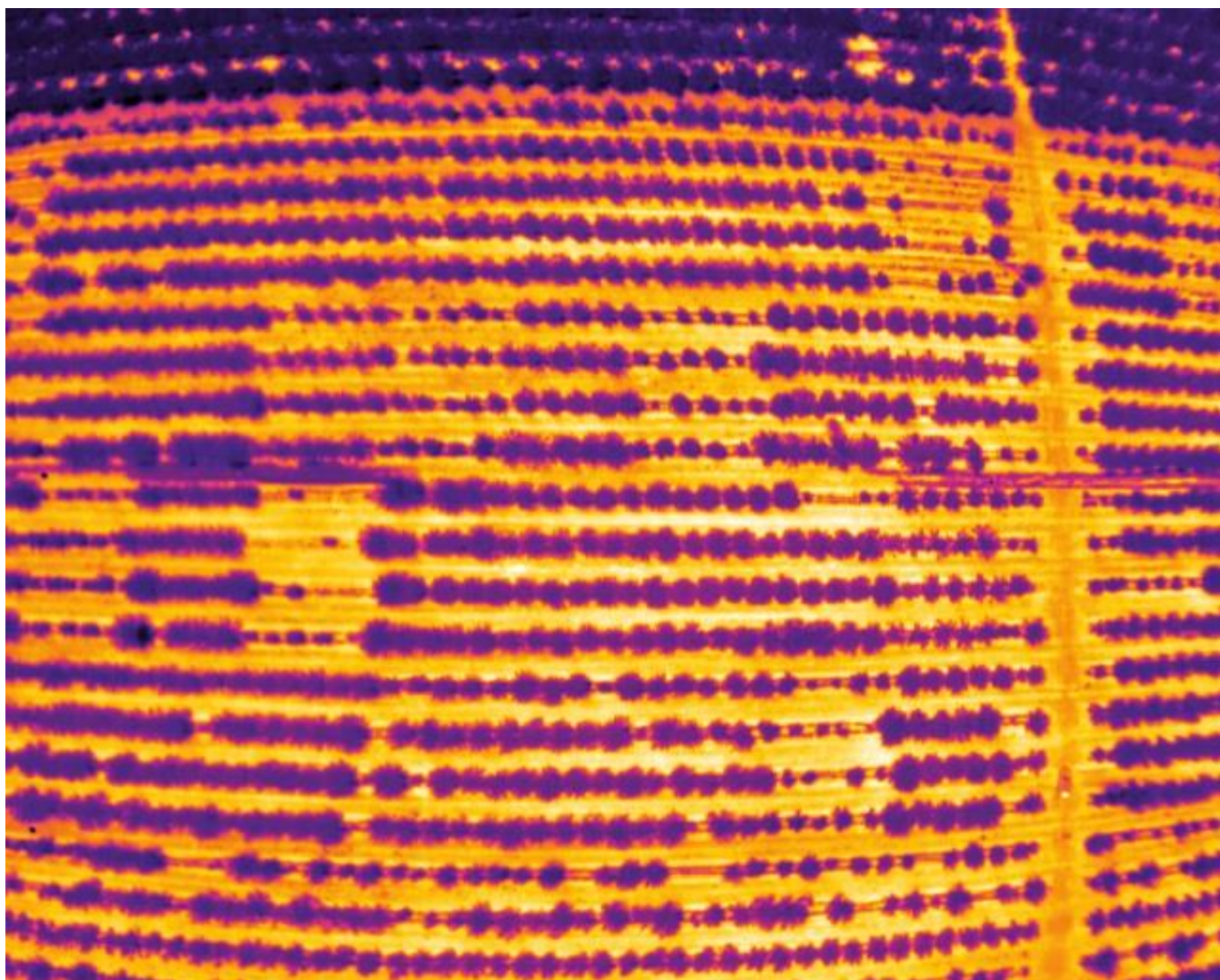


Figure 3 Example of a thermal image of the Lacton rootstock trial

SARDI is currently updating its capabilities in UAV data collection. The Irrigated Crops Science Program will soon take delivery of two new DJI M210 UAVs, which are RTK capable, and can carry larger, more sensitive RGB, thermal and multi-spectral sensors.

Hull Split and Harvest Date Assessment

During January and February 2021, the stage of hull split in nuts on Nonpareil trees grafted to the various rootstocks was assessed at weekly intervals, to evaluate the impact of rootstock on the timing of hull split and harvest, key events in the almond lifecycle.

One hundred nuts on the central tree in each treatment plot were evaluated for hull split stage according to the methodology of Thomas and Connell (2018) (see Table 2), to determine the percentage of nuts in each stage. The data was then analysed to evaluate the percentage of nuts at Stage 3 or greater (critical for the timing of pest control sprays), and the percentage of nuts at Stage 6 (ready for harvest) at each date.

Maturity curves were drawn representing the progression of nuts on each rootstock through the critical stages (Stage 3 and Stage 6). Analysis of variance revealed statistical differences at 5% significance level, in maturity between rootstocks at each date.

Table 2 Stages of Hull Split, from Thomas and Connell (2018)

Stage 1 No separation of suture 	Stage 2 V over the suture line, not visibly separated 	Stage 3 Visible opening in suture less than 1 cm in width 
Stage 4 Visible opening in suture more than 1 cm in width 	Stage 5 Initial drying of the edges of the hull 	Stage 6 Completely dry 

Results and Discussion

Canopy Size Assessment

Canopy ground cover data from the four measurement dates (27 October 2017 & 28 February 2018, 4 May 2020, and 6 May 2021) are displayed in Figure 4. Significance groupings are set out in Table 3, as they are too complex to illustrate in Figure 4.

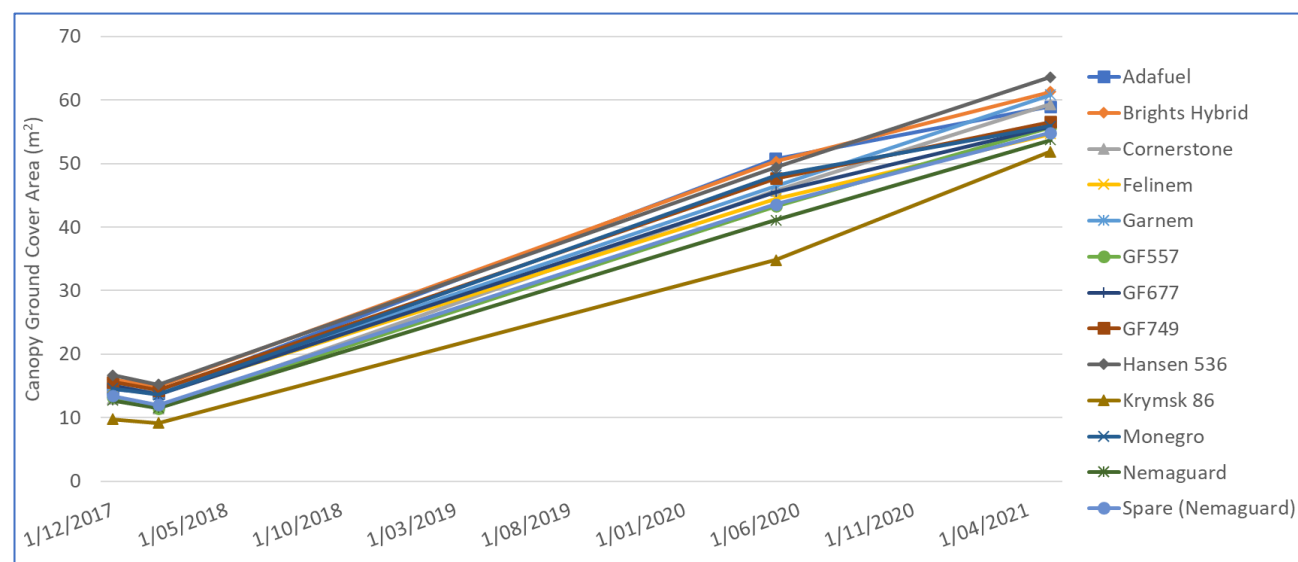


Figure 4 Average canopy ground cover area on four dates

Table 3 Average canopy ground cover area (letters indicate groups of no significant difference on a given date)

Rootstock	Average Area (m ²) and Significance Groups							
	27/10/2017		28/2/2018		4/5/2020		6/5/2021	
Hansen 536	16.70	a	15.18	a	49.41	a	63.60	a
Brights Hybrid	16.06	ab	14.94	ab	50.35	a	61.28	a
GF749	15.64	abc	14.30	abc	47.64	a	56.57	a
Garnem	15.06	abcd	13.70	abcd	46.47	a	60.80	a
GF677	15.00	abcd	13.67	abcd	45.54	a	55.79	a
Monegro	14.59	abcd	13.58	abcd	48.13	a	55.88	a
Adafuel	14.51	abcd	13.83	abcd	50.72	a	58.97	a
Felinem	14.81	abcd	13.73	abcd	44.45	ab	54.63	a
Spare (Nemaguard)	13.44	bcd	12.02	bcd	43.55	ab	54.83	a
Cornerstone	12.98	cd	11.50	cde	45.73	a	59.33	a
GF557	13.19	cd	11.49	de	43.27	ab	55.74	a
Nemaguard	12.71	d	11.51	de	41.12	ab	53.72	a
Krymsk 86	9.77	e	9.16	e	34.83	b	51.85	a

The measurements collected on 27 October 2017 were taken relatively early in the growing season, while the nuts on the trees were still small and developing. The readings taken on 28 February 2018 reflect trees ready for harvest, with the weight of fully developed nuts pulling the tree branches down. This accounts for the reduction in canopy ground cover between these dates.

The measurements taken during May 2020 and 2021 were collected after harvest, without the weight of nuts pulling the tree branches down. More significantly, they reflect the impact of 2 and 3 years of additional tree growth following the initial measurements.

It is clear from Figure 4 that the trees in this trial are still actively growing, with only minor slowing of their growth rate evident. However, the differences in tree size have become less significant over time, to the point where there were no significant differences between rootstocks in 2021. This may be because the trees are beginning to fill their allocated space, with competition from adjacent trees resulting in a slight slowing in growth rate of the larger trees, allowing the smaller trees to begin to catch up.

Leaf Area Index (LAI) data collected on 22 February 2018 is displayed in Figure 5. These readings were taken close to the canopy ground cover readings from 28 February 2018, and therefore can be directly compared with these readings.

The general pattern is similar between the two sets of measurements, with trees on Krymsk 86 having the lowest canopy ground cover and LAI, and a group of rootstocks including Hansen 536, Brights Hybrid and GF 749 having the highest readings for both parameters. This result is to be expected as LAI responds to the interception of sunlight by the canopy, which is directly influenced by the size of the canopy. Canopy density also influences LAI and may be implicated in slight differences in the order of rootstocks under the two measurements.

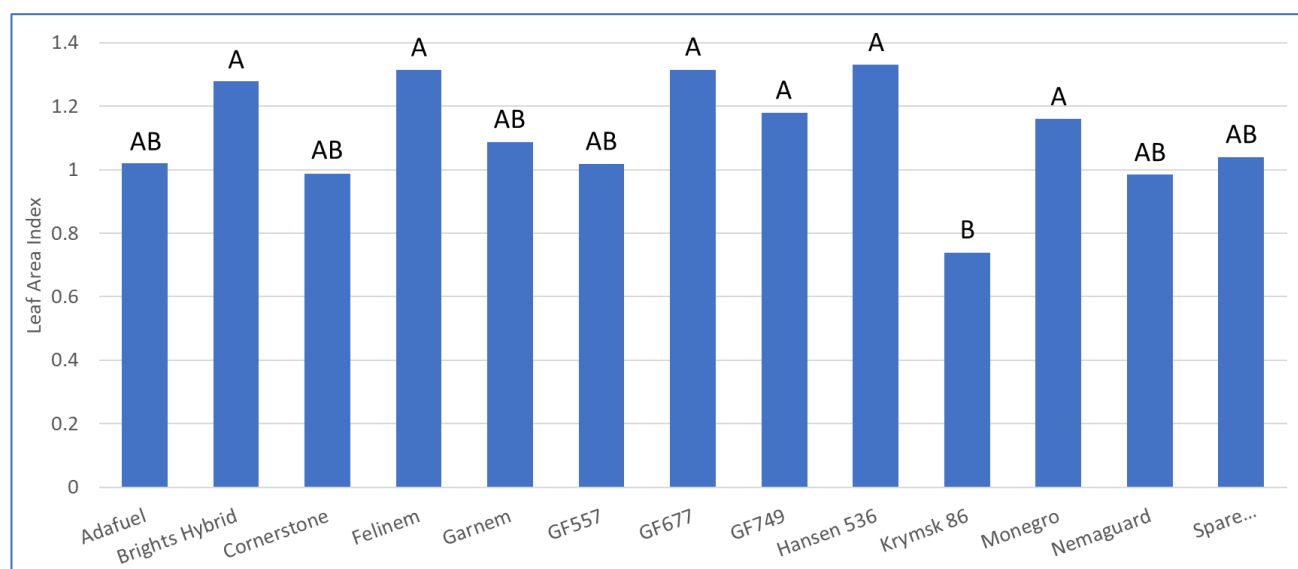


Figure 5 Average Leaf Area Index measured on 22/2/2018

Canopy Temperature Assessment

Raw data for canopy temperature is extremely variable (Figure 6), being driven primarily by the climatic conditions at the time of measurement (air temperature, cloud cover, humidity and wind). Differences between rootstocks on any given day are very small in comparison to the differences between readings taken on different days.

Relative canopy temperature is calculated as the difference in actual temperature from a standard temperature also measured at the same time as canopy temperature readings are collected. In this instance the trees in the Spare (Nemaguard) treatment were used as a standard against which all other rootstock treatments were compared. Relative canopy temperature reflects how much warmer (+) or cooler (-) trees on the given rootstock were than trees in the Spare (Nemaguard) treatment within the same replicate.

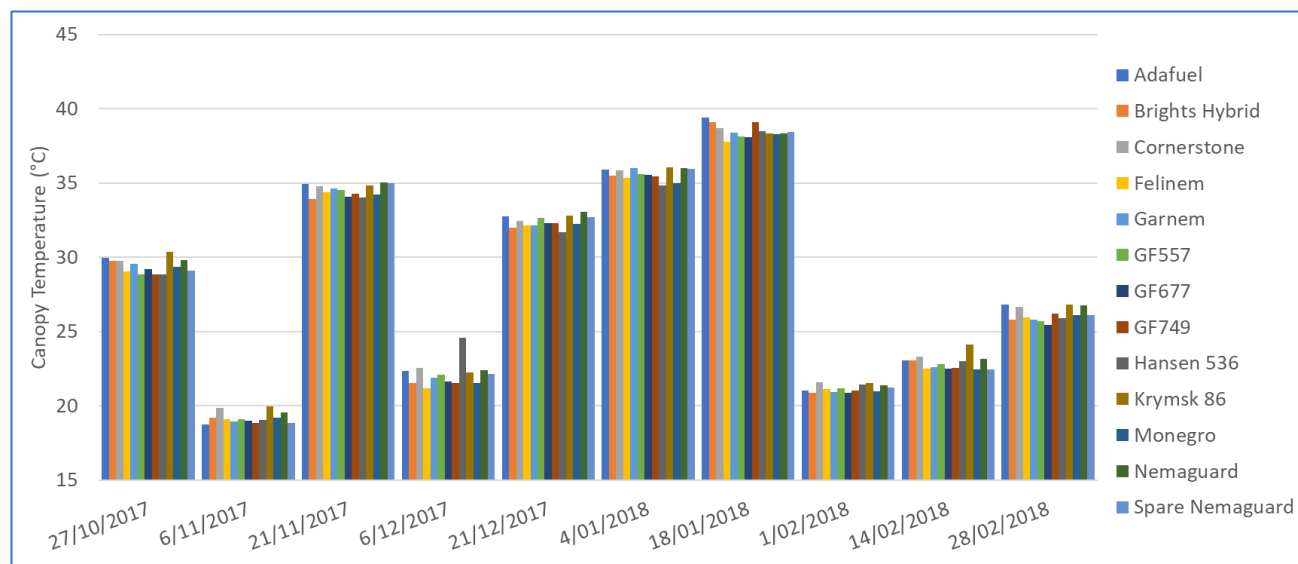


Figure 6 Absolute canopy temperatures measured on 10 different dates

Data in Figure 7 shows the relative canopy temperature of the other rootstocks, averaged across 12 trees (3 trees x 4 replicates) and all 10 measurement dates. Bars with the same letter are not significantly different.

Trees on Krymsk 86, Adafuel, Cornerstone and Nemaguard were significantly warmer on average than trees on most other rootstocks, indicating that they were generally more stressed. It is interesting to note that Krymsk 86 also produced the smallest trees (Figure 4 & Figure 5), and Cornerstone and Nemaguard trees were also among the smaller trees.

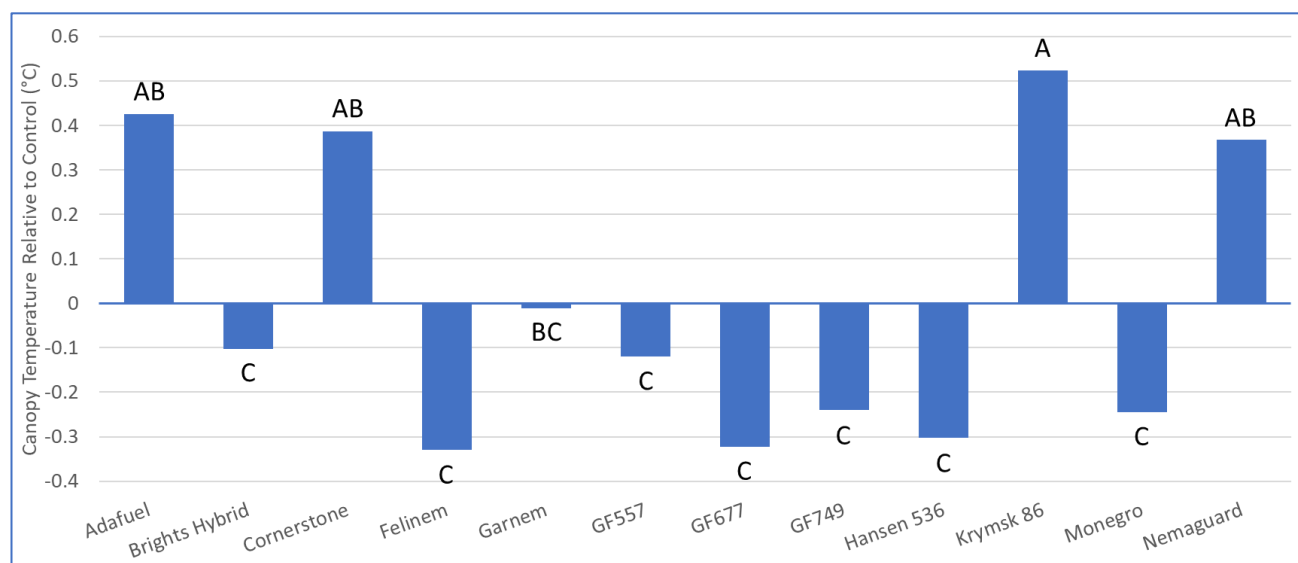


Figure 7 Average canopy temperature for each rootstock relative to Spare Nemaguard treatment across multiple dates (bars with the same letter are not significantly different)

Hull Split and Harvest Date Assessment

Hull split data were assessed and are presented against two key stages, Stage 3: Visible opening in suture less than 1 cm in width (Figure 8), and Stage 6: Completely dry (Figure 9). Stage 3 is important as it marks the opening of the hull, which provides entrance for Carob Moth and Carpophilus Beetle for egg laying (Agriculture Victoria, 2020; Madge et al.), thus dictating the

timing of pest management activities to address this. Stage 6 marks the end of nut maturation and the ideal harvest timing.

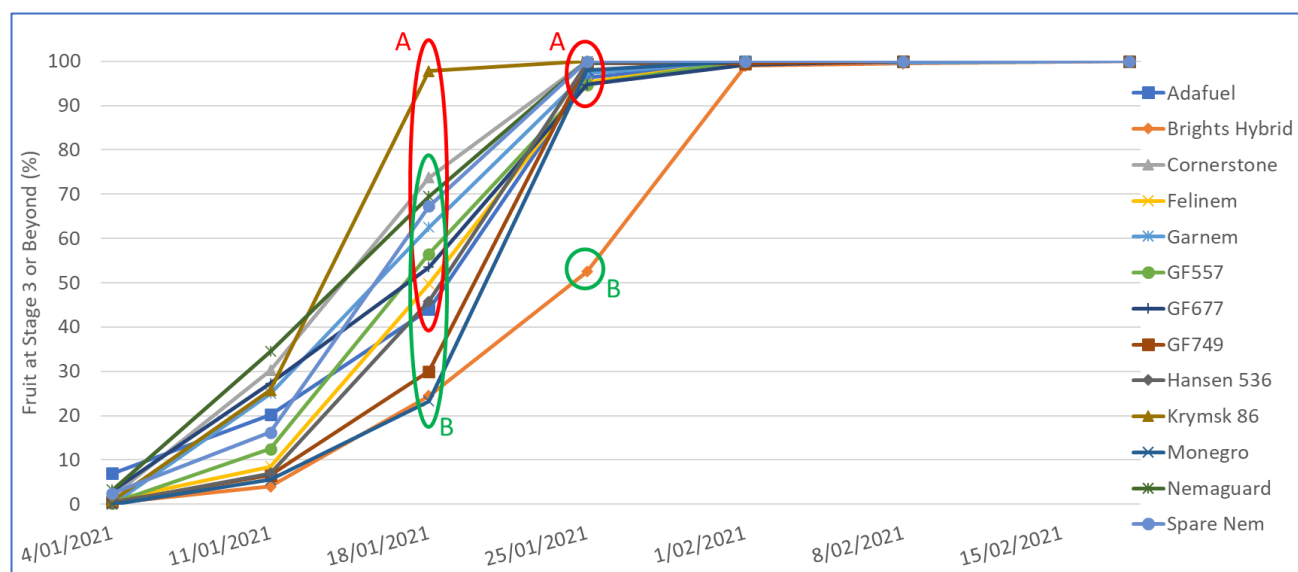


Figure 8 Percentage of nuts at Stage 3 of Hull Split at various dates (letters delineate groups of no significant difference)

Figure 6 indicates some variability in the percentage of nuts reaching Stage 3 on 18 & 25 January 2021. Almost 100% of nuts on Krymsk 86 trees have reached Stage 3 by 18 January, whilst only up to 30% of nuts on Brights Hybrid, GF 749 and Monegro trees have reached the same stage. By 25 January trees on all rootstocks exceed 94%, except for nuts on Brights Hybrid trees, of which only 53% have reached this stage.

Data for Stage 6 (Figure 9) are rather more variable, with significant differences only apparent on one date, 8 February 2021. On this date 90% of nuts on Krymsk trees have reached Stage 6, whilst for Felinem and Brights Hybrid only 31% and 26% respectively have reached this stage.

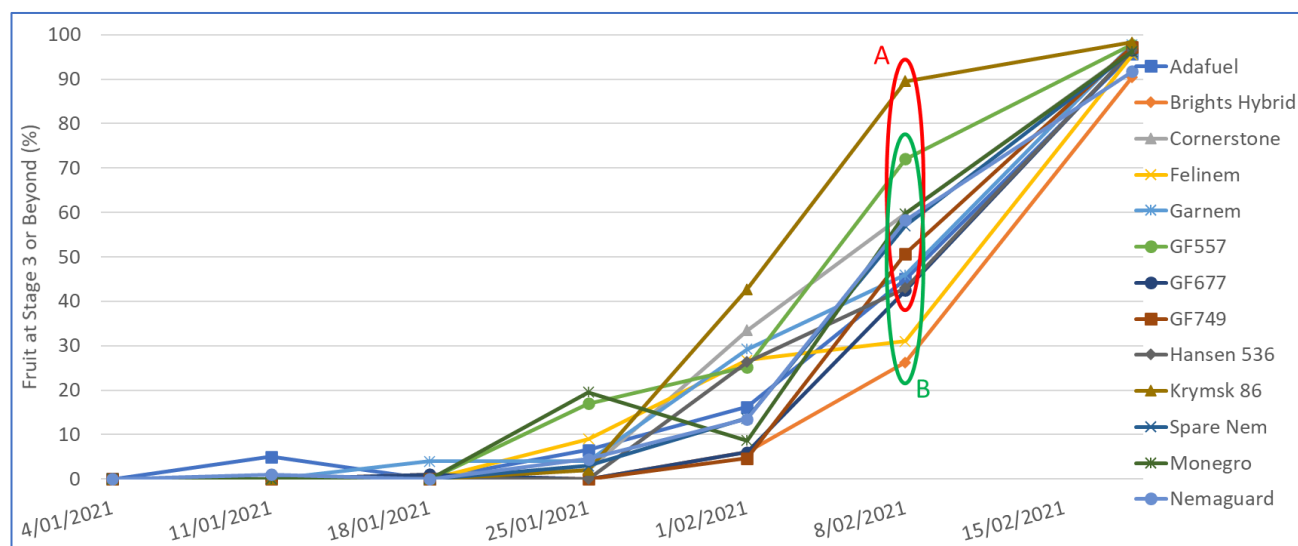


Figure 9 Percentage of nuts at Stage 6 of Hull Split at various dates (letters delineate groups of no significant difference)

Considering both sets of data together indicates that nuts growing on trees budded to Krymsk 86 tend to mature faster than nuts on trees budded to Brights Hybrid. Trees on other rootstocks lie somewhere between these two varieties, but the differences between most of these other varieties are insignificant.

Conclusions

Intermittent monitoring was carried out at the Lacton Rootstock Trial from 2017/18 until 2020/21. The aims of this monitoring changed over that time, due at least in part to limitations in the ability to apply irrigation treatments to the trial planting, as well as resourcing issues and COVID interruptions. Despite these limitations, the following conclusions can be drawn.

Tree canopy area evaluations indicated significant differences in tree size in the 2017/18 season, but these differences had diminished by 2020, and were not statistically significant by 2021 (Figure 4, Table 3). It appears that trees on some rootstocks were more vigorous in the early stages of growth, but as the trees began to fill their allocated space, the differences between rootstocks reduced.

The leaf area index (LAI) data support the 2018 canopy area data, confirming the smaller size, and therefore lower light interception, of Krymsk 86, compared to the larger size of trees on rootstocks such as Hansen 536, Brights Hybrid and GF 749.

Canopy temperature data indicated that trees on Krymsk 86, Adafuel, Cornerstone and Nemaguard were more stressed on average than trees on other rootstocks. Trees on Krymsk 86 were significantly smaller at this time than trees on other rootstocks, and trees on Cornerstone and Nemaguard were also among the smaller trees. It is not clear, however, whether the smaller size of these trees was responsible for the higher canopy temperature, or whether the apparent stress caused the trees to grow less vigorously, resulting in smaller tree size.

Evaluation of hull split stage indicated some differences between trees on different rootstocks. However, the differences were generally only significant between Krymsk 86 and Brights Hybrid, with most of the other rootstocks showing non-significant differences.

The results summarised above indicate few significant differences in the parameters measured between rootstocks within this rootstock trial. However, Krymsk 86 features in every comparison, demonstrating smaller trees, lower LAI, warmer canopy and earlier nut maturity. Similarly, Brights Hybrid demonstrated larger trees, higher LAI, cooler canopy and later maturity, although the differences were less significant from the majority of other rootstocks.

Recommendations

The results presented here represent a small data set within a much larger and longer-term trial. It is recommended that these data be further analysed in conjunction with other data collected from this trial, including long term yield data, to identify potential interactions between data sets, and to better characterise the overall performance of trees on the different rootstocks. To this end, the raw data collected during this project will be provided to ABA to pass on to an expert biometrician for further analysis.

It is further recommended that the differences in results between the Nemaguard and Spare Nemaguard treatments, both in this work and other results, is further investigated, perhaps as a component of the further analysis mentioned above.

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Statistical analyses of results of the Lacton Rootstock Trial



Prepared for

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January 2021

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Summary

This report describes statistical analyses of an almond rootstock trial. Initially 16 rootstocks were tested in buffered plots of three measurement trees. The trial had 4 replicates. The rootstocks included a 'spare' that was planted to Nemaguard. Three rootstocks (Atlas, Cadman and Nickels) had almost zero survival rates both in the original planting and replants.

Soil pH was related to the rootstocks – soil under 3 rootstocks were acidic with pH measured in water less than 4.5. There were significant differences in soil nutrients between plots planted to different rootstocks. For example, pH in CaCl₂ ranged from 4.18 in Adafuel plots to 6.63 in Krymsk plots. In another example sulfur levels were very high in Replicate 3 (220 mg/kg) and 130 in replicate 4 but less than 40 mg/kg in the other replicates. The reason for these differences is not apparent as each plot received the same fertiliser.

There were differences in petiole nutrient levels between rootstocks. Petiole sodium and chloride were highest in Krymsk and Nemaguard. Molybdenum in Krymsk was over 0.08 mg/kg, being double that of other rootstocks.

Felinem, Hansen 536, Monegro had the largest butt diameters both initially in 2016 and in 2020. Cornerstone and Nemaguard were relatively small both in 2016 and 2020. Adafuel increased its relative size during the trial period. Tree size was therefore a product of the initial planting size and genetic vigour of the rootstock.

There was considerable overlap of the confidence intervals – that must be considered when using the ranks provided.

The highest kernel yield was 4120 kg/ha for Brights Hybrid. G557 had the lowest rank for both yield per tree and kernel yield per ha.

Early husk splitting was most advanced in Krymsk but the differences between rootstocks was not significant at later stages. There was a suggestion that Nemaguard had a smaller range of splitting time.

Canopy temperature was not affected by rootstock. The trial detected differences between replicates indicating that the trial had good resolution.

There were very significant differences in the amount of stubby nematode (*Paratrichodorus sp.*) present between rootstocks. Highest levels were found in Hansen, Monegro and GF749. Other nematodes found were the pin nematode (*Pratylenchus sp.*), ring nematode (*Criconeimella sp.*) and the root knot nematode (*Meloidogyne sp.*).

Large yielding crops tended to have lower kernel weight. Overall yield was positively related to tree height and leaf area index (LAI). Yield was positively related to the concentration of calcium and magnesium in the petiole and negatively to sodium, potassium, sulfur and chloride.

Yield was not correlated with nematode incidence or numbers.

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1 Introduction

This report describes statistical analyses of the Lacton Almond Rootstock Trial. The assessment SADI 2021 became available only after much of the current report had been completed. The results complement those of SARDI 2021.

1	Nemaguard	
2	GF557	
3	GF677	
4	GF749	
5	Adafuel	
6	Garnem	
7	Felinem	
8	Monegro	
9	Brights Hybrid	
10	Hansen 536	
11	Cornerstone	
12	Nickels	
13	Krymsk 86	
14	Cadaman (Was Penta)	
15	Atlas (was Tetra)	
16	Spare (Nemaguard)	

The layout of the trial was limited by:

- The inclusion of buffer rows as recommended by industry representatives; and
- The requirement for a pollinator trees adjacent to the monitoring trees.

A summary of the tree types is given in Table 1. The trial had four replicates and the layout is shown in Table 2 and Table 3. Row spacing was 7.30 m and tree spacing within the row was 4.00 m.

Table 1. Rootstock trial legend.

Abbreviation	Expansion
NP	Nonpareil (non-pollinator)
C	Carmel (pollinator)
P	Peerless (pollinator)
o	Monitored trees
ND	No Data
o	Dead Data tree
NP	Original Trial tree replanted

Table 2 Field plan of replicates 1 and 2.

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[illegible]

2 Data

File Name	Assessment trait	Comments
ABA DATA (Sent via email 21/6/21)		
Rootstock trial map	-	Map of trial site – Key on the right of map.
AL16006 Butt cir. Lacton – 2020 update	Butt Circumference	Row numbers align with ‘Rootstock trial map’ Raw data is in Rootstock Observations tab, column W. Data for Nonpareil trial trees as well as Carmel/ Peerless.
Rootstock trial Flowering 2020	Flowering dates	Start, Full bloom (80% open), End of bloom for R1
2021 Soil Nutrition analysis	Soil Nutrition	Labels in column K – Sample taken to 30cm at centre sample tree
2021 Leaf Nutritional analysis	Leaf Nutrition	Labels in column H – Petiole Samples taken across the 3 trees
2021 Nematode sampling	Nematodes	2021 Nematode sampling
2020 RS heights	Tree Canopy	Observed trial tree heights (Average) 2020 September
2020-21 yield data	Yield	Raw data for each replicate spread across tabs. Crack-out was 100 nuts cracked out by hand.
SARDI DATA (Since provided)		
	Hull split	Progressive dates of when hull split occurred
	Tree Canopy	Tree area by ariel image analysis

3 Statistical Methods

3.1 Multiple comparisons

The use of multiple comparisons is a perennial problem in trials such as this. With 16 rootstocks, there are 120 possible comparisons so at least one comparison would be expected to be significant at the $p < 0.05$ level. Two common strategies are:

1. Only use simple t comparisons where the overall F value is significant (Fisher’s protected LSDs); or
2. Use a more stringent test (e.g. Tukey’s Honest Significant Difference).

Fisher’s protected lsd may give some false positive significances. On the other hand, there were cases when F was significant, but no pair of rootstocks was significantly different according to Tukey’s HSD.

Fisher’s protected LSD has been used but where appropriate Tukey’s has been indicated.

Where considered appropriate, rootstocks have been ordered in ascending order, and those not differing according to Fisher's protected LSD have the same letter following.

3.2 *Standard errors*

Standard errors of treatments were derived from the analysis of variance. An average standard error is shown in barplots which is the same for each rootstock.

3.3 *Treatment of 'Spare' plots*

The Nemaguard and 'Spare' were treated as separate rootstocks even though they had the same treatment. The comparison of those two treatments gave a realistic check on the estimates of significant difference – in only one case did those treatments statistically differ according to Fisher's protected LSD.

3.4 *Tree survival*

A generalised linear model with binomial errors was used for assessing significance of tree deaths. A clearer picture was obtained by using simple means.

The main analyses were randomised blocks performed in the R package. For yield data analyses also included trends across the rows using a cubic polynomial. The results were cross-checked using GenStat.

3.5 *Temperature*

Temperature data was on a per tree basis. A split plot analysis was used where the three tree plots were treated as main plots and the trees as subplots.

3.6 *Split husks*

The data give stage of split for each of 4 dates. A weighted average of the degree split can be found, and also the number of husks that have reached Stage 3 is given.

4 Results and Discussion.

4.1 Tree survival

The number of trees measured for butt circumference is shown in Table 4. IN 2017 there was replanting of failed trees. The replants did not survive in Atlas, Cadman and Nickels. GF749 had last 2 trees by 2017 and there was subsequent loss of 3 trees.

There was no measurement of one Garnem tree in 2019 but there was in 2020. Similarly with Cornerstone, but in that case a replant may have been measured for the first time in 2020.

The total tree losses can be inferred from Table 4, For Atlas, there were 6 replants in 2017 and no measurement trees in 2020 – together this implies 18 losses.

Slightly different estimates of tree losses were obtained from the numbers of trees measured for canopy area (Table 4).

On the basis of the above observations, Atlas, Cadman and Nickels were poor survivors both initially and following replants. GF47 initially lost 2 trees and apparently 3 replants. The total losses give additional support to the poor performance of Atlas, Cadman and Nickels.

Table 4. Numbers of trees measured at each year.

	2015	2016	2017	2018	2019	2020	Implied losses	Loss Area
Adafuel	12	11	12	10	10	10	2	2
Atlas	6	6	12	6	0	0	18	NA
Brights Hybrid	12	12	12	12	11	11	1	1
Cadaman	0	0	11	0	9	0	24	
Cornerstone	11	11	12	11	11	12	1	1
Felinem	12	12	12	12	12	12	0	0
Garnem	12	12	12	12	11	12	0	2
GF557	12	12	12	12	12	11	1	0
GF677	12	12	12	12	12	12	0	0
GF749	10	10	12	10	10	9	5	2
Hansen 536	12	12	12	12	12	12	0	0
Krymsk 86	12	12	12	12	12	12	0	0
Monegro	12	12	12	12	12	12	0	0
Nemaguard	12	12	12	12	12	11	1	0
Nickels	6	5	11	0	1	0	19	NA
Spare	12	12	12	12	12	12	0	0

Note: Yellow filled cells indicate replants

4.2 Tree growth

4.2.1 Butt circumference

There were statistically different differences between the rootstocks at each of the yearly assessments. These differences are shown in Figure 1. Three key measurement times are detailed in Table 5. The means for 2016 would potentially include a nursery effect.

The ranking of rootstocks for 2018 was similar to those of 2020. The means for Nemaguard and Spare did not differ as expected because they were the same genotype.

Table 5. Comparison of butt circumferences (mm) for each rootstock.

Rootstock 2016		Rootstock 2018		Rootstock 2020	
Atlas	205.3	Atlas	429.8 a	Cornerstone	540.4 a
Nickels	287.0 a	Cornerstone	442.2 ab	Nemaguard	549.8 a
Cornerstone	302.1 a	Nemaguard	442.8 ab	Spare	556.3 a
Nemaguard	320.9 b	Krymsk 86	450.0 abc	Brights Hybrid	560.4 ab
Krymsk 86	321.3 b	Spare	450.2 abc	GF557	564.6 ab
Adafuel	326.7 bc	Brights Hybrid	450.3 abc	Krymsk 86	568.8 abc
Spare	328.3 bc	GF557	459.9 abcd	GF677	569.5 abc
GF557	329.0 bc	GF749	464.6 bcd	Garnem	572.1 abc
Brights Hybrid	335.9 bcd	Garnem	468.5 bcd	GF749	572.3 abc
GF749	338.0 bcd	GF677	473.0 bcd	Adafuel	600.2 bcd
GF677	344.5 cde	Adafuel	479.7 de	Felinem	605.4 cd
Garnem	353.0 de	Felinem	490.2 de	Monegro	608.8 cd
Felinem	355.9 de	Monegro	492.3 de	Hansen 536	619.6 d
Hansen 536	358.5 de	Hansen 536	511.7 e	Atlas	NA
Monegro	362.7 e	Cadaman	NA	Cadaman	NA
Cadaman	NA	Nickels	NA	Nickels	NA
p value	<0.001	p value	<0.01	p value	<0.01
se	8.0	se	11.7	se	14.0
lsd Fisher	22.9	lsd Fisher	33.6	lsd Fisher	40.2
lsd Tukey	42.2	lsd Tukey	62.0	lsd Tukey	74.1

Notes: Units of measure are mm of circumference.

Rootstocks that share the same letter do not differ at the 5% levels using Fisher's protected LSD.

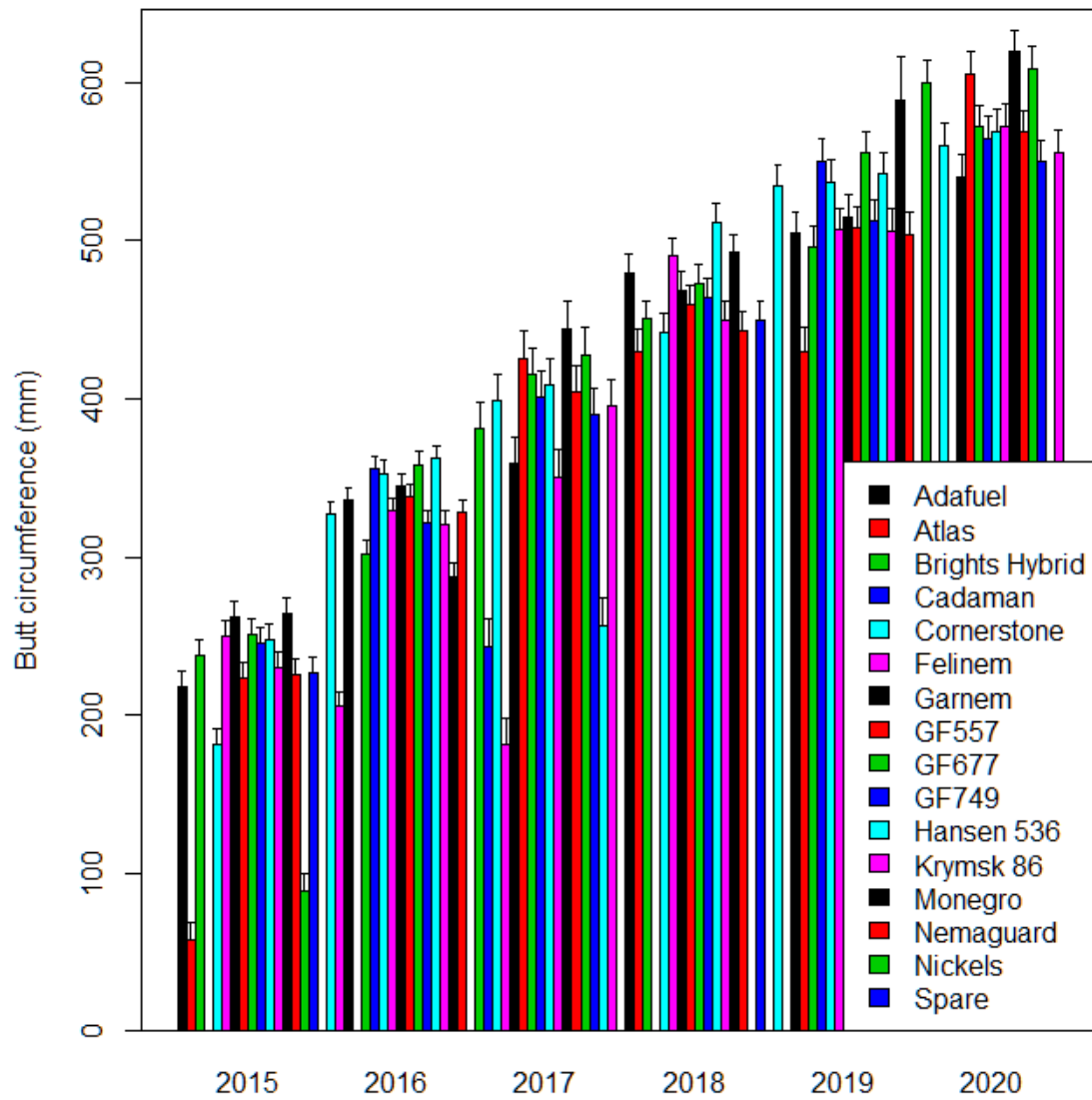


Figure 1. Barplot of butt circumferences for each rootstock for each measurement year. Error bars are standard errors.

Table 6. Growth increments for each year for each variety. High values are highlighted in blue and low values in green. LSDs are Fisher's protected least significant differences.

Rootstock	2016	2017	2018	2019	2020	2021
Adafuel	38.4	46.7	47.4	51.6	45.0	59.3
Brights Hybrid	45.4	44.4	36.7	34.9	42.0	46.7
Cornerstone	26.4	46.4	42.4	40.6	40.1	51.3
Felinem	49.7	51.2	43.5	47.4	49.8	50.6
Garnem	56.2	46.6	42.9	48.4	46.4	52.8
GF557	39.9	46.4	42.1	40.5	36.2	49.0
GF677	50.5	44.1	38.4	45.4	33.1	46.9
GF749	48.1	43.1	40.3	40.8	33.7	55.6
Hansen 536	49.2	53.3	55.3	51.5	37.4	59.9
Krymsk 86	42.5	40.2	47.8	31.6	47.4	48.7
Monegro	55.7	49.0	41.0	47.5	41.1	60.9
Nemaguard	40.6	40.8	38.5	33.2	48.8	36.7
Spare	41.1	44.8	38.6	37.2	41.1	44.3
SE	3.5	2.2	3.8	4.4	5.8	8.2
p value	< 0.001	0.005	0.084	0.023	0.537	0.735
LSD	7.0	4.4		9.0		

A summary of the growth increments is given in Table 7. The large differences observed in 2016 growth may be due to a nursery effect. Hansen showed fairly consistent high growth whereas Nemaguard showed low growth.

There was a general increase in growth increment as shown in Table 7. The actual increase in cross sectional area would be greater than that as the increase in area would be proportional to the increase in diameter and the circumference.

4.2.2 Tree height

There were differences in tree height that were significant at the $p < 0.01$ level. The mean heights of each rootstock are shown in Table 7.

Nemaguard had the lowest height (4.65 m). It differed from 'Spare' according to Fisher's protected LSD of 0.165 but not by Tukey's HSD of 0.30.

Table 7. Ranking of tree heights (m) of each rootstock.

Rootstock	Height	Letters
Nemaguard	4.650	a
Cornerstone	4.775	a
Krymsk 86	4.775	ab
Spare	4.825	bc
GF557	4.875	bc
Monegro	4.875	bc
Hansen 536	4.900	bc
Adafuel	4.925	bc
Brights Hybrid	4.925	bc
Felinem	4.925	bc
GF677	4.925	bc
Garnem	4.975	c
GF749	4.975	c
SED	0.081	
P value	0.012	
LSD	0.164	

Note: Rootstocks that share the same letter do not differ at the 5% levels using Fishers protected LSD.

4.2.3 Tree area

Data on tree area were supplied by SARDI.

Request for explanation of reversal in tree area data]

Table 8. Effect of rootstock on tree area at each of four times.

	Area2017	Area2018	Area2019	Area2020
Adafuel	14.5	13.8	50.7	59.0
Brights Hybrid	16.1	14.9	50.4	61.3
Cornerstone	13.0	11.5	45.7	59.3
Felinem	14.8	13.7	44.5	54.6
Garnem	15.1	13.7	46.5	60.8
GF557	13.2	11.5	43.3	55.7
GF677	15.0	13.7	45.5	55.8
GF749	15.3	14.1	46.6	55.4
Hansen 536	16.7	15.2	49.4	63.6
Krymsk 86	9.8	9.2	34.8	51.9
Monegro	14.6	13.6	48.1	55.9
Nemaguard	12.7	11.5	41.1	53.7
Spare	13.4	12.0	43.6	54.8
pval	0.004	0.007	0.293	0.263
se	1.5	1.5	6.4	5.0

Table 9. Correlations between years of tree areas.

	Area 2017	Area 2018	Area 2019	Area 2020
Area 2017	1.00			
Area 2018	0.90	1.00		
Area 2019	0.67	0.59	1.00	
Area 2020	0.56	0.54	0.55	1.00

4.2.4 Leaf area index (LAI)

Only rootstocks with at least 10 of the 12 measurement trees were considered. There were very significant ($p < 0.001$) differences among the LAI of the 13 rootstocks considered. Krymsk 86 had the lowest LAI. The best 6 rootstocks did not differ significantly according to the least conservative Fisher's protected LSD.

4.2.5 Correlations among size variables

The correlations among the size measures are shown in **Error! Reference source not found.** There was a strong correlation between 2015 and 2016 circumferences, probably due to persistence of a nursery effect. The correlations between the 2018, 2019 and 2020 circumferences are probably attributable to the effects of the rootstocks. That is consistent with the very similar rankings in the 2018 and 2020 circumference data shown in Table 5.

Correlations between circumference and height were moderate, indicating they are not closely related. This may be in part due to measurement variability in assessing tree height.

Table 10. Correlations among tree size measures.

	Butt 2016	Butt 2018	Butt 2020	Height	Area 2017	Area 2018	Area 2019	Area 2020	LAI
Butt 2016	1.00								
Butt 2018	0.82	1.00							
Butt 2020	0.77	0.96	1.00						
Height	0.61	0.53	0.47	1.00					
Area 2017	0.64	0.60	0.47	0.69	1.00				
Area 2018	0.67	0.64	0.54	0.71	0.98	1.00			
Area 2019	0.39	0.49	0.41	0.60	0.88	0.89	1.00		
Area 2020	0.24	0.37	0.26	0.43	0.71	0.68	0.77	1.00	
LAI	0.69	0.61	0.46	0.59	0.90	0.88	0.68	0.47	1

Table 11. Estimates of leaf area index for 13 rootstocks.

Rootstock	Estimate	
Krymsk 86	0.74	
Nemaguard	0.98	a
Cornerstone	0.99	a
GF557	1.02	a
Adafuel	1.02	a
Spare	1.04	a
Garnem	1.09	ab
Monegro	1.16	abc
GF749	1.18	abc
Brights Hybrid	1.28	bc
Felinem	1.31	bc
GF677	1.32	bc
Hansen 536	1.33	c

Notes Standard error was 0.076. Entries followed by the same letter do not differ by Fisher's protected LSD. Tukey's HSD was 0.45.

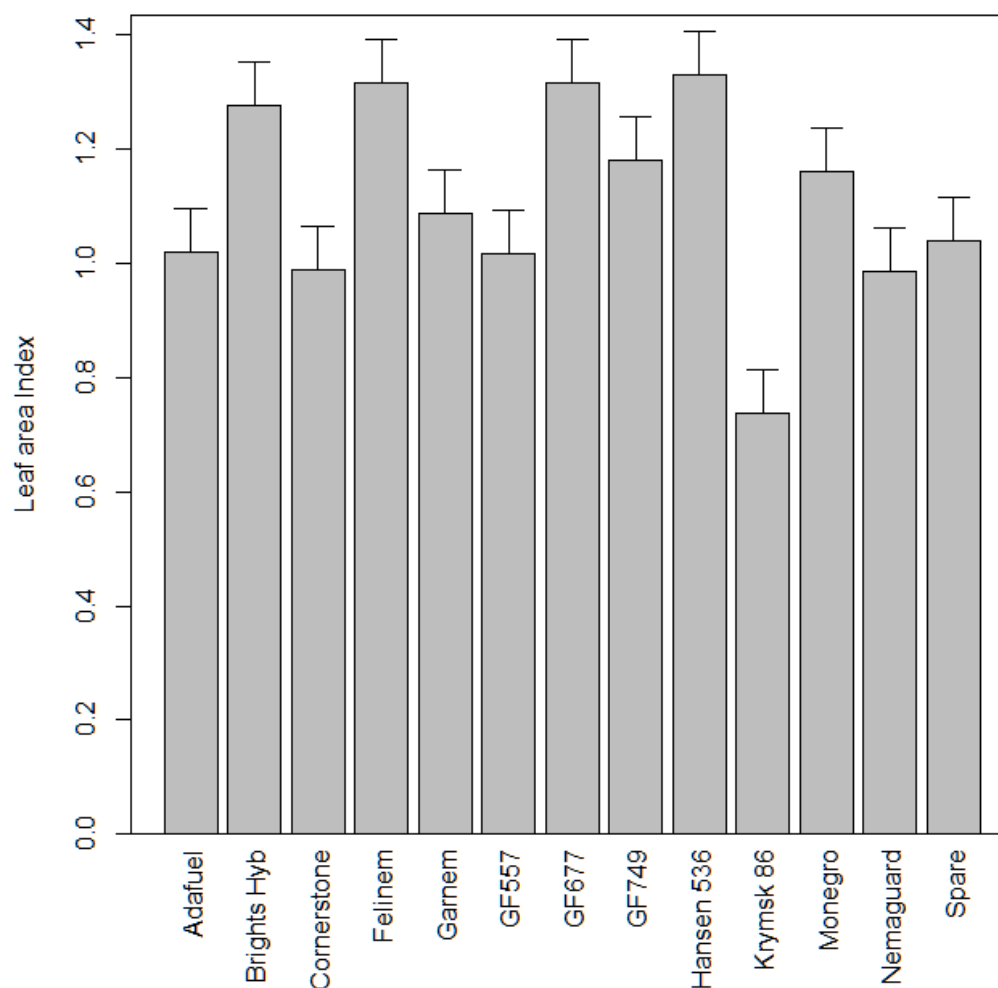


Figure 2. Comparison of leaf area index of trees from 13 rootstock. Error bars are standard errors.

4.3 Soil nutrients

A summary of soil nutrient levels is given in Table 12. Further details of each nutrient are given below.

Table 12. Mean soil nutrient levels for each rootstock.

Rootstock	pH.H ₂ O	pH.CaCl ₂	OC	Nitrate N	Ammonia N	Col.P	Tot.P	K	S	EC	TDS
Adafuel	5.32	4.18	0.58	2.63	3.65	63	56	280	16	0.06	37
BrightsHyb	6.02	4.83	0.61	1.53	14.95	58	49	348	19	0.07	43
Cornerstone	5.35	4.21	0.52	1.70	9.45	57	58	273	18	0.06	36
Felinem	6.69	6.23	1.43	4.25	9.88	76	42	425	104	0.29	187
Garnem	7.16	6.63	0.9	5.98	4.55	57	46	450	29	0.16	102
GF557	5.18	4.06	0.69	3.67	6.13	47	53	300	21	0.07	42
GF677	6.23	5.28	0.77	1.75	6.05	25	45	408	14	0.10	66
GF749	5.32	4.24	0.55	18.23	5.75	60	59	333	34	0.09	59
Hansen	6.21	5.25	0.63	1.31	4.95	45	51	345	23	0.11	71
Krymsk	5.97	5.20	0.64	3.58	2.95	96	67	373	16	0.11	65
Mongero	5.91	5.17	0.86	2.65	6.10	80	50	415	31	0.13	81
Nemaguard	6.25	5.28	0.93	2.60	5.45	30	43	320	25	0.09	59
Spare	5.75	4.80	0.99	3.30	5.43	43	45	345	28	0.10	66
pval	0.001	0.001	0.006	0.010	0.439	0.003	0.345	0.270	0.032	0.009	0.007
se	0.30	0.40	0.15	2.21	3.16	10.8	6.71	50	16	0.04	23.5
LSD	0.86	1.15	0.43	6.33	NA	31	NA	NA	46	0.11	67

4.3.1 pH 1:5 water

There were significant differences between the plots with different rootstocks as illustrated in Figure 3. The pH ranged from 5.2 in GF557 to 7.16 in Garnem.

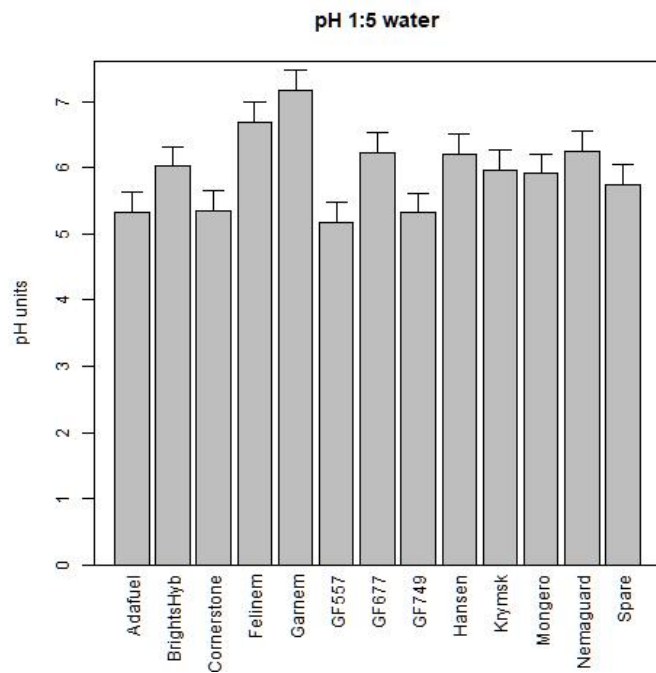


Figure 3. Barplot of pH measured in water for each rootstock.

4.3.2 pH CaCl₂ (following 4A1)

There were very significant ($p < 0.001$) differences in CaCl₂ measured pH with the highest pH from the Garnem plots (Figure 5). The two measures of pH were strongly correlated (Figure 5). That plot shows some clustering of the rootstocks into groups. That plot supports the conclusion of the differences between the rootstocks.

The lowest pH was 4.06, which is acidic. There were 4 rootstocks with soil pH less than 4.5.

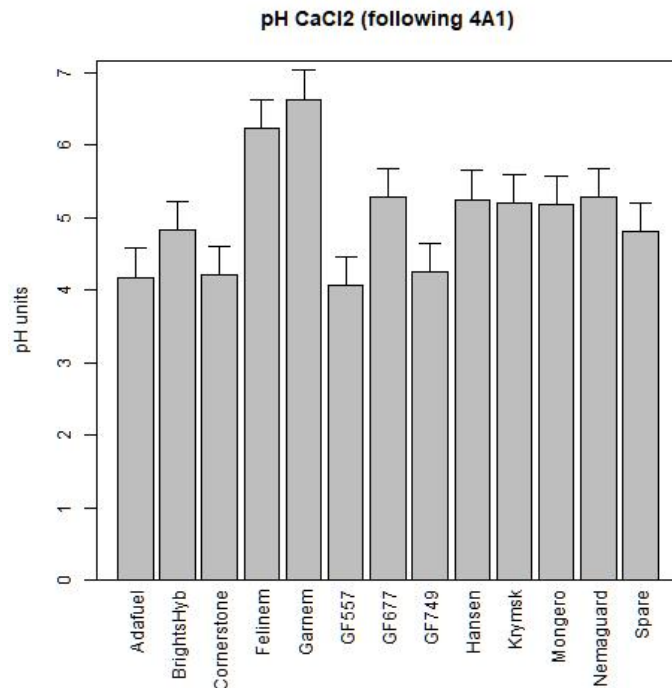
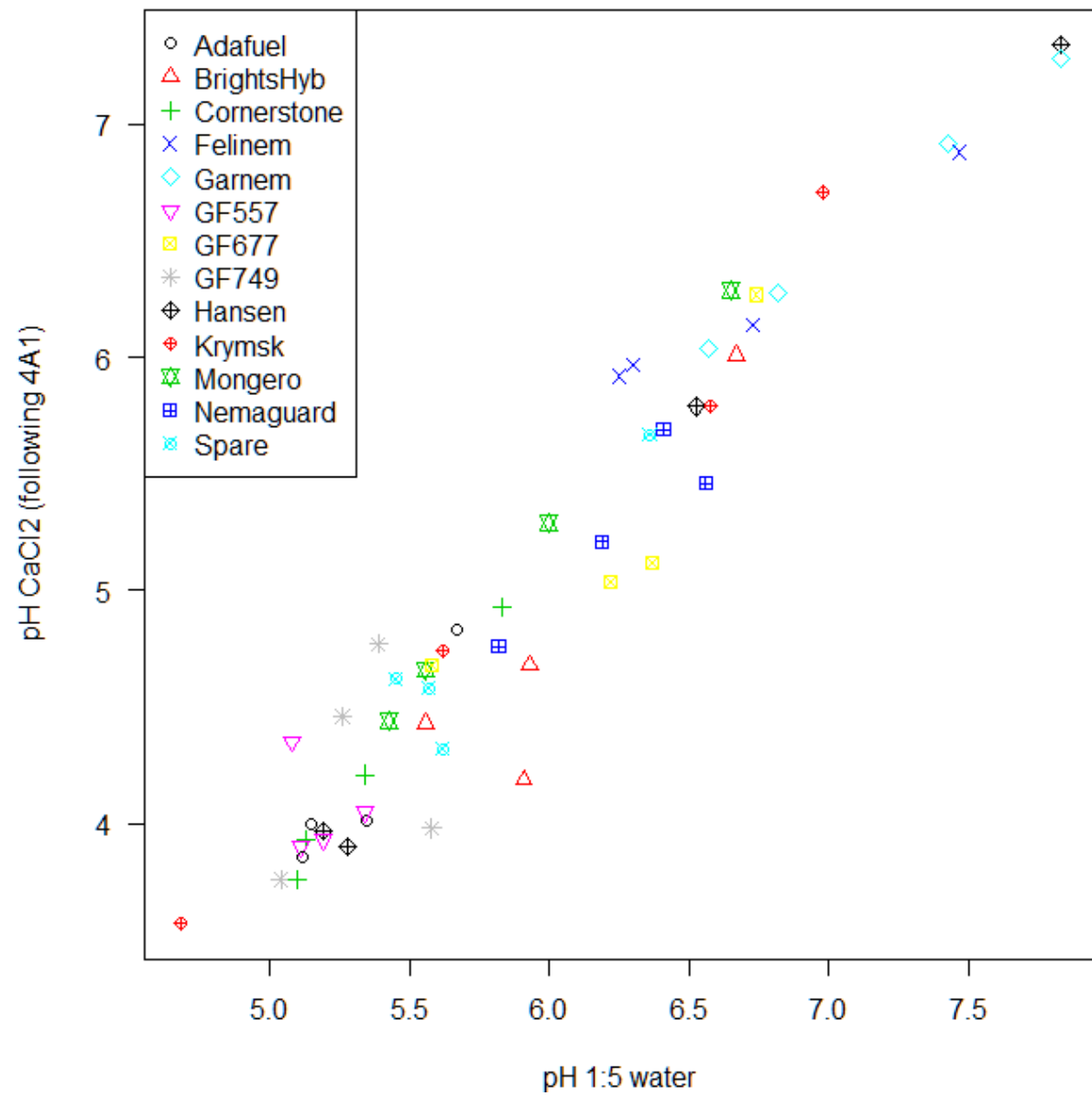


Figure 4. Barplot of pH measured in CaCl₂ for each rootstock. Error bars are standard errors.



4.3.3 Organic Carbon (W&B)

The distribution of mean organic carbon levels is shown in Figure 6. The OC of soil from the Felinem plots was 1.4%. High values of over 0.9 % were found in both Nemaguard and 'Spare'. The two highest levels were in the R1 and R4 Felinem plots (2.14 and 1.99%) but the other two replicates of Felinem had levels less than 1%. Only 10 of the plots had OC levels greater than 1%.

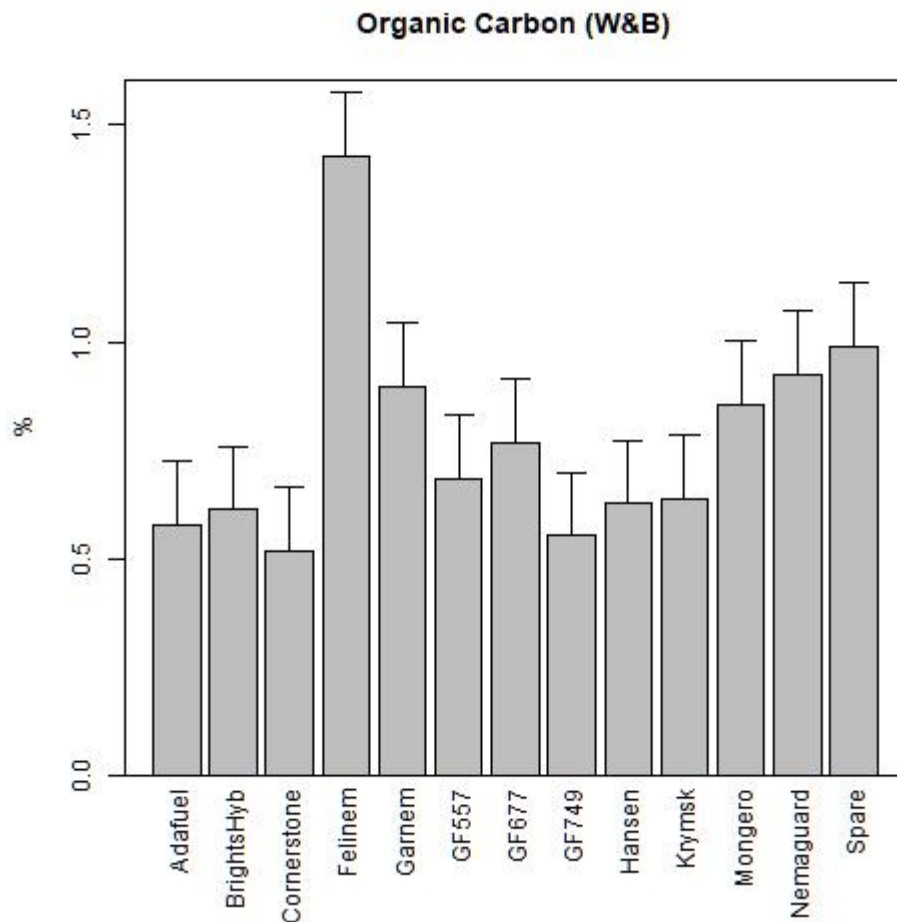


Figure 6. Comparison of Organic Carbon measured in water or CaCl_2 . Error bars are standard errors.

4.3.4 Nitrate - N (2M KCl)

There was an outlier in nitrate N of 29 mg/kg and this translated to a mean of 18.2 mg/kg because there were missing values in Replicates 1 and 3. The high mean shown in Figure 7 is therefore poorly replicated and not precisely measured.

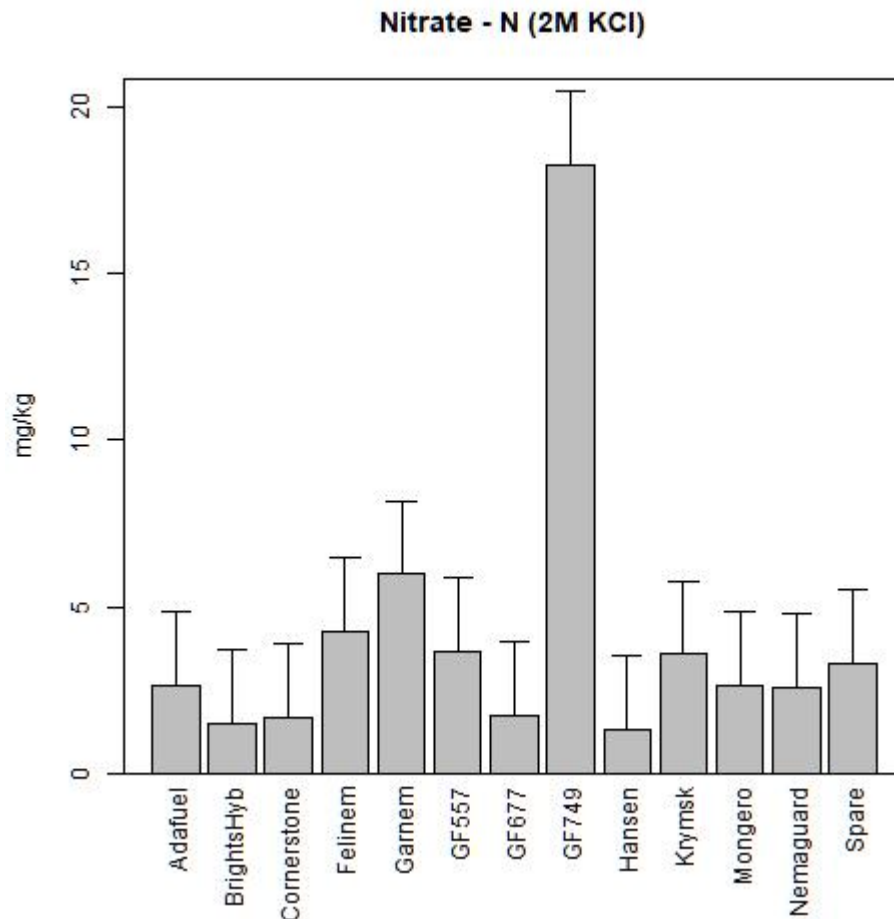


Figure 7. Comparison of nitrate levels in soil in each type of rootstock. Error bars are standard errors.

4.3.5 Ammonium - N (2M KCl)

There was an ammonium-N outlier of 42 mg/kg in Bright's Hybrid (R3) but there were data in the other 3 replicates, so the effect was not so apparent.

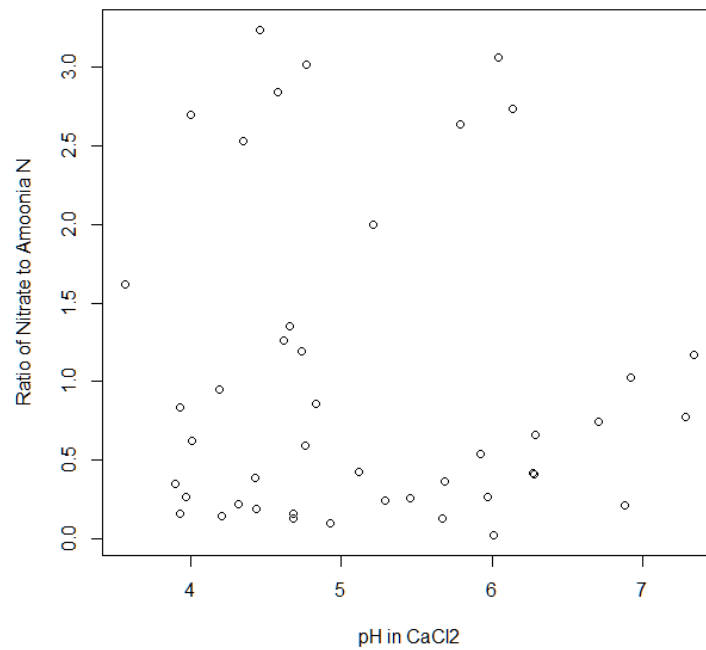


Figure 8. Effect of pH on the ratio of nitrate to ammonium N.

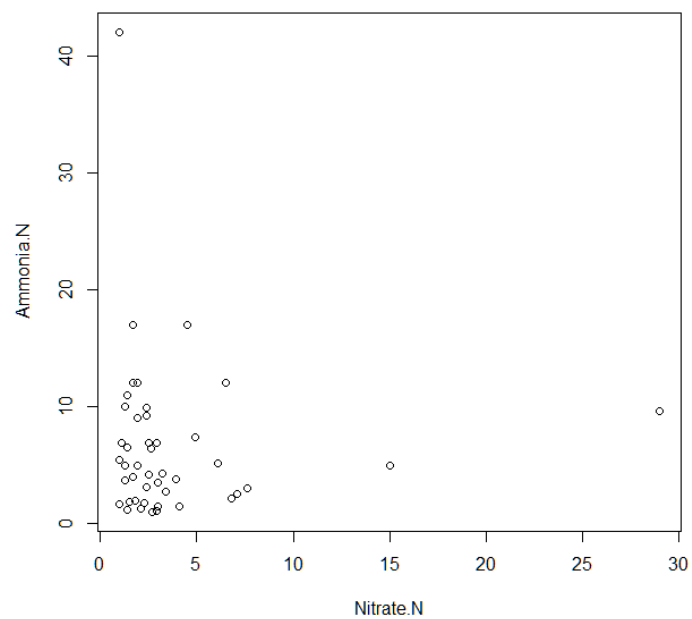


Figure 9. Relationship between nitrate N and ammonium N.

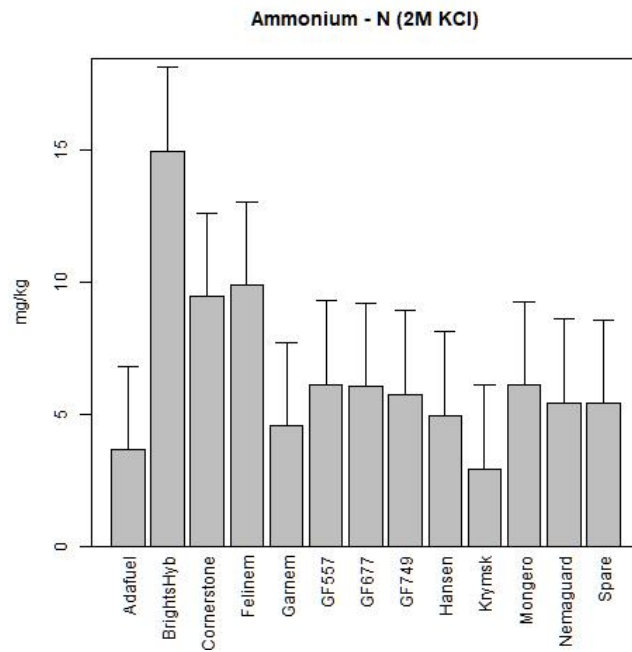


Figure 10. Comparison of nitrate levels in soil in each type of rootstock. Error bars are standard errors.

4.3.6 Colwell Phosphorus

The mean Colwell P values are shown in Figure 11. There were significant ($p < 0.01$) differences between the rootstocks.

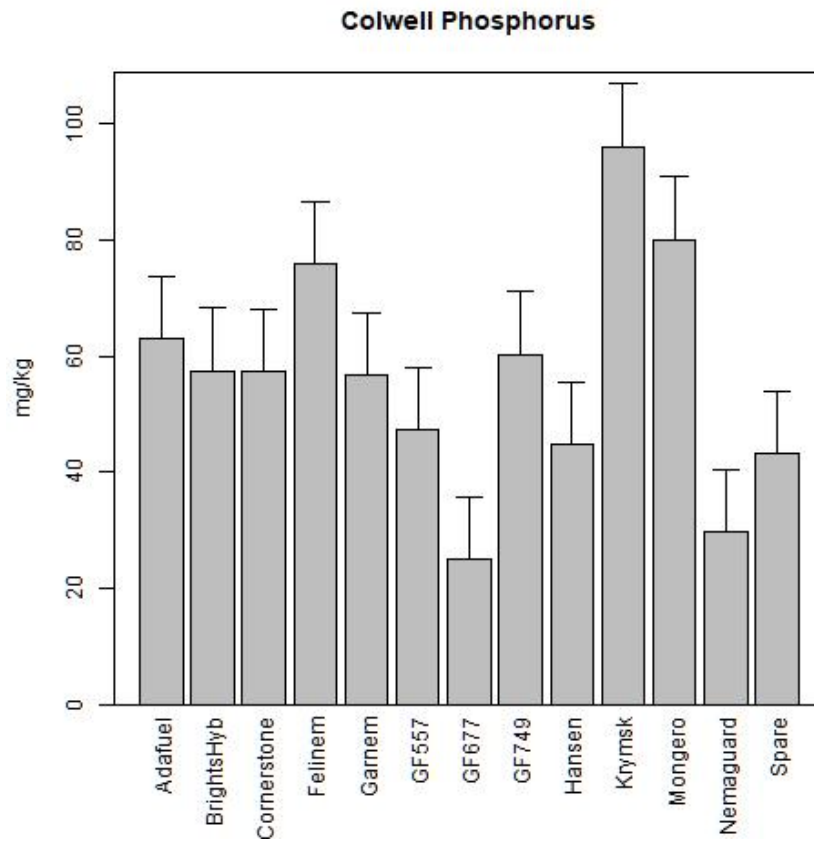


Figure 11. Comparison of nitrate levels in soil in each type of rootstock. Error bars are standard errors.

4.3.7 PBI + Col P

There was no significant effect of the rootstock on the PBI + Col P result. There was some relationship between Col P and PBI + Col P (Figure 13) but there were points below the 1:1 line. The PBI (phosphate binding index) is a measure of the ability of the soil to bind phosphate.

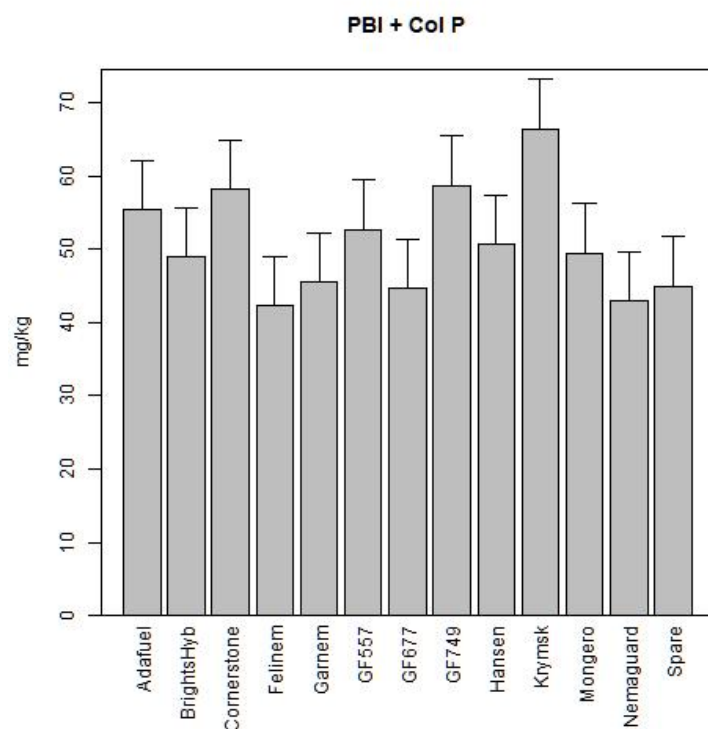


Figure 12. Comparison of nitrate levels in soil in each type of rootstock. Error bars are standard errors.

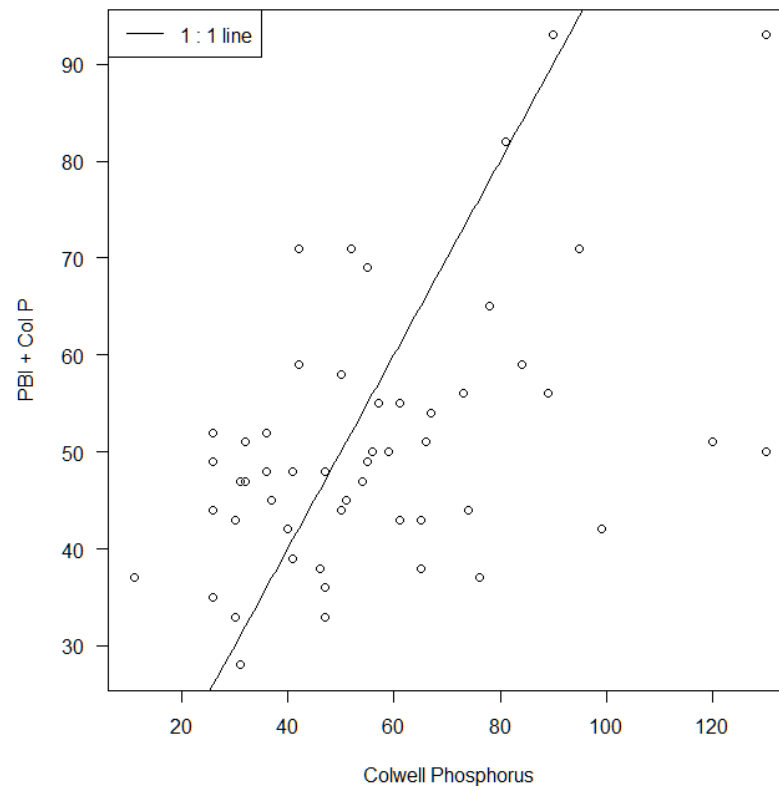


Figure 13. Relationship between Col P and PBI + Col P

4.3.8 Colwell Potassium

There was no statistically significant effect of rootstocks on Colwell P values.

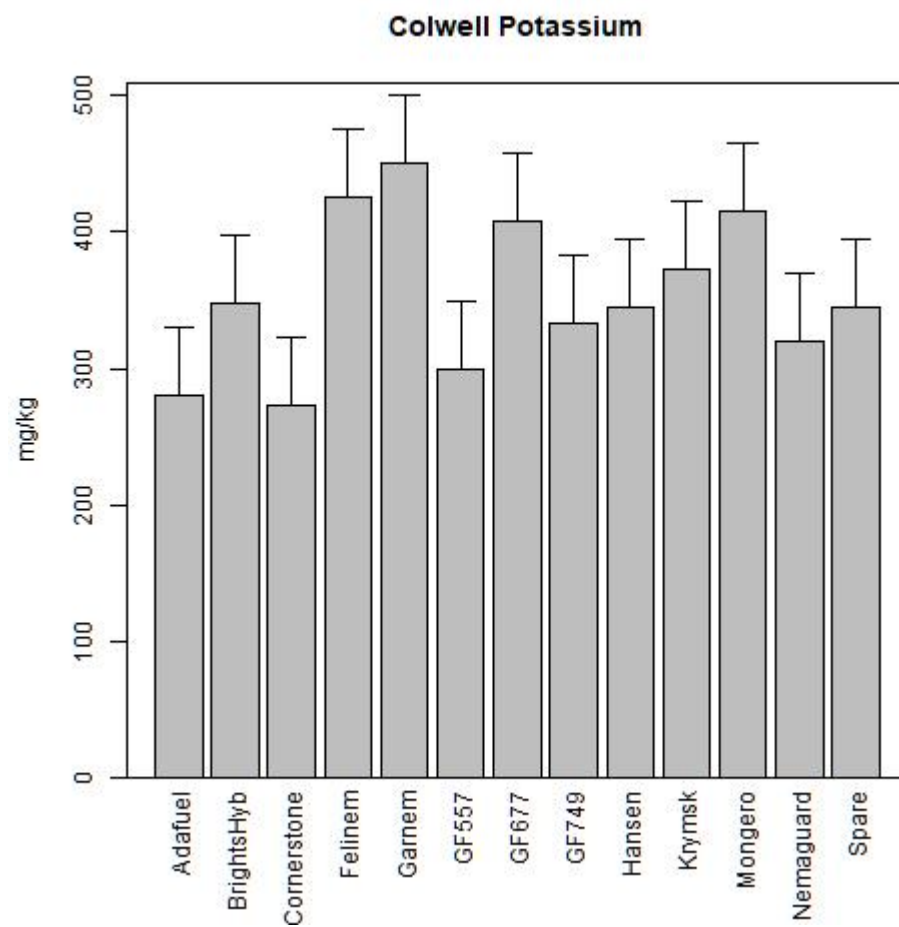


Figure 14. Comparison of nitrate levels in soil in each type of rootstock. Error bars are standard errors.

4.3.9 KCl Sulfur (S)

There was marginal significance ($p < 0$) of KCL extracted S rootstocks. This was attributed to a mean value of 104 mg/kg, caused by an outlier of 220 mg/kg for a Felinem in Replicate 3 and a value of 130 in replicate 4. That plot also had very high TDS (320 mg/kg) and high Colwell P (610 mg/kg).

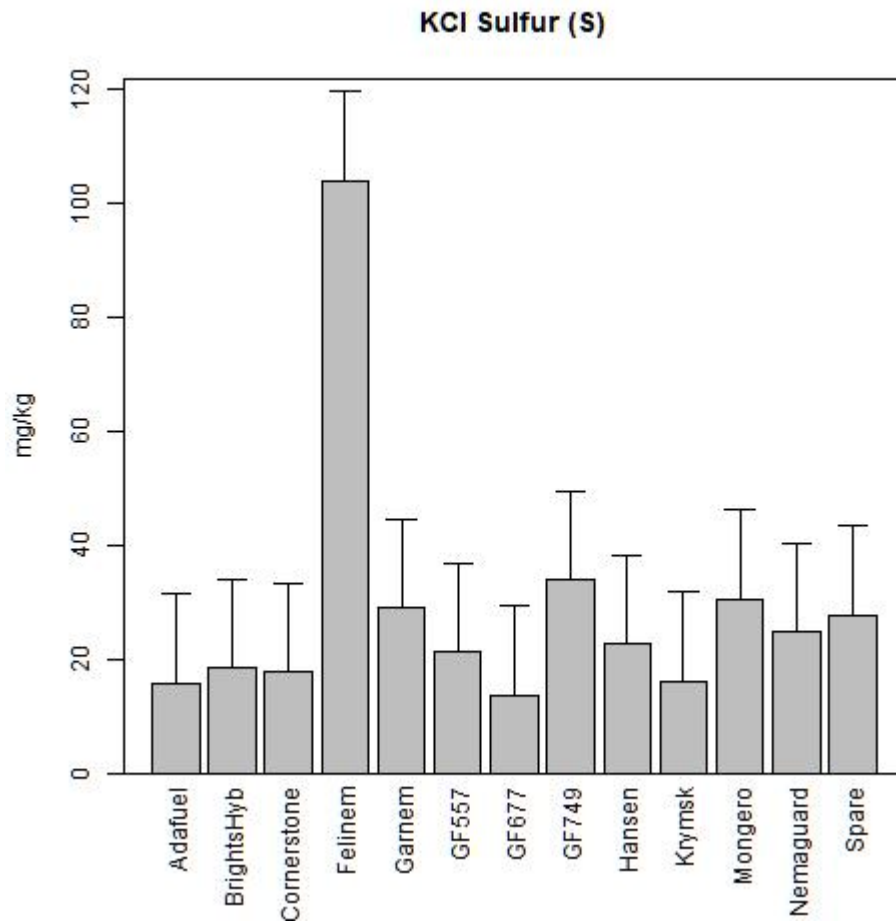


Figure 15. Comparison of sulfur levels in soil in each type of rootstock. Error bars are standard errors.

4.3.10 Salinity EC 1:5

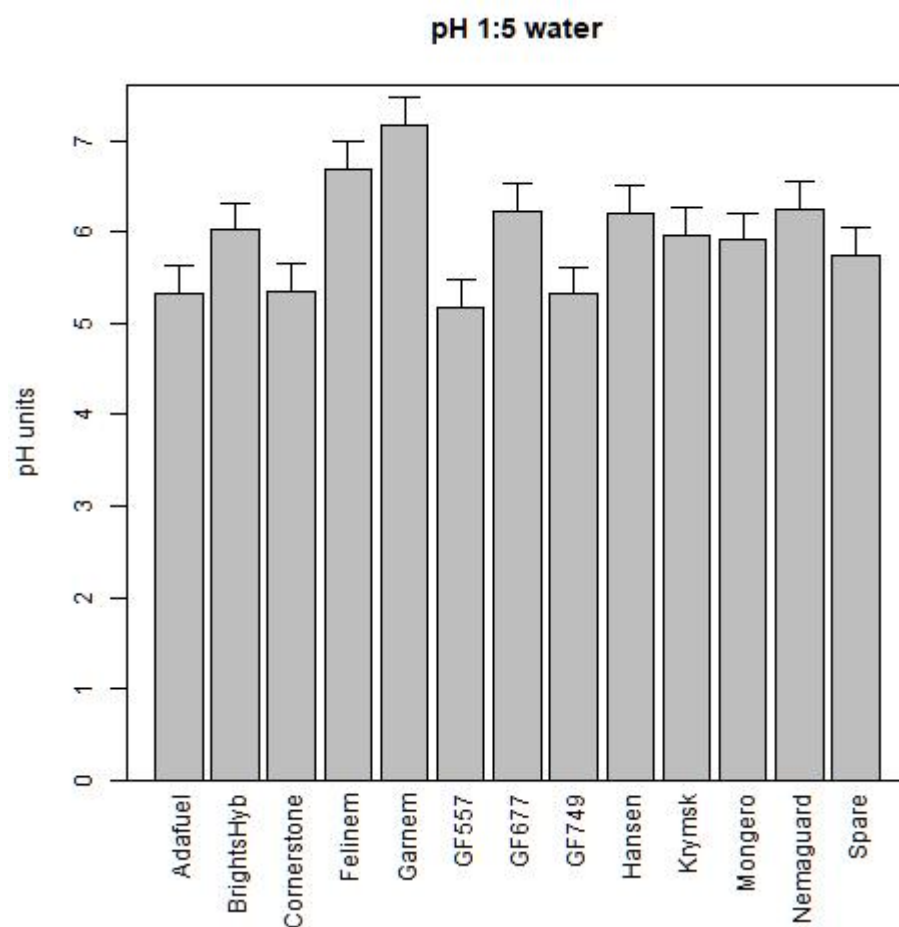


Figure 16. Comparison of soil pH measured in plots from each type of rootstock. Error bars are standard errors.

4.3.11 TDS

There was a very close relationship (adjusted $R^2 = 0.998$) between TDS and EC (Figure 18). Based on those data it is recommended that only one of those measures should be taken in future and use the relationship

$\text{TDS (mg/L)} = \text{EC (dS/m in 1:5 slurry)} \times 640$. [is TDS based on a 1:5 slurry?]

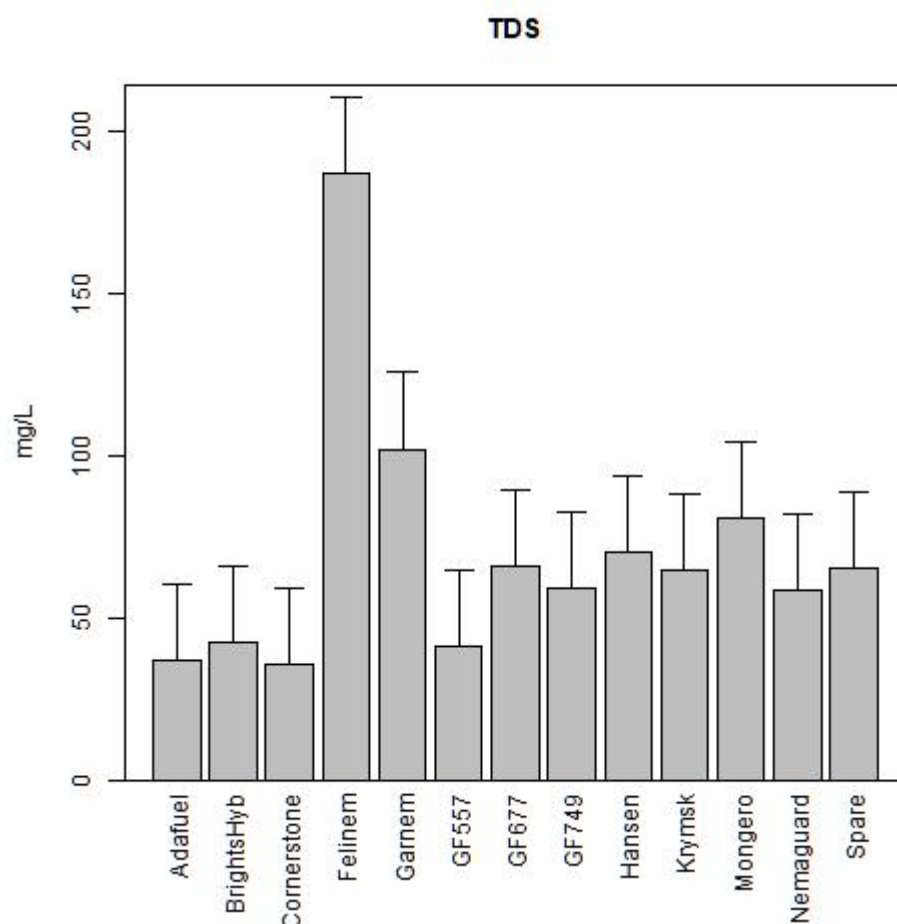


Figure 17. Comparison of TDS levels in soil in each type of rootstock. Error bars are standard errors.

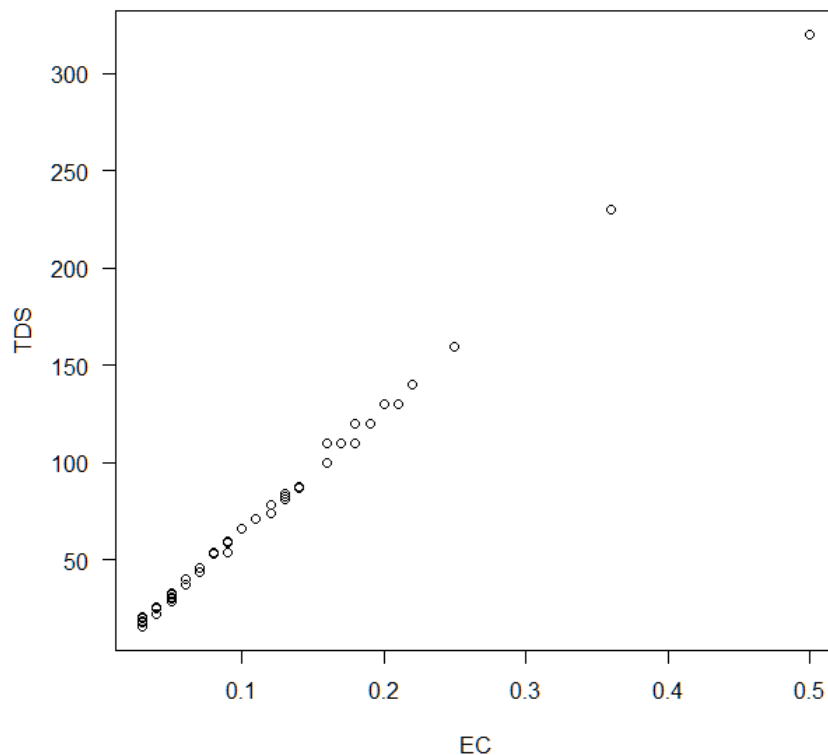


Figure 18. Relationship between TDS and EC.

No large differences were expected in the nutrient levels of soil from plots of different because each plot received the same fertiliser treatment. In the case of sulfur, there seems to have been contamination in two of the replicates. The soil sampling was made using a single core. One possibility for the outliers is that the soil sampling included material from the nursery.

The soil sampling could be improved by taking a several small cores – generally it is advisable to choose a core number and core diameter so that the amount of soil sampled is acceptable to the laboratory – such a procedure eliminates the need for subdividing the sample with the inherent biases.

4.4 *Tree nutrition*

A summary of the nutritional data is given in Table 13. Comments on individual nutritional data are given below.

It was noted that sodium, potassium and boron behaved similarly - in each case the maximum was with the Krymsk rootstock.

Calcium and magnesium were correlated as to a lesser extent was manganese.

These extensive data on petiole nutrient levels will be useful in assessing the need for advising on future fertilizer applications. Those data should be compared with data in Reuter and Robinson (1997) or some other source.

Table 13. Nutritional values and statistical significance for each rootstock.

Rootstock	Nitrate.N Mg/kg	Nitrogen %	Phosphorus %	Potassium %	Calcium %	Magnesium %	Sodium %	Sulfur %
Adafuel	173	2.380	0.125	2.97	2.800	0.46	0.0090	0.1875
Brights	225	2.463	0.123	2.95	2.600	0.48	0.0107	0.1950
Corners	95	2.368	0.120	3.17	2.495	0.48	0.0099	0.1950
Felinem	202	2.340	0.115	3.21	2.768	0.47	0.0102	0.1900
Garnem	161	2.343	0.120	2.94	2.833	0.52	0.0088	0.1850
GF557	132	2.358	0.125	3.11	2.558	0.44	0.0083	0.2000
GF677	141	2.325	0.123	2.93	2.878	0.43	0.0094	0.1825
GF749	111	2.300	0.125	2.82	2.963	0.47	0.0085	0.1775
Hansen	177	2.258	0.123	2.93	3.208	0.59	0.0100	0.2050
Krymsk	133	2.420	0.115	3.42	2.235	0.43	0.0130	0.2075
Mongero	239	2.388	0.125	2.90	2.823	0.51	0.0084	0.1825
Nemagua	134	2.360	0.118	3.08	2.218	0.40	0.0115	0.1850
Spare	129	2.340	0.123	3.03	2.263	0.41	0.0123	0.1775
pval	0.549	0.009	0.391	0.228	0.0000	0.0000	0.0049	0.0022
se	46	0.031	0.0035	0.14	0.099	0.018	0.00087	0.0053
LSD	NA	0.089	NA	NA	0.284	0.052	0.0025	0.0152

Rootstock	Boron mg/kg	Copper mg/kg	Zinc mg/kg	Manganese mg/kg	Iron mg/kg	Aluminium mg/kg	Molybdenum mg/kg	Chloride %
Adafuel	29.75	7.28	78.0	418	120.0	135.0	0.0475	0.105
Brights	28.75	7.73	71.5	420	125.0	137.5	0.0483	0.115
Corners	28.75	7.98	82.0	395	120.0	130.0	0.0458	0.105
Felinem	30.75	8.30	81.0	453	122.5	132.5	0.0420	0.148
Garnem	30.25	7.18	70.0	428	117.5	130.0	0.0450	0.188
GF557	29.50	8.08	75.0	350	120.0	132.5	0.0298	0.095
GF677	29.50	9.45	95.5	418	117.5	127.5	0.0388	0.078
GF749	29.00	8.75	80.3	405	117.5	125.0	0.0438	0.068
Hansen	32.25	7.75	86.0	518	122.5	135.0	0.0360	0.130
Krymsk	35.25	7.05	58.8	303	120.0	127.5	0.0875	0.400
Mongero	30.25	7.90	72.5	435	117.5	127.5	0.0410	0.118
Nemaguad	30.75	7.45	80.0	363	120.0	142.5	0.0435	0.580
Spare	30.50	7.40	75.0	375	111.5	130.0	0.0458	0.543
pval	0.0000	0.18	0.051	0.0005	0.809	0.861	0.00000	0.00000
se	0.72	0.553	6.2	26	4.2	6.5	0.0025	0.039
LSD	2.06	NA	NA	75	NA	NA	0.0072	0.112

Notes: Red or brown indicates p values of <0.001 or < 0.01.

4.4.1 Petiole Nitrate

Petiole Nitrate – N levels did not differ significantly between rootstocks but that may have been a result of the high SE (Fisher's LSD = 141).

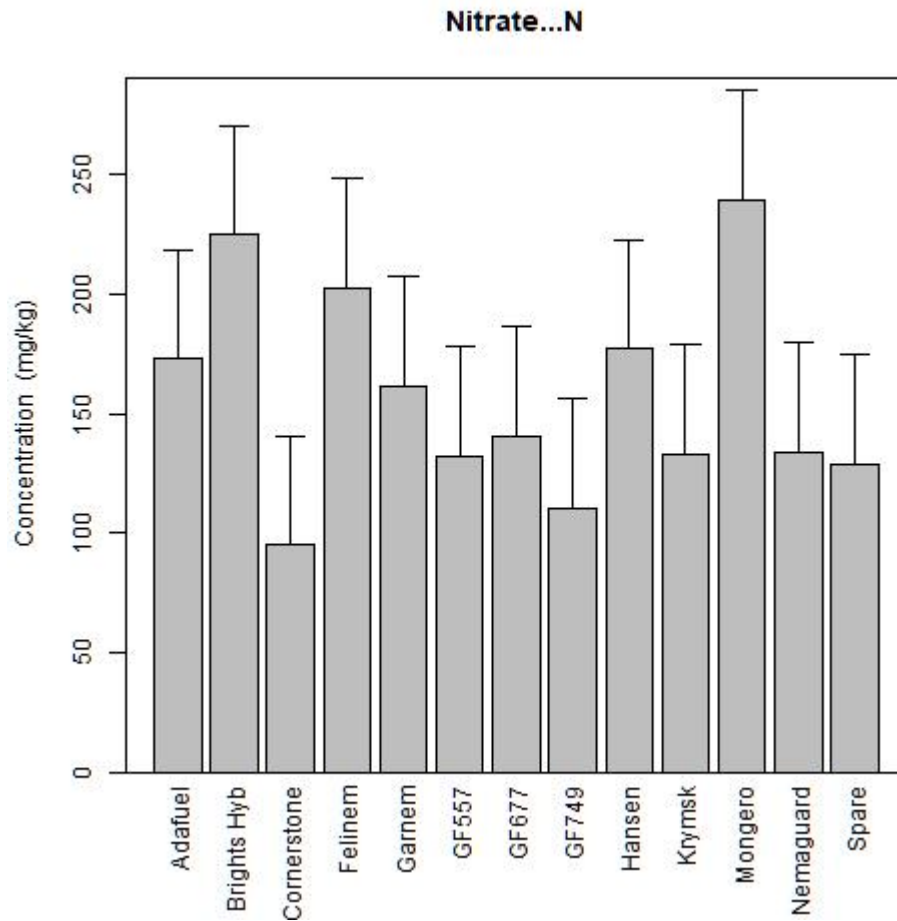


Figure 19. Comparison of petiole nitrate N between rootstocks. Error bars are standard errors.

4.4.2 Petiole Nitrogen levels

Nitrogen levels differed significantly between rootstocks ($p < 0.01$) but there was no clear pattern.

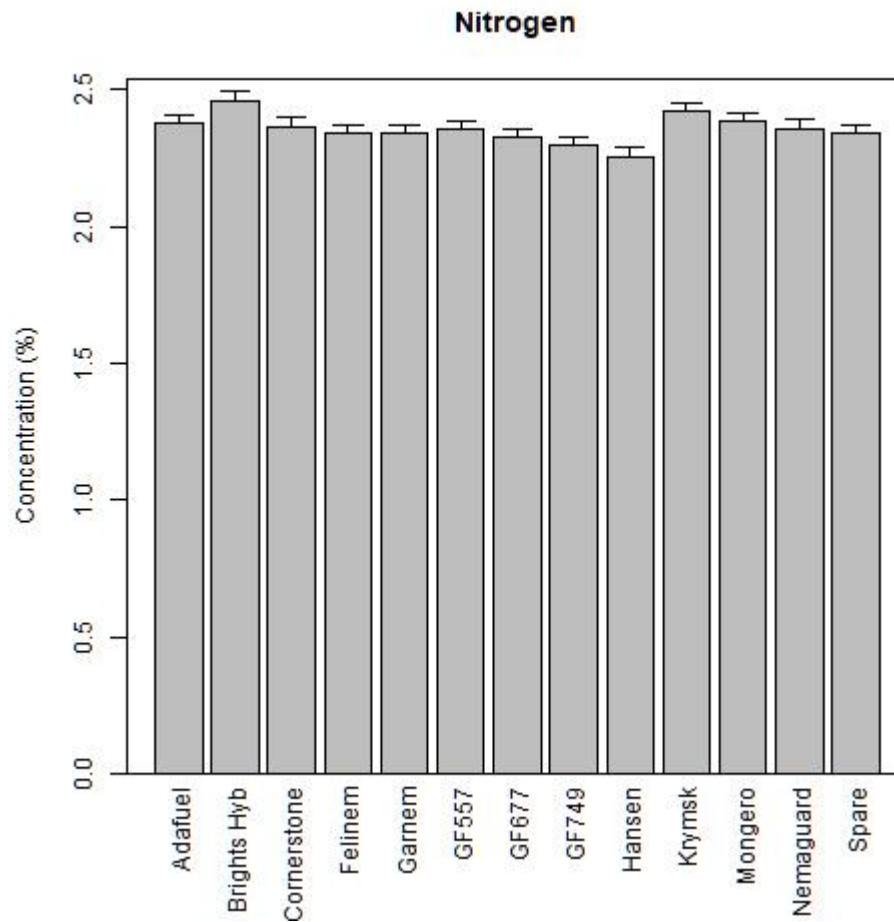


Figure 20. Comparison of petiole nitrogen between rootstocks. Error bars are standard errors.

4.4.3 Petiole Phosphorus

There was no significant effect of rootstock on petiole phosphorus levels.

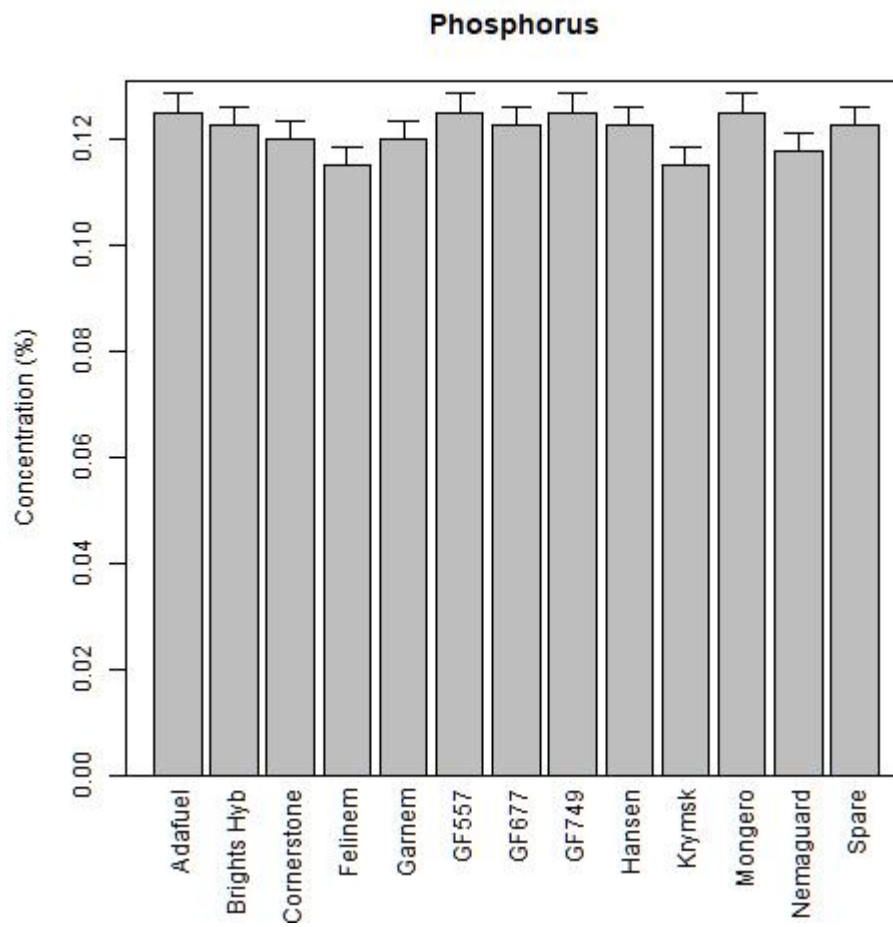


Figure 21. Comparison of petiole phosphorus between rootstocks. Error bars are standard errors.

4.4.4 Petiole Potassium

There was no significant effect of rootstock on petiole potassium levels.

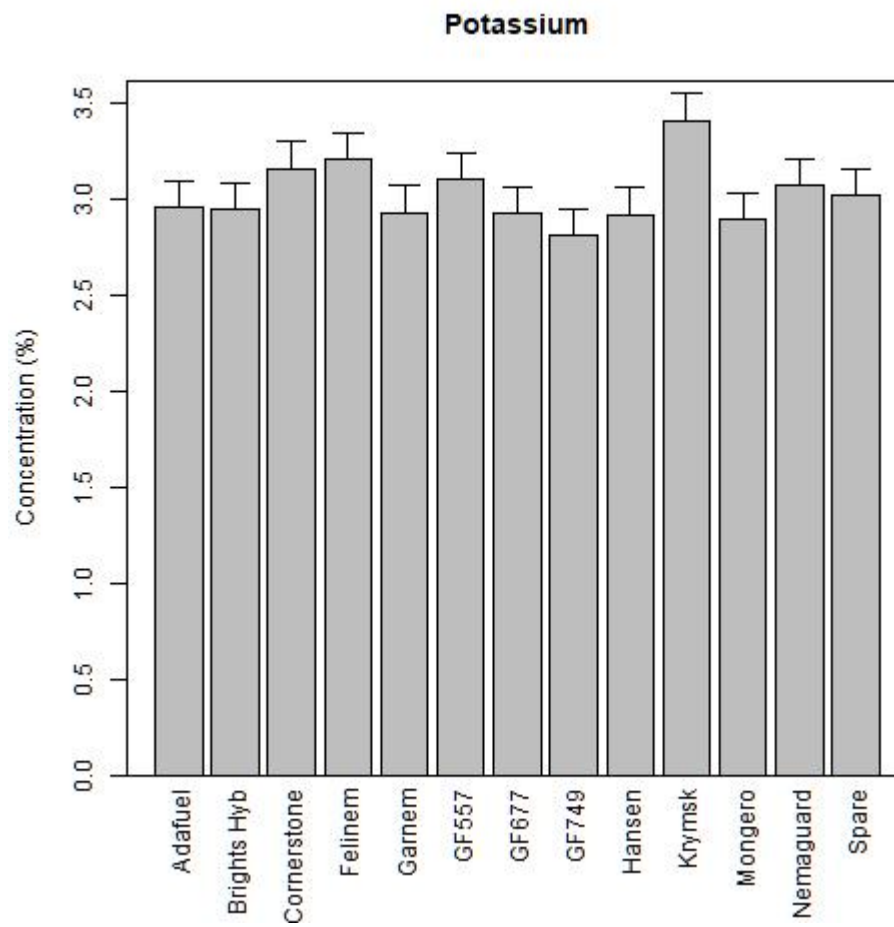


Figure 22. Comparison of petiole potassium between rootstocks. Error bars are standard errors.

4.4.5 Petiole Calcium

There were very high petiole calcium levels in Hansen (3.2%). The levels in that rootstock were consistently high with a maximum of 3.62%. There was also strong variation among the rootstocks. Hansen had the highest level of 0.59%. The two lowest levels were in the Nemaguard and 'Spare' and Krymsk rootstocks.

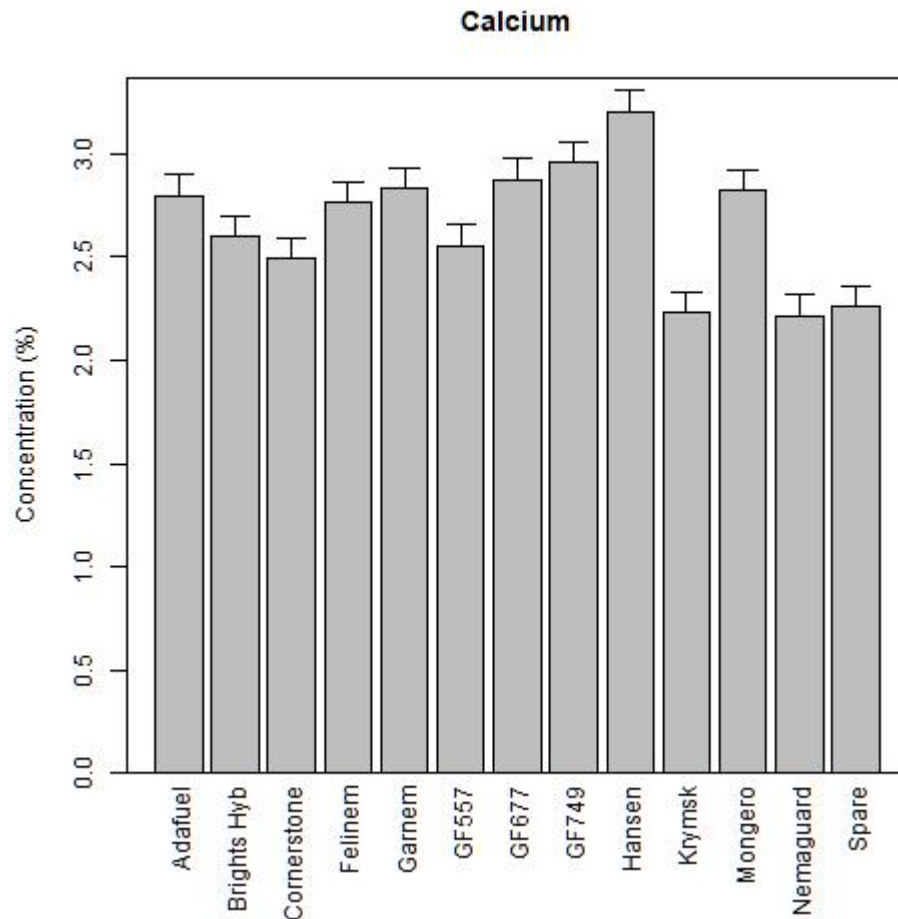


Figure 23. Comparison of petiole calcium between rootstocks. Error bars are standard errors.

4.4.6 Petiole Magnesium

Petiole magnesium levels followed a similar pattern to petiole calcium, with the highest level of 0.59% in Hansen and the two lowest in Nemaguard.

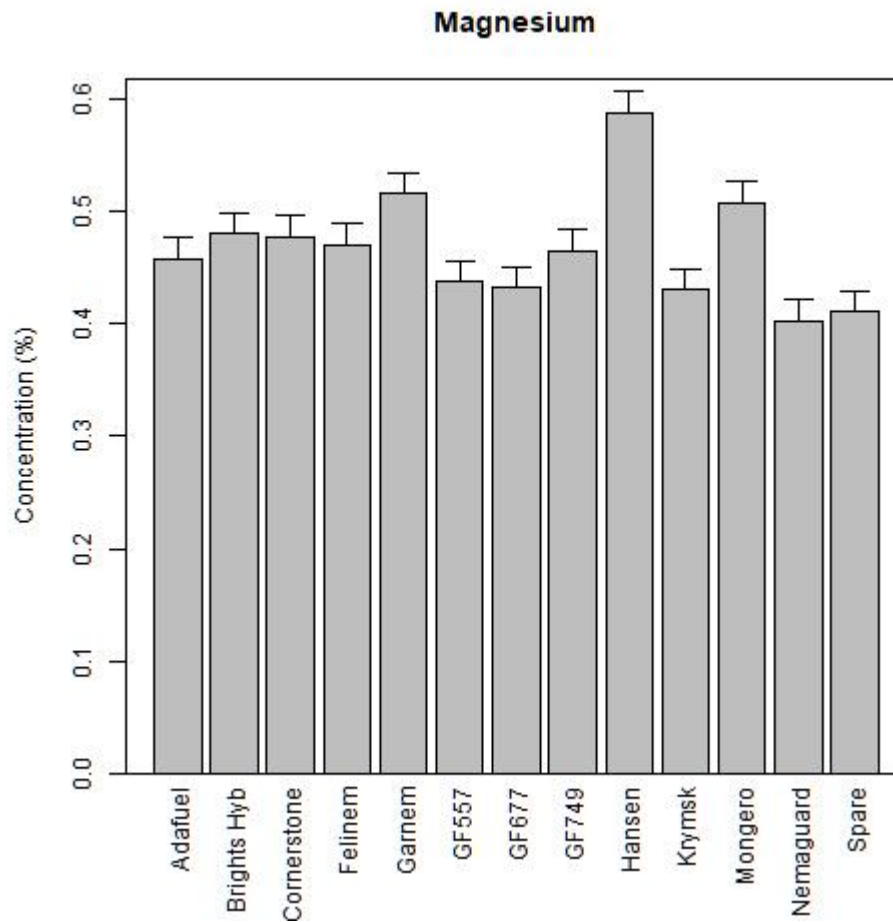


Figure 24. Comparison of petiole magnesium between rootstocks. Error bars are standard errors.

4.4.7 Petiole Sodium

There were significant differences of petiole sodium among the rootstocks with highest levels found in Krymsk, Nemaguard and 'spare'. This was similar to the pattern found for petiole potassium.

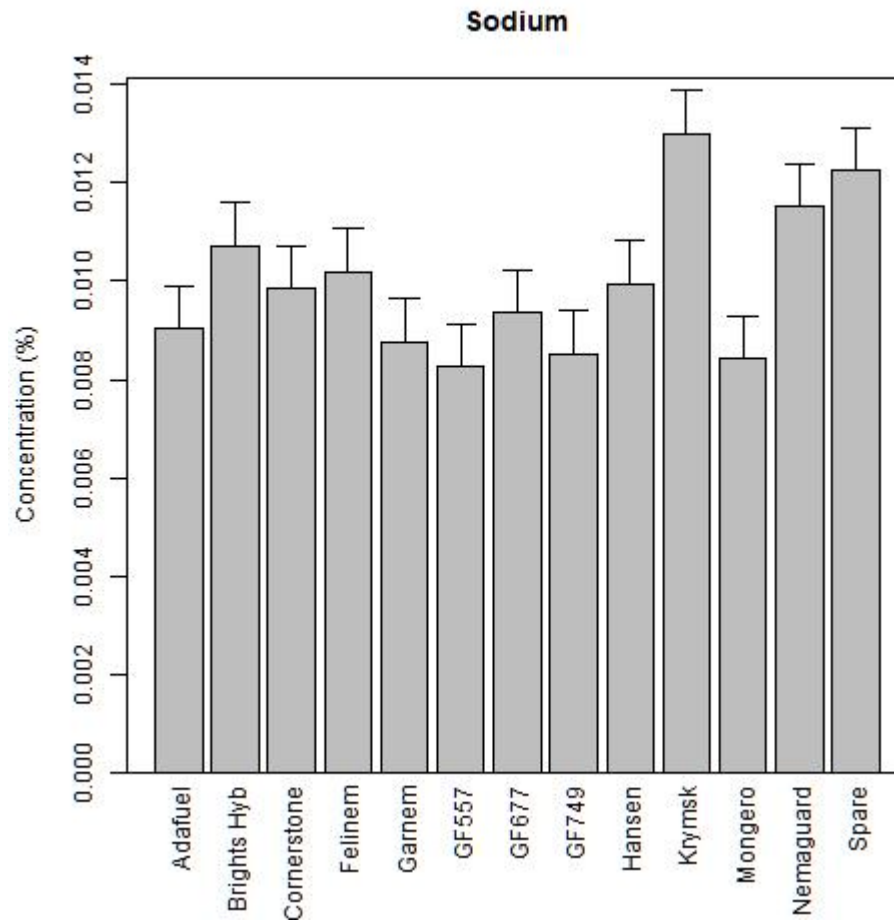


Figure 25. Comparison of petiole sodium between rootstocks. Error bars are standard errors.

4.4.8 Petiole Sulfur

There were significant differences in the petiole sulphur content from plants on the different rootstocks ($p < 0.01$). The variation is shown in the figure below.

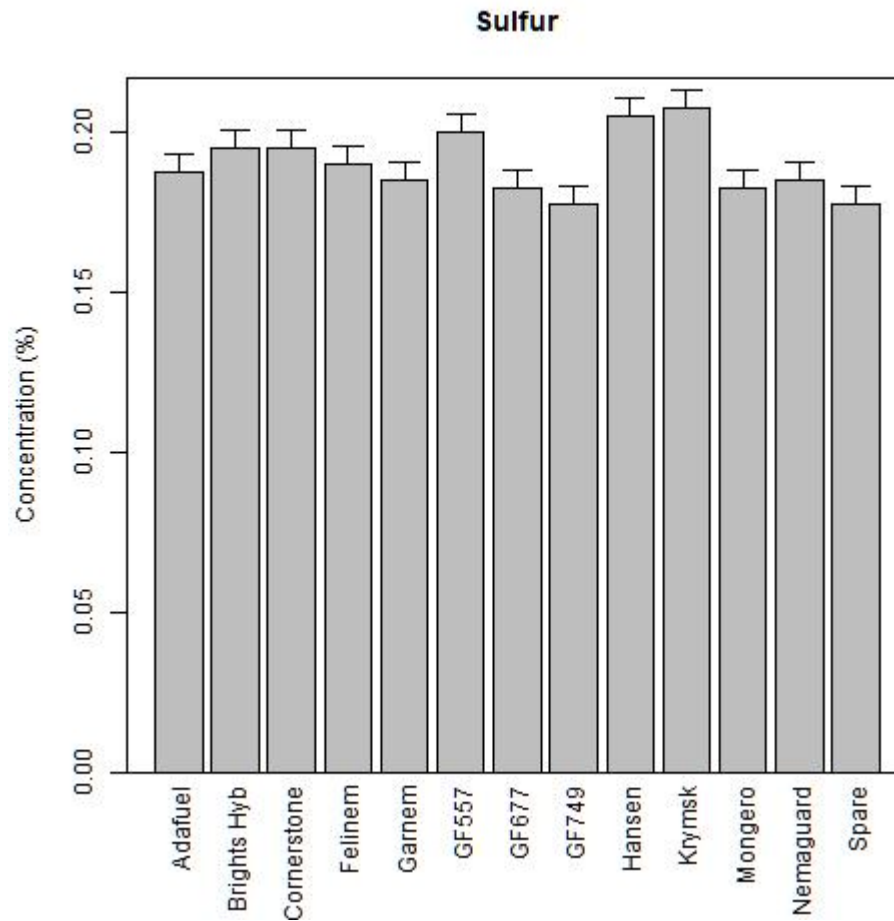


Figure 26. Comparison of petiole sulfur between rootstocks. Error bars are standard errors.

4.4.9 Petiole Boron

There were very significant ($p < 0.001$) differences of petiole boron among trees on the rootstocks. Krymsk had the highest level (355.25 mg/kg) followed by Hansen (32.2 mg/kg).

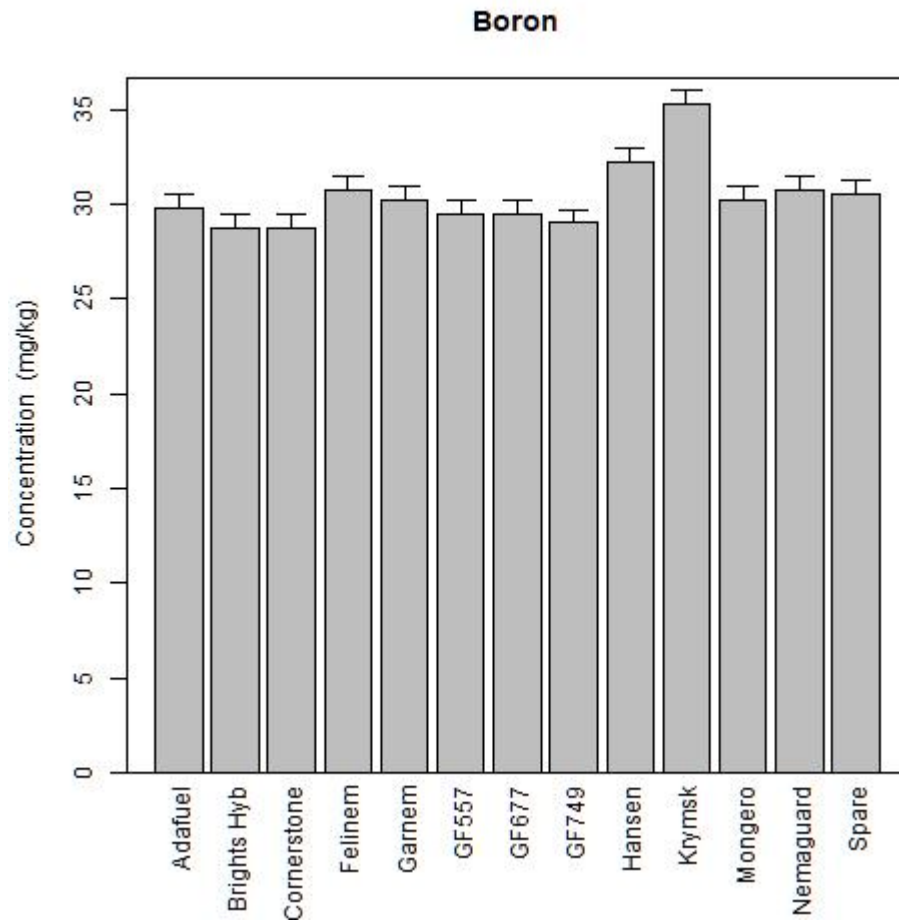


Figure 27. Comparison of petiole boron between rootstocks. Error bars are standard errors.

4.4.10 Petiole Copper

There was no significant difference between the petiole copper content from trees on different rootstocks.

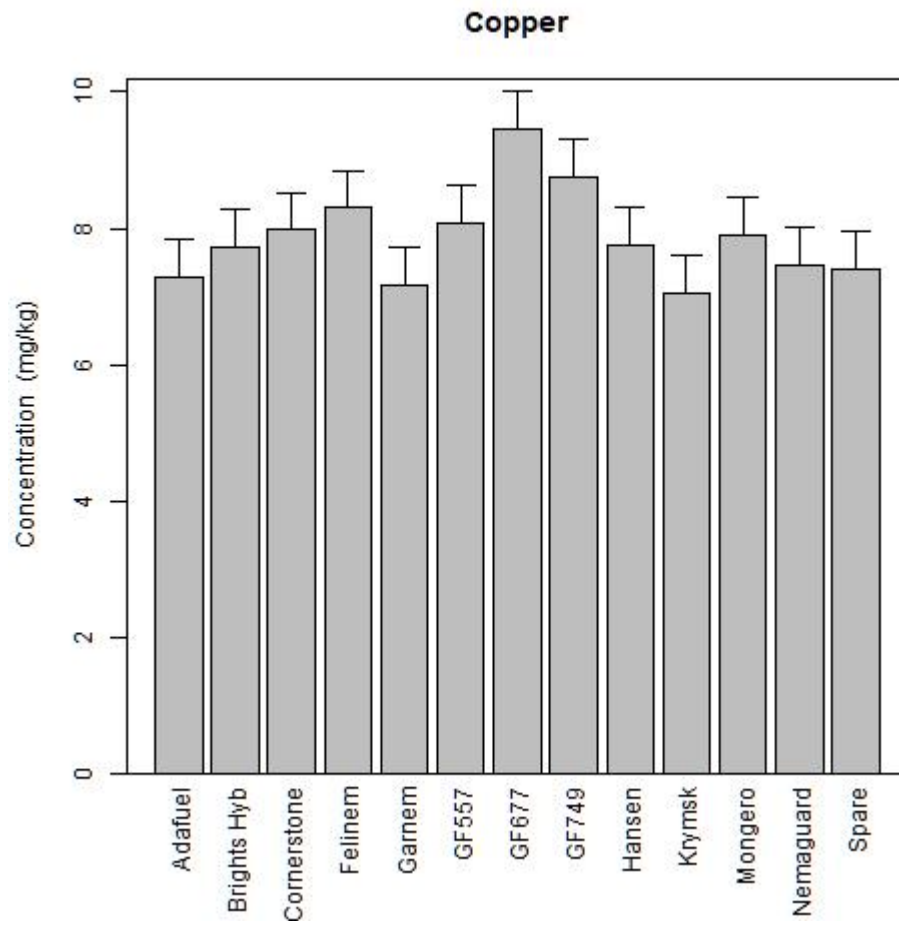


Figure 28. Comparison of petiole copper between rootstocks. Error bars are standard errors.

4.4.11 Petiole Zinc

There was no significant difference between the petiole zinc content from trees on different rootstocks.

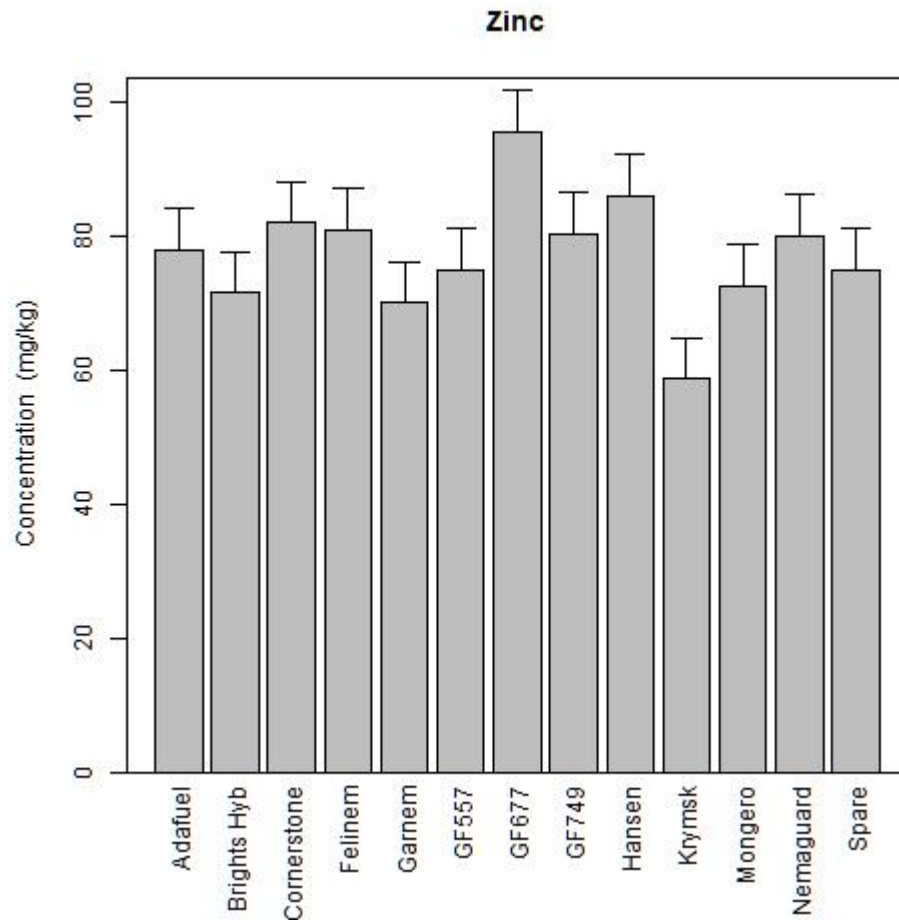


Figure 29. Comparison of petiole zinc between rootstocks. Error bars are standard errors.

4.4.12 Petiole Manganese

There were very significant differences between the petiole manganese concentration from the rootstocks. Hansen had the highest concentration (518 mg/kg) but in contrast to calcium and magnesium, Nemaguard levels were not elevated.

The levels in Kymnsk were low (303 mg/kg).

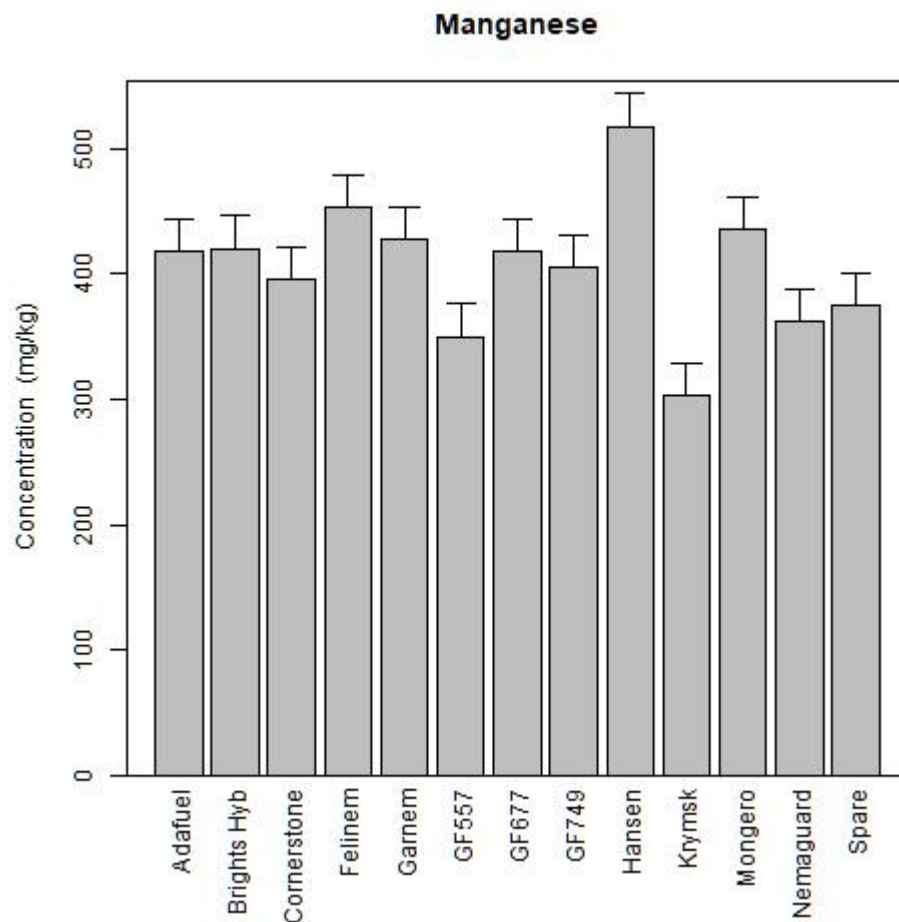


Figure 30. Comparison of petiole manganese between rootstocks. Error bars are standard errors.

4.4.13 Petiole Iron

There was no statistically significant effect of rootstock on the petiole iron concentrations.

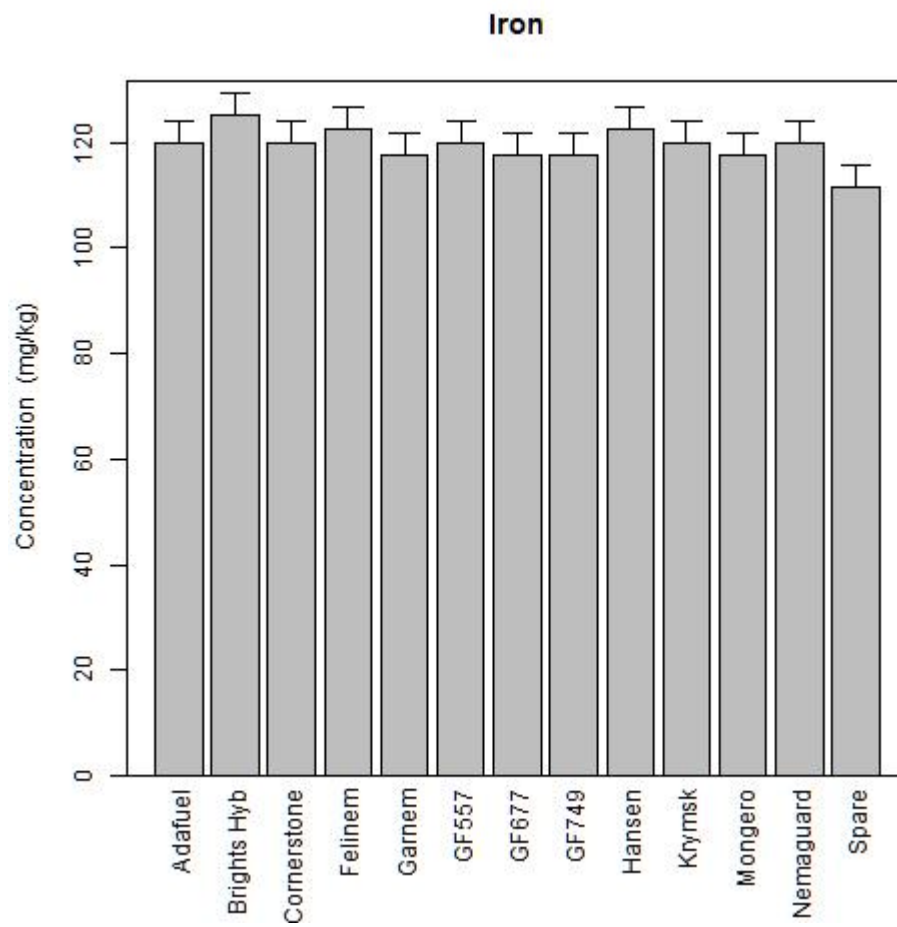


Figure 31. Comparison of petiole iron between rootstocks. Error bars are standard errors.

4.4.14 Petiole Aluminium

There was no statistically significant effect of rootstock on the petiole aluminium concentrations.

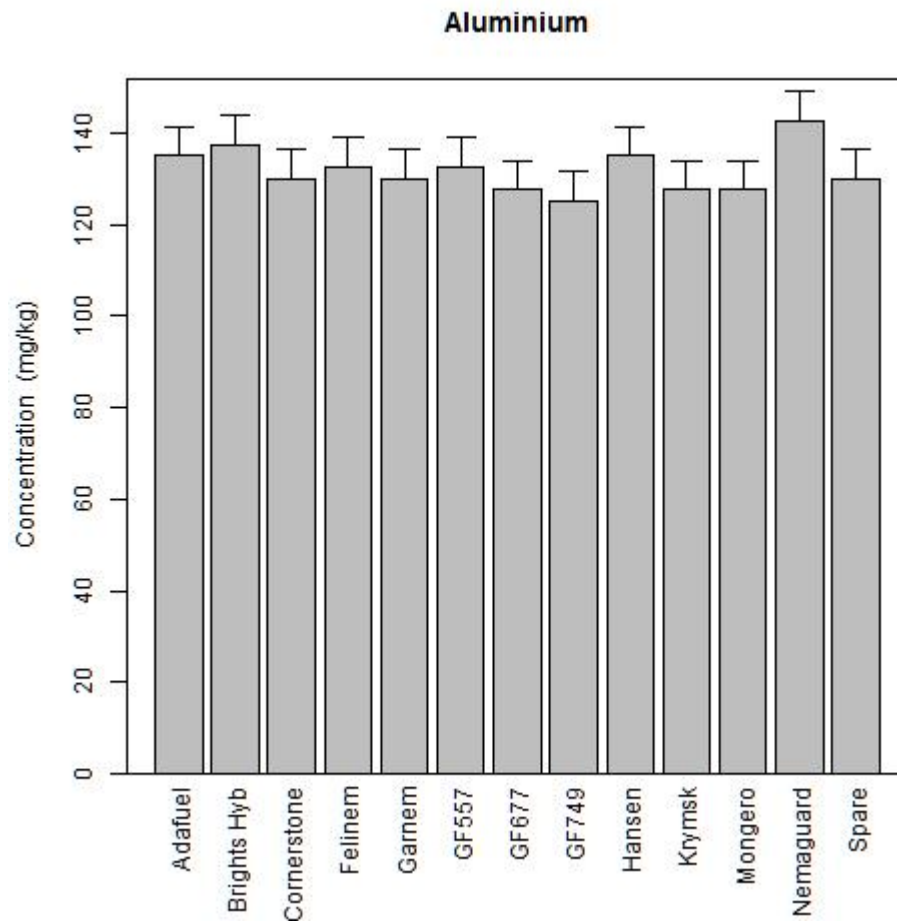


Figure 32. Comparison of petiole aluminium between rootstocks. Error bars are standard errors.

4.4.15 Petiole Molybdenum

There was a very significant effect of rootstock on the molybdenum levels. In particular, the concentration in Krymsk of 0.088 mg/kg was approximately double of that of any other rootstock. By contrast, GF557 had 0.030 mg/kg.

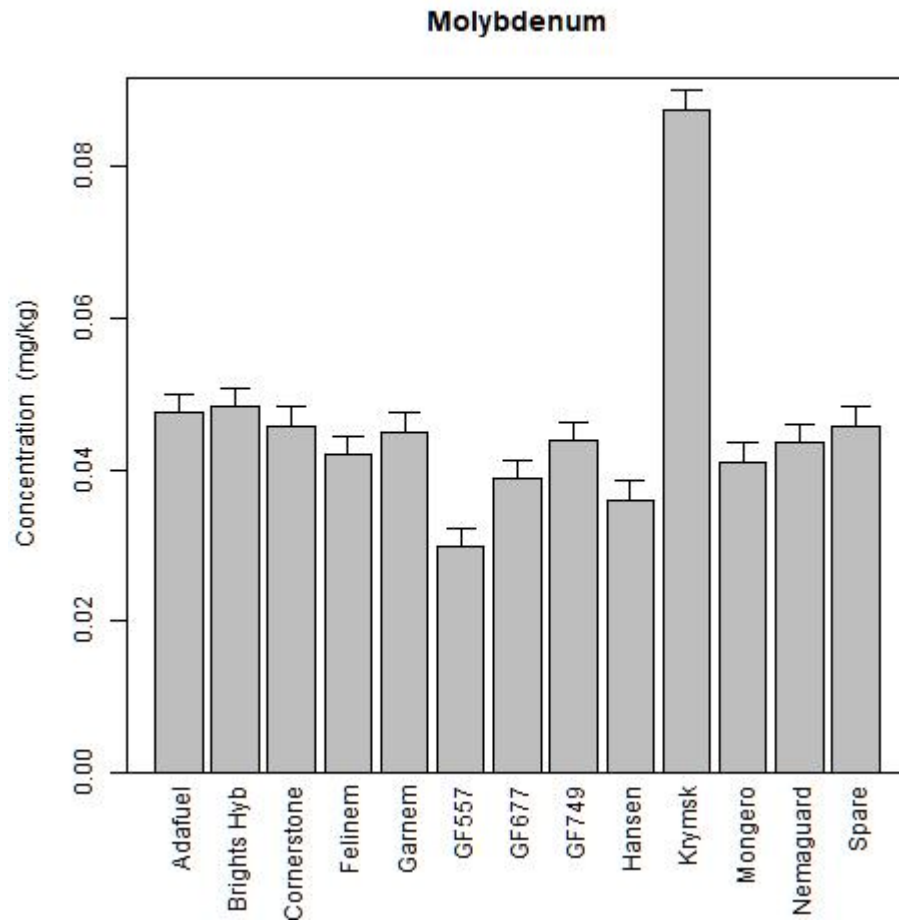


Figure 33. Comparison of petiole nitrate N between rootstocks. Error bars are standard errors.

4.4.16 Petiole Chloride

There were very high levels in chloride in Nemaguard and 'Spare' with an average value of 0.56%. The next highest levels was 0.40 % in Krymsk. The high levels noted were consistent across the four replicates. Those high levels did not appear to be matched with corresponding cations.

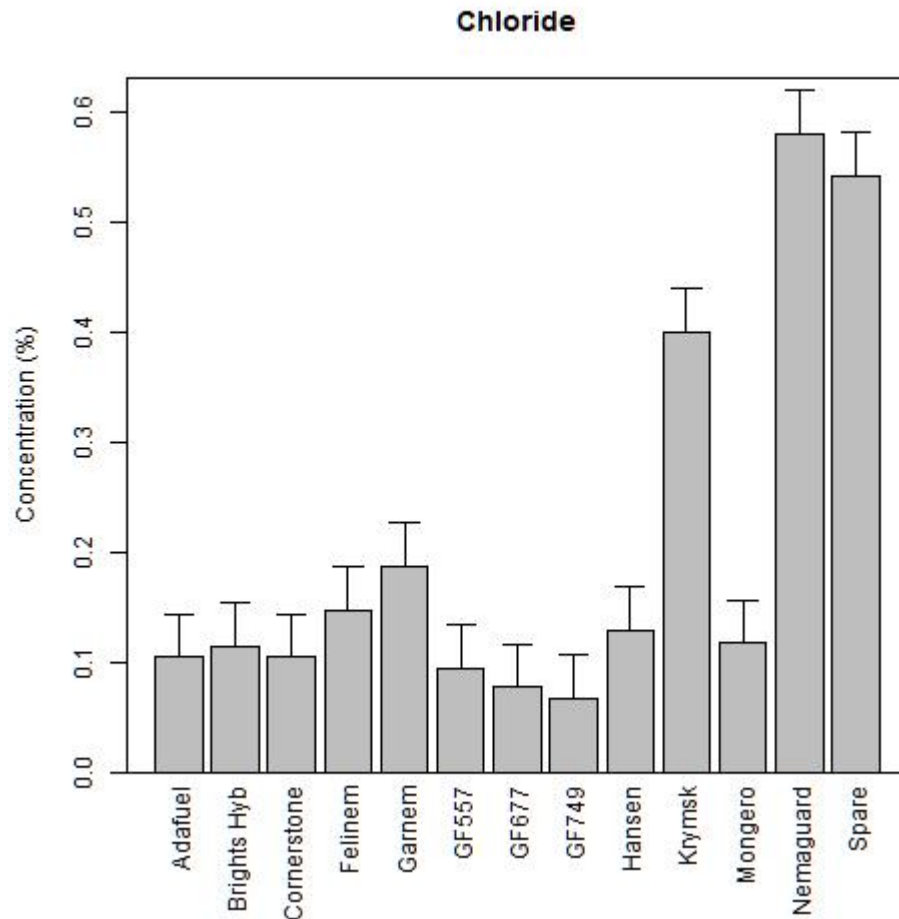


Figure 34. Comparison of petiole nitrate N between rootstocks. Error bars are standard errors.

4.5 Flowering

The distribution of flowering times for trees on each rootstock is shown in Figure 35. No formal statistics were available to assess the variability of those data.

The shortest flowering interval was 24 days for GF557 and the longest was Cornerstone (34 days).

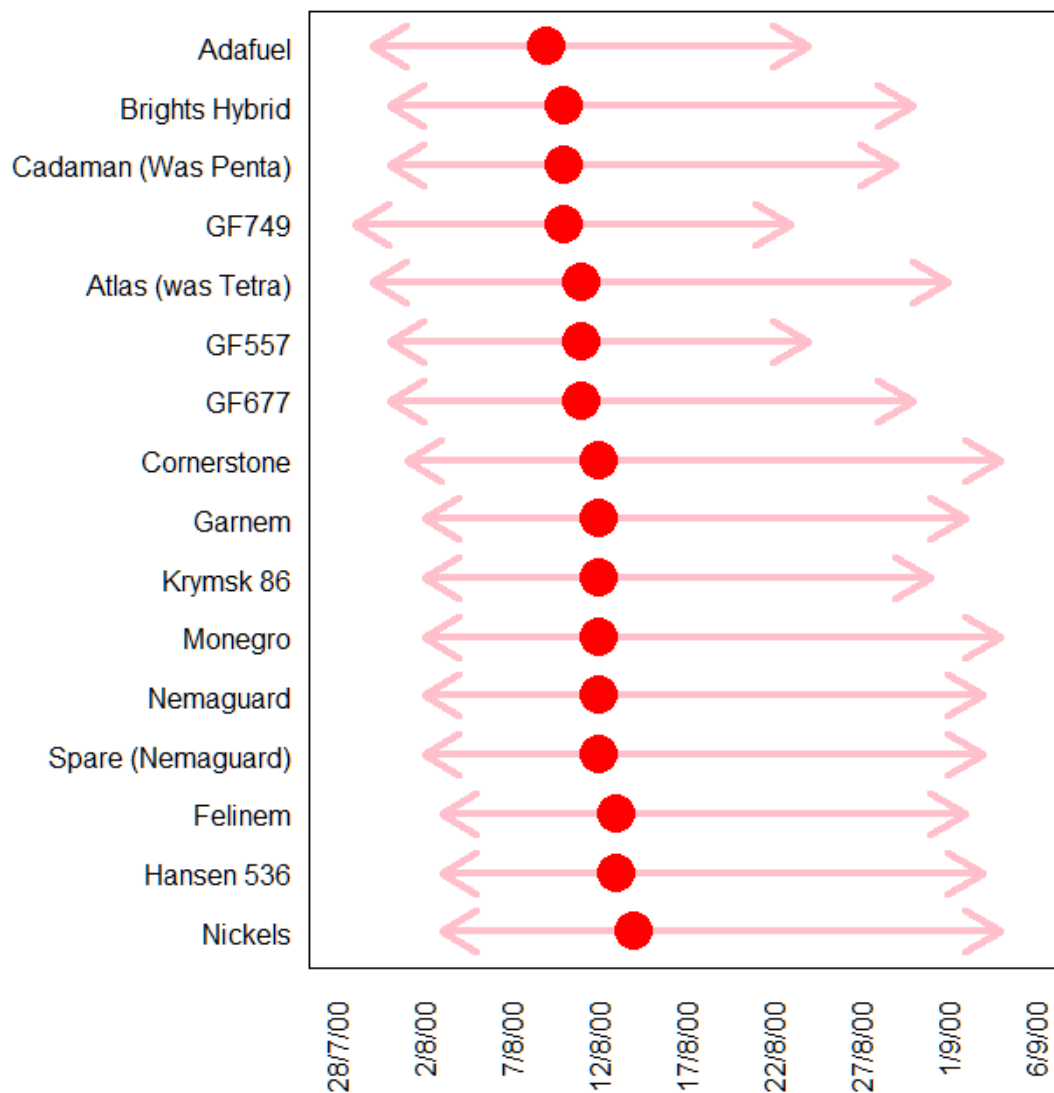


Figure 35. Distribution of flowering times of scion on each rootstock ranked in order of time of full blossom.

4.6 Yield

A summary of the yield data are given in Table 14.

Table 14. Yield results for each rootstock adjusted for row effects.

Rootstock	Kg/ 3 tree	Kg.ha kenrnels	Fruit100	Kernal100	Crackout
Adafuel	83.3	3440	475	148	32
Brights Hybrid	99.4	4120	455	149	33
Cornerstone	70.6	2850	525	151	29
Felinem	89.7	3110	486	148	31
Garnem	83.1	3160	473	146	31
GF557	64.7	2190	527	157	30
GF677	93.6	3480	468	151	32
GF749	84.2	3790	418	135	32
Hansen 536	90.8	3340	460	144	31
Krymsk 86	71.6	2240	526	149	28
Monegro	100.8	3700	427	138	32
Nemaguard	71.9	2330	538	155	29
Spare	76.2	2630	514	152	30
pval	0.027	0.049	0.013	0.118	0.030
se	7.9	424.0	24.6	5.0	1.0
LSD	22.7	1219	71	NA	2.9

4.6.1 Amount of yield

The yield data on a per tree basis are shown in Figure 36 and Figure 38. The differences between rootstocks were only marginally significant. The ranks of the two yield measures differed slightly the two variables. For example, the highest raw yield was 100.8 kg/per plot of 3 trees by the highest per ha kernel yield was 4120 kg/ha for Brights Hybrid. G557 had the lowest rank for both yield per tree and kernel yield per ha.

Differenced between rows were estimated using a cubic polynomial. A randomised block analysis lacked the precision to show statistically significant differences between the yields for the rootstocks.

Table 15. Change in yield from each rootstock at each harvest year.

Rootstock	2016	2017	2018	2019	2020	2021
Adafuel	250	1110	2160	2580	3360	3440
Brights Hybrid	470	1190	1890	2690	3660	4120
Cornerstone	60	1120	1970	3160	3120	2850
Felinem	460	1120	1920	4150	4060	3110
Garnem	400	1290	1930	3880	4110	3160
GF557	390	820	1820	3140	3030	2190
GF677	560	1000	1780	3960	2920	3480
GF749	460	1120	1910	4420	3680	3790
Hansen 536	370	1080	1930	3650	3920	3340
Krymsk 86	440	700	1360	2310	2560	2240
Monegro	500	1290	1990	4500	3200	3700
Nemaguard	510	730	1850	2860	3590	2330
Spare (Nemaguard)	490	870	2100	3590	3240	2630
p value	0.017	0.001	0.569	0.084	0.041	0.049
SE	70	100	220	490	390	410
LSD (Fisher's protected)	142	203	NA	NA	793	834

Table 16. Ranking of rootstocks by kernel yield. Rootstocks sharing a common letter do not differ by Fisher's protected LSD. Means were corrected for row effects.

Rootstock	Kg/ha	Letter
GF557	2190	a
Krymsk 86	2240	ab
Nemaguard	2330	ab
Spare	2630	abc
Cornerstone	2850	abc
Felinem	3110	abcd
Garnem	3160	abcd
Hansen 536	3340	bcd
Adafuel	3440	bcd
GF677	3480	cd
Monegro	3700	cd
GF749	3790	cd
Brights Hybrid	4120	d

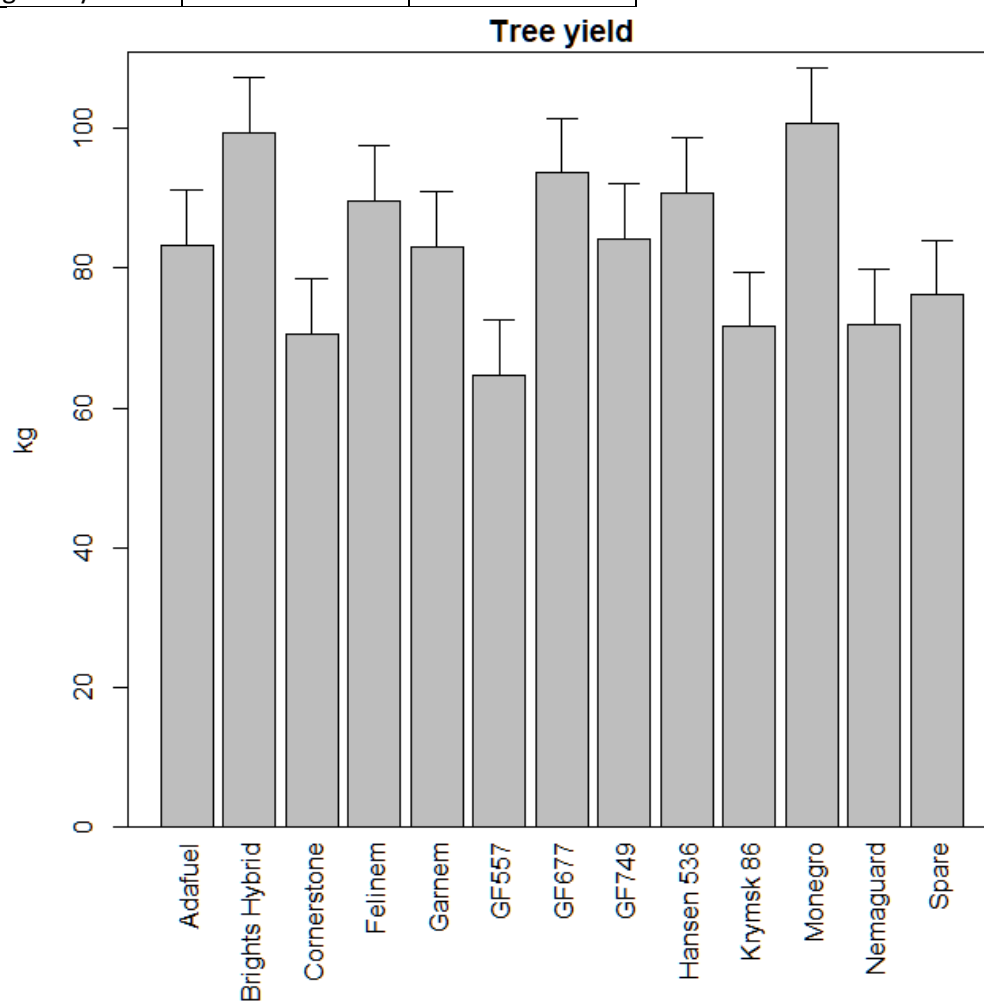


Figure 36. Comparison of gross yield per tree for each rootstock.

Data were also available for the accumulative yield expressed as kg/ha. Those data are of more relevance to growers as they averaged out much of the seasonal variation and therefore reflect. The accumulated totals were based on 2016 – 2012 harvest. The derived running average yield may have been underestimated by that calculation as it would appear that the trees came to maturity in 2019.

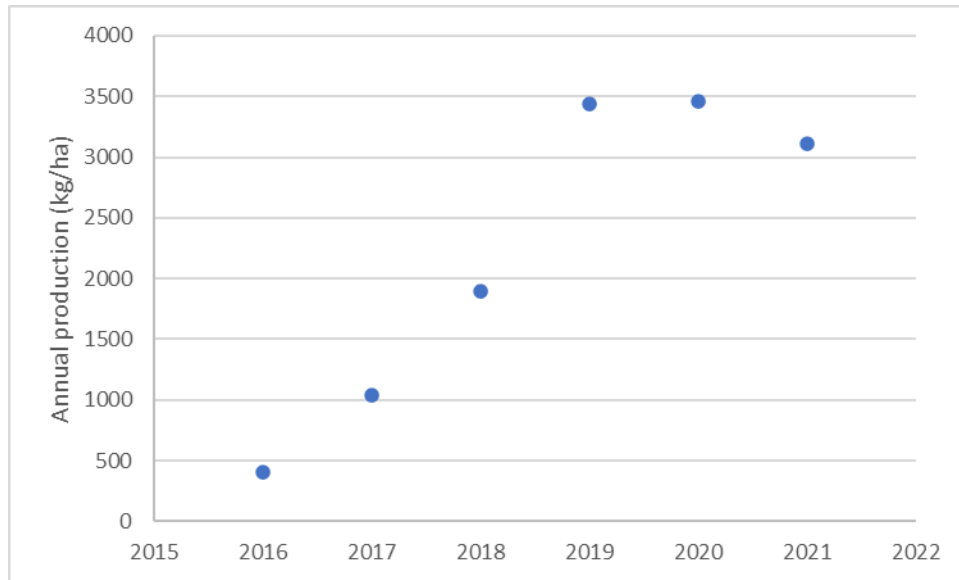


Figure 37. Annual production across years.

Table 17. Ranking of cumulative yield (kg/ha) of each variety.

Variety	Cumulative Yield	Running average yield	Fisher Letter	HSD Letter
Krymsk 86	9204	1534		a
Nemaguard Spare	11738	1956	a	ab
GF557	11886	1981	ab	abc
Cornerstone	11987	1998	abc	abc
Adafuel	12588	2098	abcd	abc
Nemaguard	13243	2207	abcde	abc
Brights Hybrid	13519	2253	abcdef	bc
GF677	14089	2348	bcdef	bc
Hansen 536	14276	2379	cdef	bc
Garnem	14877	2479	def	bc
Felinem	15169	2528	ef	bc
Monegro	15369	2562	ef	bc
GF749	15597	2600	f	c
SED	1147	191		
LSD	2321	387		

Note: Varieties sharing the same letter do not differ significantly. Fisher letters are based Fisher's protected LSD and HSD are based on Tukey's Honest Significant Difference.

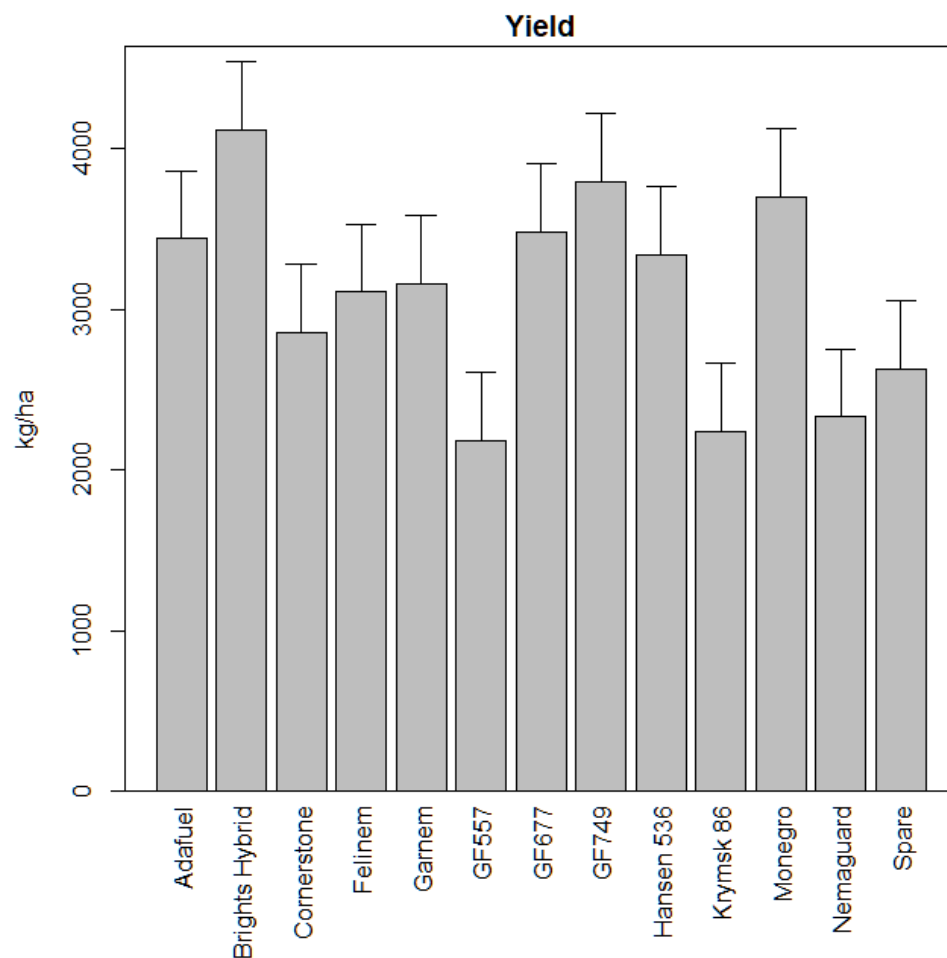


Figure 38. Comparison of kernel yield per hectare for each rootstock.

4.6.2 Fruit quality

There were significant differences among the 100 fruit weights but not between the kernel weights. This was because there was a significant difference in the crack-out % between rootstocks. The distributions of fruit weight, kernel weight and crack-out percent is shown in Figure 39 to Figure 41.

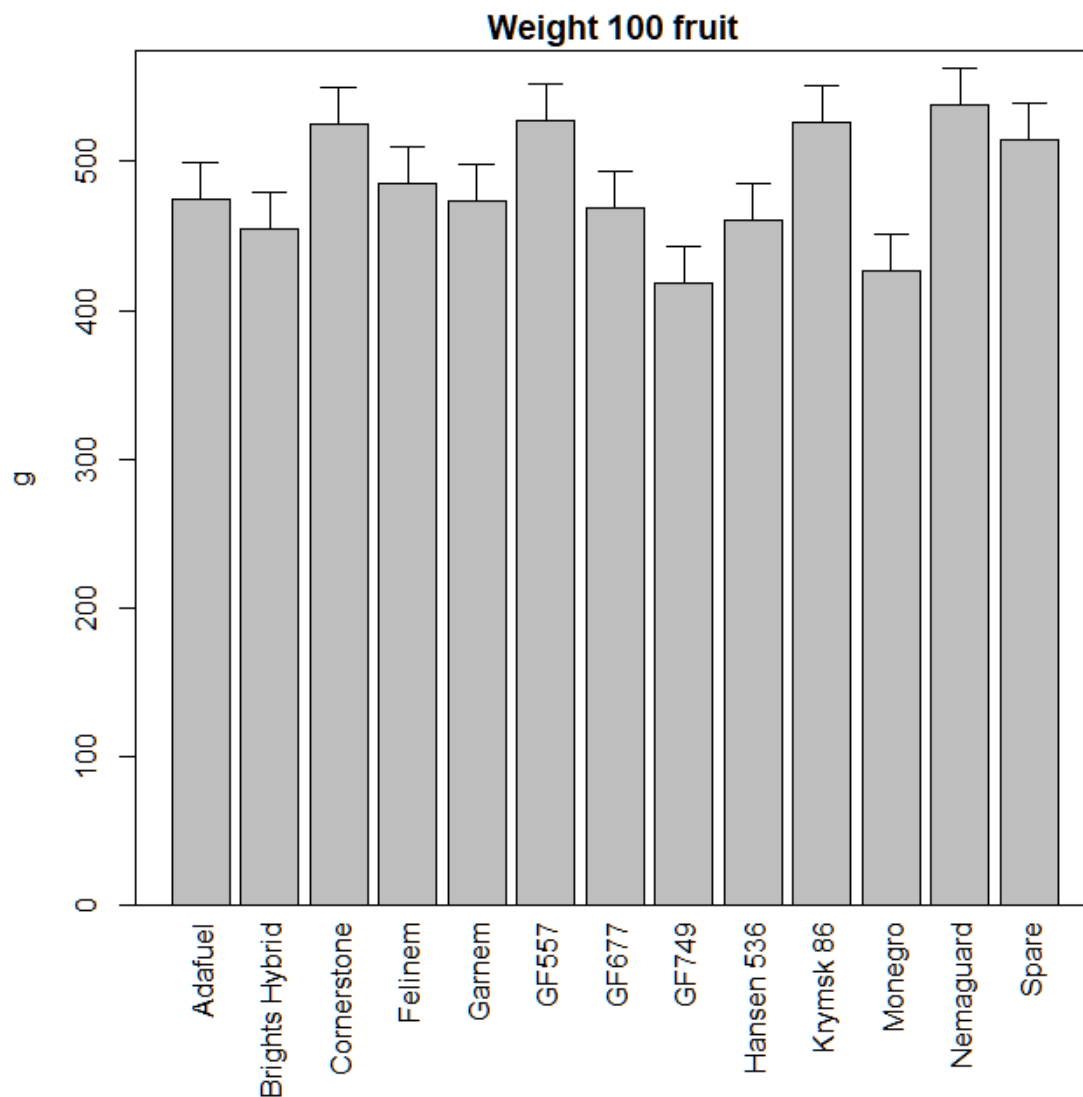


Figure 39. Distribution of 100 fruit weights.

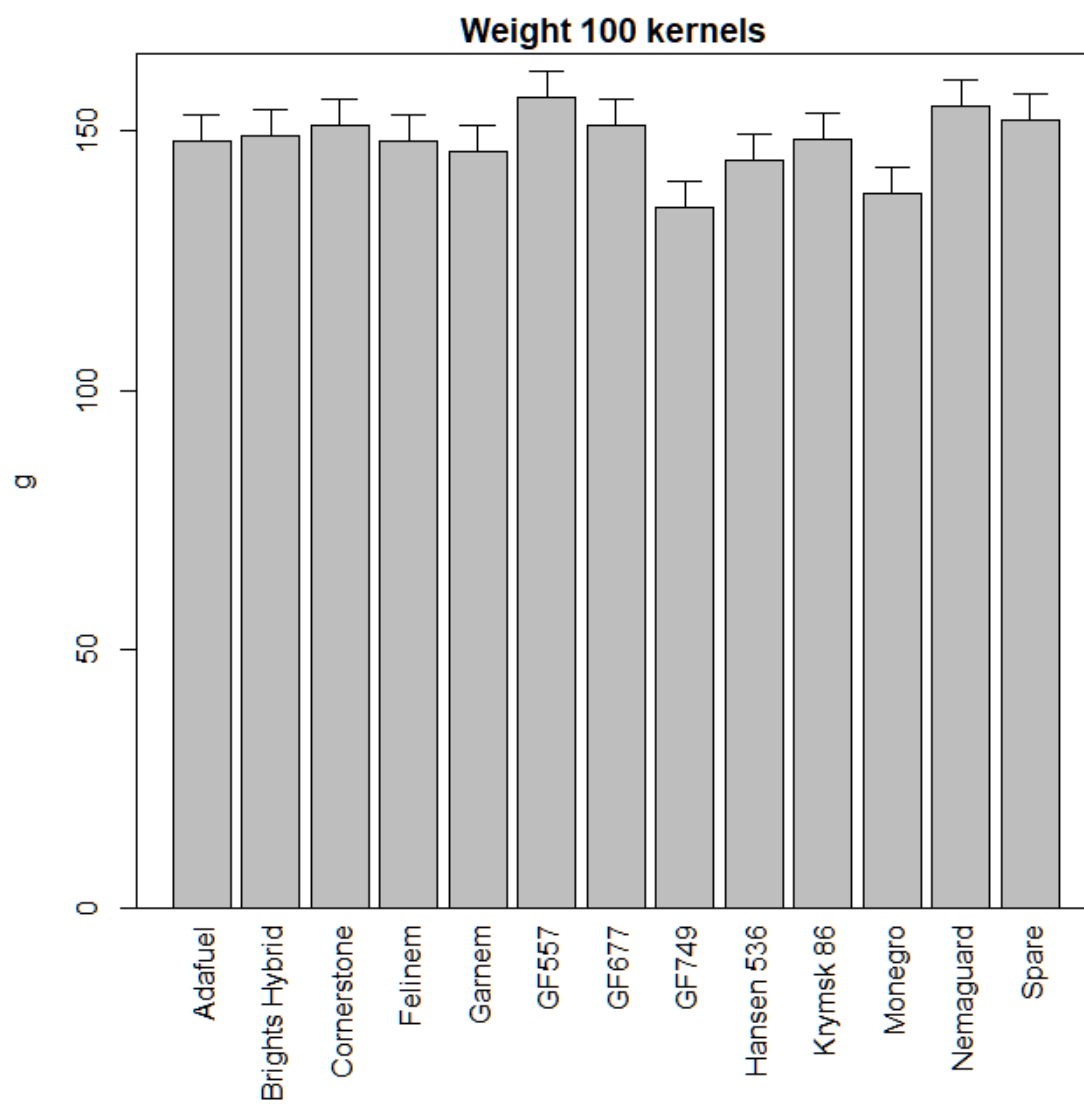


Figure 40. Distribution of 100 kernel weights using different rootstocks.

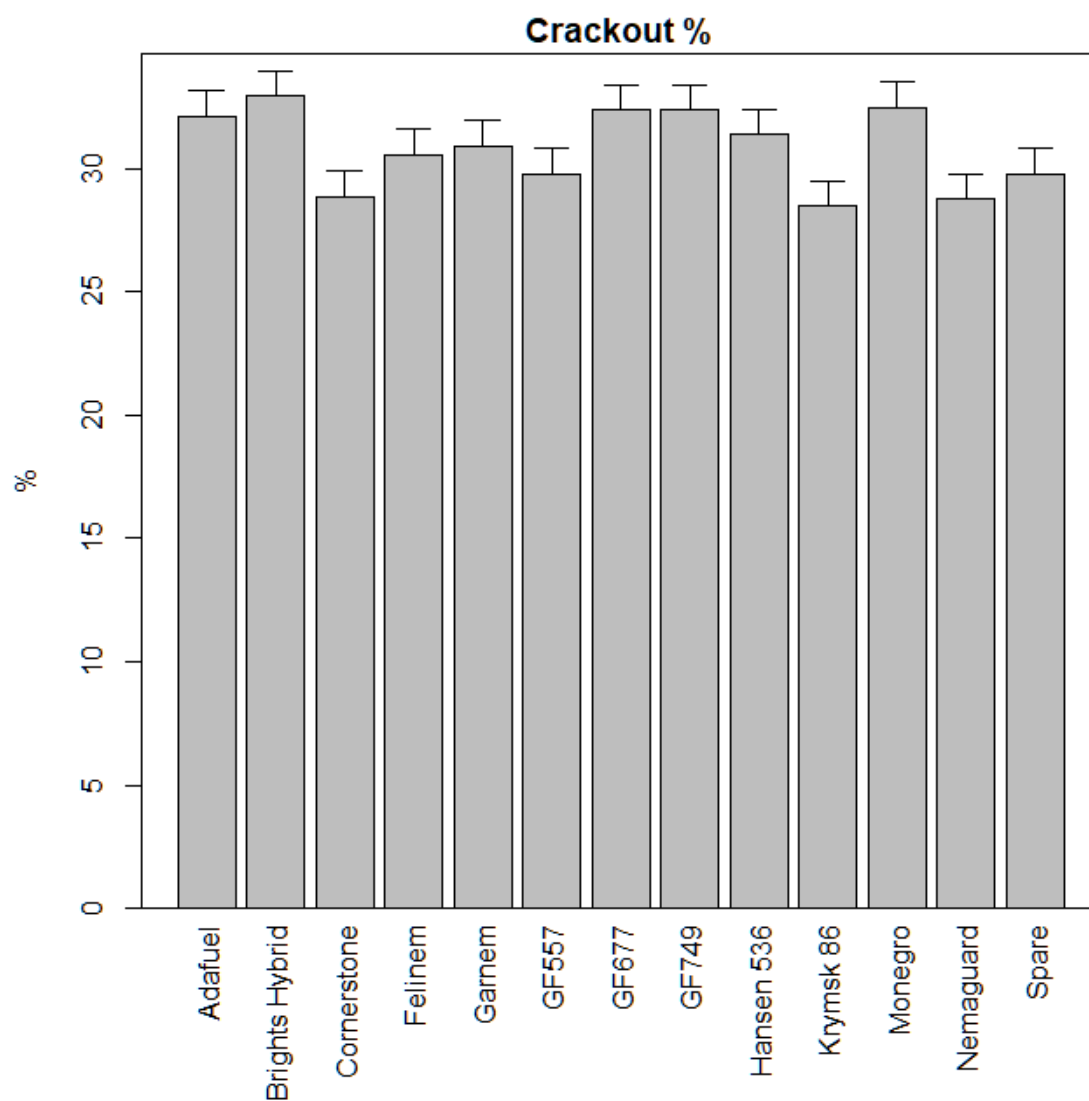


Figure 41. Distribution of crack-out % using different rootstocks.

4.6.3 Kernel weight

The statistical significance of the effect of rootstock on kernel weight was 0.049, so just less than the accepted 0.05 level. The rootstocks have been ranked in

Rootstock	2016	2017	2018	2019	2020	2021
Adafuel	250	1110	2160	2580	3360	3440
Brights Hybrid	470	1190	1890	2690	3660	4120
Cornerstone	60	1120	1970	3160	3120	2850
Felinem	460	1120	1920	4150	4060	3110
Garnem	400	1290	1930	3880	4110	3160
GF557	390	820	1820	3140	3030	2190
GF677	560	1000	1780	3960	2920	3480
GF749	460	1120	1910	4420	3680	3790
Hansen 536	370	1080	1930	3650	3920	3340
Krymsk 86	440	700	1360	2310	2560	2240
Monegro	500	1290	1990	4500	3200	3700
Nemaguard	510	730	1850	2860	3590	2330
Spare (Nemaguard)	490	870	2100	3590	3240	2630
p value	0.017	0.001	0.569	0.084	0.041	0.049
SE	70	100	220	490	390	410
LSD (Fisher's protected)	142	203	NA	NA	793	834

Table 16 and differences shown using the Fisher's protected LSD of 1216 kg/ha. The more stringent Tukey HSD was 2164 kg/ha. By Tukey's criterion, no difference was statistically significant.

4.7 Splitting of husks

Husk splitting data (stages 1 to 6) were recorded on 11 and 18 January and 1 and 18 of February.

The splitting stage of 100 fruits was assessed on a scale of 1 to 6. The number of fruits at a given stage was used as weights for a weighted average.

$$average = \frac{\sum_{i=1 \text{ to } 6} i \times n_i}{100}$$

where n_i is the number of fruits in the i^{th} stage.

A simpler measure of the degree of splitting that was provided was the number of fruits that had reached at least stage 3.

Another measure that was used was the standard deviation (sd) of the stage. This is a measure of the spread of the stages. A uniform measure of the stage would have a low spread (low sd). A limitation to this approach is that initially all fruits are at stage 1 a (hence zero sd) and finally all will be at stage 6 (again with sd = 0). The measure of spread is only useful during the maturing stages.

Data supplied for this report were from 4 times of observation, whereas in fact observations were reported from 7 times in SARDI (2021). From their graph it was apparent

4.7.1 Average stage of splitting

The percent of fruits at Stage 3 and Stage 6 of splitting is shown in Table 18 and Table 19. The average stage of splitting is shown in Table 20. The greatest difference between varieties was found in 1 February data. Krymsk 86 was the most advanced but there was no significance difference between most pairs.

Table 18. Average percent of fruits split to Stage 3 at each assessment date.

	4-Jan	11-Jan	18-Jan	25-Jan	1-Feb	8-Feb	18-Feb
Adafuel	7	20.25	44	96.25	100	100	100
Brights Hybrid	0.25	4	24.5	52.5	99	100	100
Cornerstone	1.75	30.25	73.75	100	100	99.5	100
Felinem	1	8.5	49.75	95.25	100	100	100
Garnem	0	25	62.5	97.25	100	99.75	100
GF557	0.25	12.5	56.5	94.75	100	100	100
GF677	3.5	27.25	53.5	94.75	99.25	100	100
GF749	0.5	6.5	30	99.5	99.5	100	100
Hansen 536	0.25	7	45.75	99.5	100	100	100
Krymsk 86	0.75	25.75	97.75	100	100	100	100
Monegro	0	5.5	23.25	98	100	100	100
Nemaguard	3.25	34.5	69.5	100	100	100	100
Spare Nemaguard	2.5	16.25	67.25	100	100	100	100
p value	0.590	0.130	0.002	<0.001	0.638	0.544	1.000

Table 19. Average percent of fruits split to Stage 6 at each assessment date.

	4-Jan	11-Jan	18-Jan	25-Jan	1-Feb	8-Feb	18-Feb
Adafuel	0	1.25	0	3.25	16.25	68.25	95.75
Brights Hybrid	0	0	0.25	0	3	47	90.5
Cornerstone	0	0	0.25	1	33.5	56	96.5
Felinem	0	0	0	2.25	26.75	74.25	95.5
Garnem	0	0	1	1	29.25	54.25	97.75
GF557	0	0	0	4.25	25.25	43.25	97.75
GF677	0	0	0.25	0	1.5	46.75	96.5
GF749	0	0	0	0	3.5	52.5	97.25
Hansen 536	0	0	0	0	19.75	41.5	96.5
Krymsk 86	0	0	0	0.5	42.75	51.25	98.25
Monegro	0	0	0	9.75	6.5	57.75	96.25
Nemaguard	0	0.25	0	2.25	13.5	28.75	91.75
Spare Nemaguard	0	0	0	0.75	10.25	59.25	96.25
p value	1.000	0.504	0.618	0.635	0.214	0.613	0.063

Table 20 Average splitting stages for each rootstock ordered by 1-Feb data

Rootstock	11-Jan	18-Jan	1-Feb	Letter	8-Feb	18-Feb
GF677	2.30	3.05	4.30	a	5.46	5.97
Brights Hybrid	1.68	2.30	4.32	a	5.47	5.91
GF749	1.88	2.32	4.63	ab	5.52	5.97
Monegro	1.65	2.27	4.70	ab	5.57	5.96
Felinem	1.94	2.69	4.86	ab	5.74	5.96
Adafuel	2.14	2.71	4.88	ab	5.07	5.96
GF557	2.08	2.71	4.97	ab	5.39	5.98
Nemaguard	2.43	3.13	4.99	ab	5.23	5.92
Spare Nemaguard	2.03	3.20	4.99	ab	5.59	5.96
Hansen 536	1.88	2.65	5.00	ab	5.41	5.97
Garnem	2.06	3.06	5.16	ab	5.50	5.98
Cornerstone	2.28	3.07	5.30	ab	5.47	5.97
Krymsk 86	2.16	3.80	5.42	b	5.50	5.98
pval	0.410	0.012	0.003	NA	0.132	0.063
se	0.45	0.53	0.37	NA	0.150	0.033

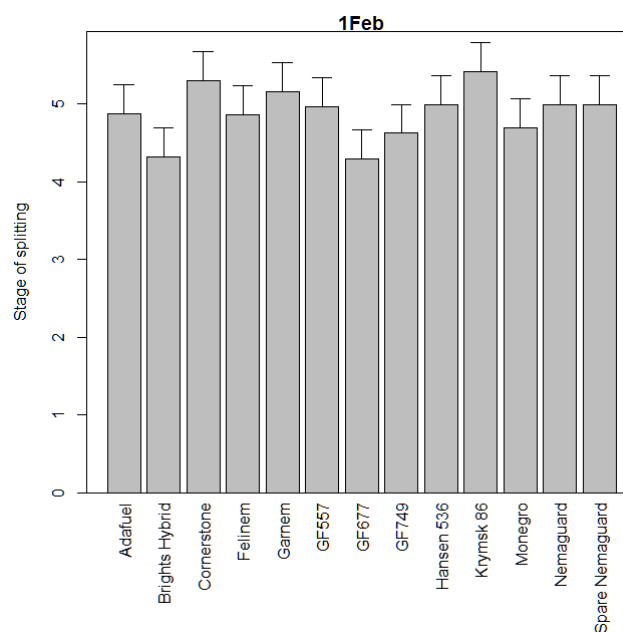


Figure 42. Distribution of stages of splitting across rootstocks. Error bars are averages standard errors.

4.7.2 Percent of splitting to at least Stage 3

The proportion of nuts at Stage 3 or more is shown in Table 21. For Krymsk 86, there were 97.75% split (391/400). Because of the high proportion, the approximation to normality is not tenable. Use of a generalised linear model did not give better separation of the varieties. For Krymsk 86, the confidence limits of the percent split were 96 – 99%. By 1 Feb effectively all the fruits were split to stage 3.

Table 21. Percent of nuts that showed splitting to at least Stage 3.

	4-Jan	11-Jan	18-Jan	25-Jan	1-Feb	8-Feb	18-Feb
Adafuel	7	20.25	44	96.25	100	100	100
Brights Hybrid	0.25	4	24.5	52.5	99	100	100
Cornerstone	1.75	30.25	73.75	100	100	99.5	100
Felinem	1	8.5	49.75	95.25	100	100	100
Garnem	0	25	62.5	97.25	100	99.75	100
GF557	0.25	12.5	56.5	94.75	100	100	100
GF677	3.5	27.25	53.5	94.75	99.25	100	100
GF749	0.5	6.5	30	99.5	99.5	100	100
Hansen 536	0.25	7	45.75	99.5	100	100	100
Krymsk 86	0.75	25.75	97.75	100	100	100	100
Monegro	0	5.5	23.25	98	100	100	100
Nemaguard	3.25	34.5	69.5	100	100	100	100
Spare Nemaguard	2.5	16.25	67.25	100	100	100	100
p value	0.590	0.130	0.002	<0.001	0.638	0.544	1.000

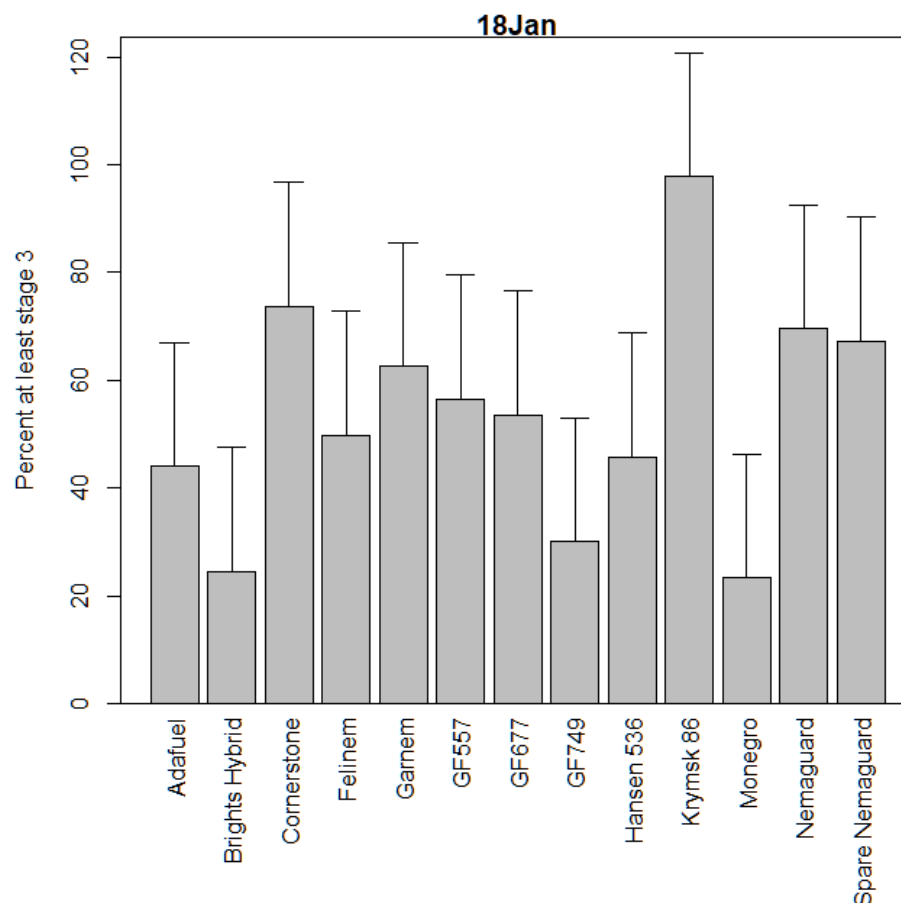


Figure 43. Distribution of stages of percent of husks at least stage 3 across rootstocks. Error bars are averages standard errors.

Box plot, Early v yield, Early v damage Yield 21

4.7.3 Percent of splitting to at least Stage 6

By 1 Feb effectively the maximum percent split was 43% in Krysk, but by 8 February the highest was 68% in Adafuel, with Krymsk 51%.

The proportion of nuts at Stage 6 or more is shown in Table 21. For Krymsk 86 at 18 February, there were 98.25% split (393/400) by 18 January (confidence limits 96 – 99% after rounding). Use of a generalised linear model did not give better separation of the varieties. For Krymsk 86, the confidence limits of the percent split were 96 – 99%. By 1 Feb effectively all the fruits were split to stage 3.

There was no significant difference between the rootstocks for number of fruits achieving Stage 6 split.

Table 22. Percent of nuts that showed splitting to at least Stage 6.

	4-Jan	11-Jan	18-Jan	25-Jan	1-Feb	8-Feb	18-Feb
Adafuel	0	1.25	0	3.25	16.25	68.25	95.75
Brights Hybrid	0	0	0.25	0	3	47	90.5
Cornerstone	0	0	0.25	1	33.5	56	96.5
Felinem	0	0	0	2.25	26.75	74.25	95.5
Garnem	0	0	1	1	29.25	54.25	97.75
GF557	0	0	0	4.25	25.25	43.25	97.75
GF677	0	0	0.25	0	1.5	46.75	96.5
GF749	0	0	0	0	3.5	52.5	97.25
Hansen 536	0	0	0	0	19.75	41.5	96.5
Krymsk 86	0	0	0	0.5	42.75	51.25	98.25
Monegro	0	0	0	9.75	6.5	57.75	96.25
Nemaguard	0	0.25	0	2.25	13.5	28.75	91.75
Spare Nemaguard	0	0	0	0.75	10.25	59.25	96.25
p value	1.000	0.504	0.618	0.635	0.214	0.613	0.063

4.7.4 Variability of stages

The variability of splitting at any stage was computed as the standard deviation of the stages based on the 100 nut examined at that time of assessment. The relationship between the ripening stage and variability has to be considered when assessing variability.

On 18 Jan data, Krymsk 86 stands out – partly because it is more advanced and partly because it had less variability at that stage (Figure 45). By 1 Feb, it is noted that Nemaguard and ‘Spare’ had lower variability than other varieties at the same stage of maturity.

Table 23. Variability of stage of splitting ordered by 18 Jan data.

Rootstock	11-Jan	18-Jan	Letter	1-Feb	18-Feb
Monegro	0.461	0.470	a	0.607	0.181
GF749	0.491	0.567	a	0.686	0.139
Brights Hybrid	0.498	0.589	a	0.832	0.287
GF677	0.624	0.701	ab	0.678	0.121
GF557	0.402	0.708	ab	0.608	0.145
Hansen 536	0.569	0.729	ab	0.559	0.182
Krymsk 86	0.608	0.747	ab	0.466	0.064
Adafuel	0.719	0.762	ab	0.677	0.198
Cornerstone	0.536	0.765	ab	0.497	0.177
Felinem	0.439	0.798	ab	0.640	0.165
Garnem	0.648	0.802	ab	0.454	0.129
Spare Nemaguard	0.702	0.932	ab	0.446	0.160
Nemaguard	0.848	0.974	b	0.464	0.272
pval	0.026	0.020		0.089	0.130
se	0.168	0.177		0.176	0.093

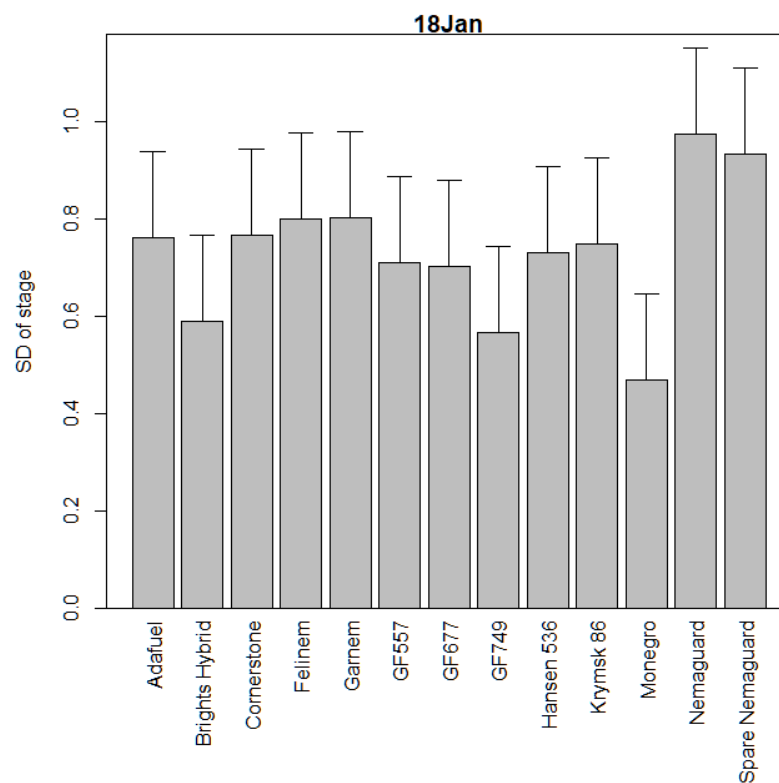


Figure 44. Distribution of variability of splitting across rootstocks. Error bars are averages standard errors.

At Stage 5 Nemaguard (and ‘Spare’) had lower variability than other rootstocks (Figure 46),

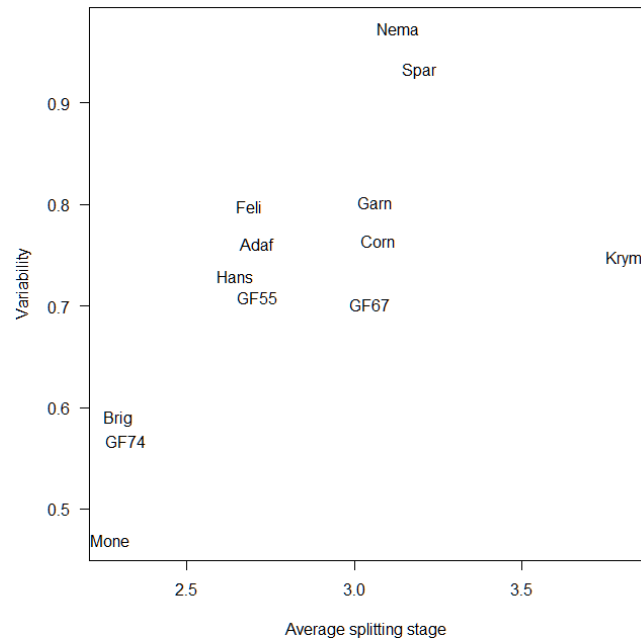


Figure 45. Relationship between splitting stage and variability based on 18 January data.

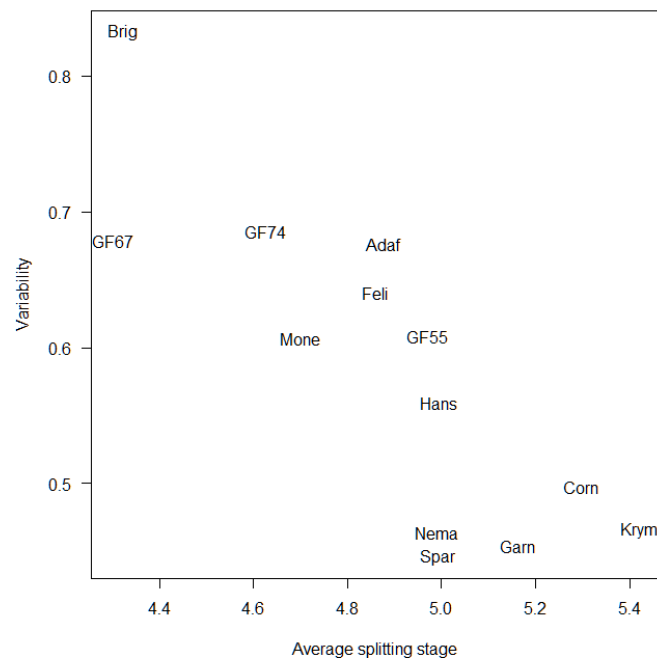


Figure 46. Relationship between splitting stage and variability based on 1 February data.

4.7.5 Modelling Split Stage

An inverse logistic function was used to model the splitting. The data were transformed to an empirical logit using the formula

$$\lambda = \exp((\text{count} + 1)/(100 - \text{count} + 1))$$

A weighted regression was then used to fit

$$\lambda = a + b \times \text{day}$$

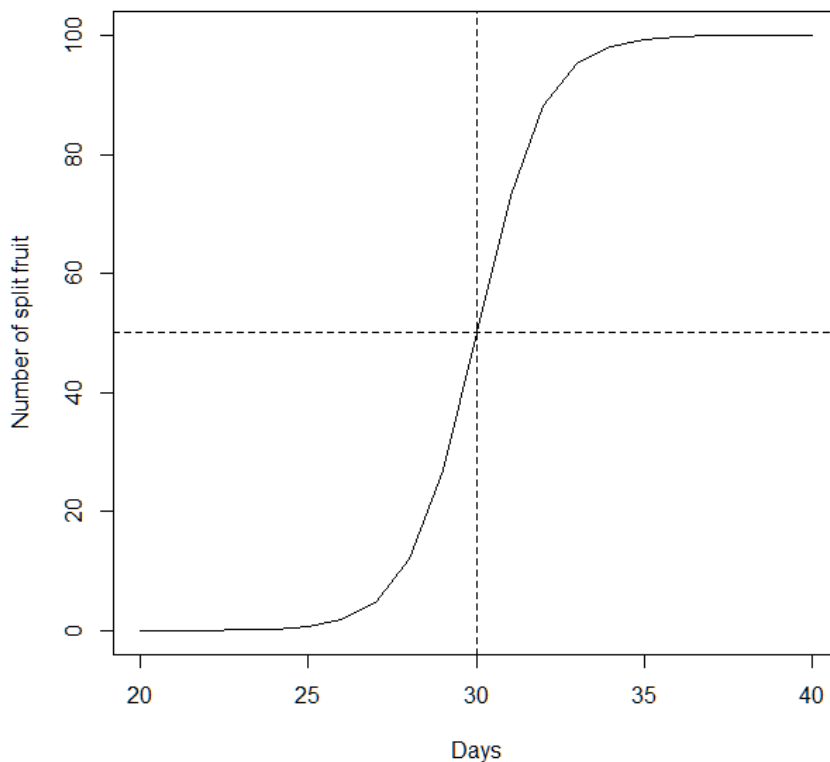


Figure 47. Form of logistic curve used for modelling time to split stage.

When $\lambda = 0$, half the fruits would have reached that stage. The method was then used to estimate the day when 50% of the nuts had reached Stage 3 or Stage 6 for each plot using the data from each examination time. Krymsk was first rootstock to have 50% of fruits to Stage 3 and Brights Hybrid last approximately 13 day later.

The time to achieve 50% split to Stage 6 was less clear. Krymsk was first to achieve 50% but there were no significant difference between the rootstocks. This may have been due to measurement variation – for example in Replicate 1, the number of fruits at Stage 1 was 78, 18 and 100 on 1 Feb, 8 Feb and 18 Feb. There appears to have been problems with those measurements.

Overall, it can be said that Krymsk initiates splitting early but there was no significant difference between rootstock to achieve Stage 6 splitting.

Table 24. Estimated days in 2021 before 50% of fruits split to Stage 3 or Stage 6.

Rootstock	Stage 3	Stage 6
Adafuel	16.55	36.16
Brights Hybrid	22.99	39.23
Cornerstone	13.63	36.24
Felinem	17.91	35.89
Garnem	15.10	36.83
GF557	17.04	36.80
GF677	15.46	39.01
GF749	18.49	38.62
Hansen 536	17.50	41.36
Krymsk 86	13.01	35.88
Monegro	19.50	37.48
Nemaguard	14.00	39.91
Spare Nemaguard	15.99	37.61
p value	< 0.001	0.363
SE	1.44	1.62

4.8 Conversion efficiency

Efficiency in this context was defined as Yield per tree/Growth.

A summary of the efficiency data is given in Table 25 and illustrated in Figure 48. There were significant differences between the varieties in 2017 but not in the other years.

Table 25. Analysis of efficiency data for each year.

Variety	2016	2017	2018	2019	2020
Nemaguard	0.018	0.069	0.135	0.235	0.204
GF557	0.032	0.092	0.157	0.301	0.220
GF677	0.008	0.080	0.148	0.242	0.186
GF749	0.025	0.077	0.126	0.243	0.286
Adafuel	0.023	0.095	0.119	0.265	0.238
Garnem	0.024	0.061	0.141	0.270	0.231
Felinem	0.036	0.077	0.122	0.381	0.237
Monegro	0.033	0.084	0.147	0.383	0.212
Brights Hybrid	0.023	0.059	0.120	0.292	0.218
Hansen 536	0.028	0.040	0.135	0.162	0.143
Cornerstone	0.029	0.095	0.133	0.320	0.251
krymsk 86	0.037	0.057	0.161	0.186	0.307
Spare (Nemaguard)	0.032	0.070	0.175	0.269	0.262
SE	0.006	0.010	0.019	0.059	0.066
p value	0.056	0.008	0.665	0.315	0.949
LSD	NA	0.028	NA	NA	NA

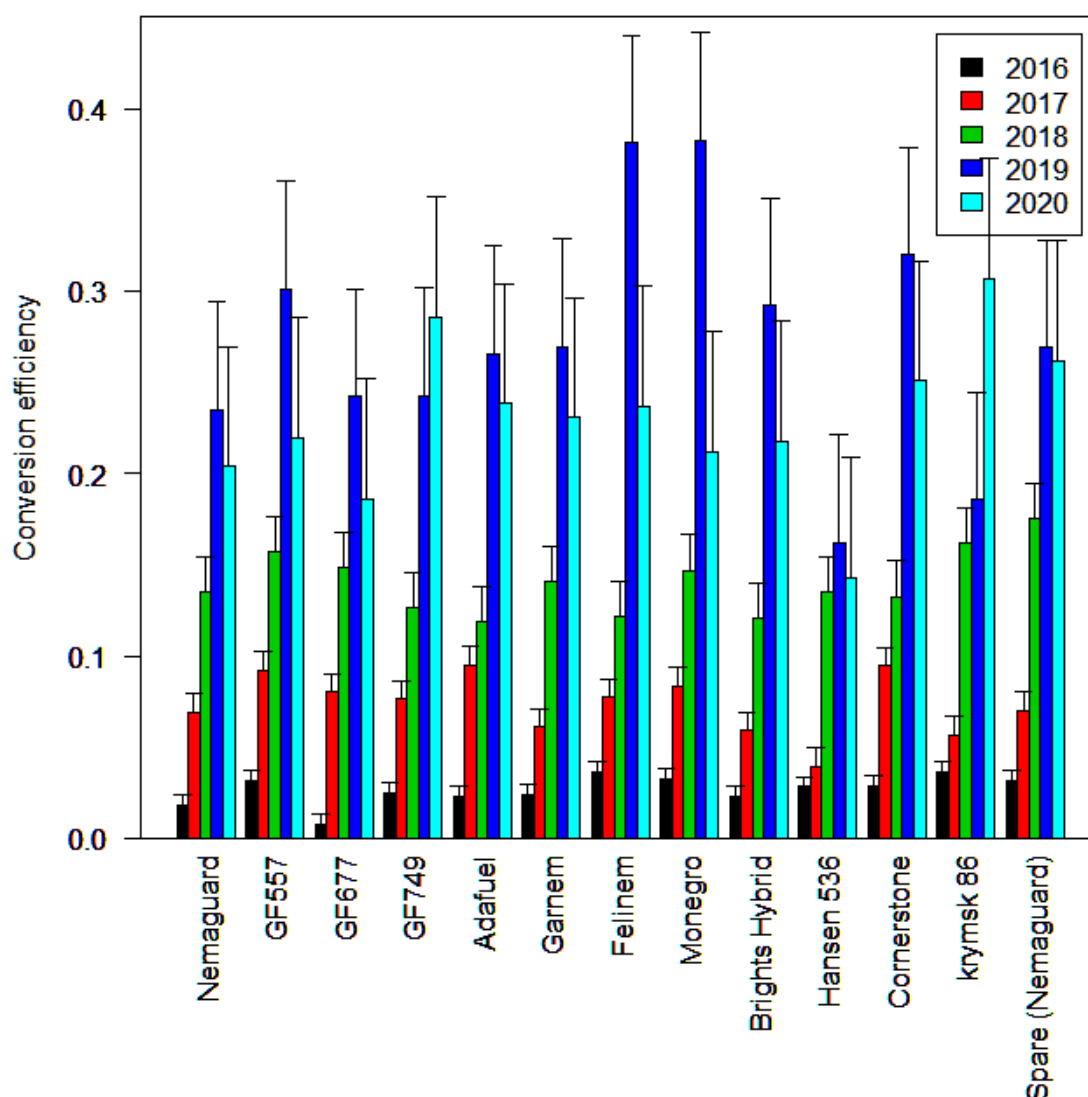


Figure 48. Analysis of efficiency data for each year. Error bars are standard errors.

4.9 Tree temperature

A summary of the tree canopy temperatures is given in Table 26. The p values in that table were derived using a split-plot technique where the groups of 3 trees were considered as a main plots and the trees as sub-plot. No significant difference was noted between the rootstocks.

A further analysis was performed on the temperature data averaged across measurement times (Table 27). No significant difference was found.

The ranking of the temperature data matches that of SARDI (2021). SARDI reported a significant difference between rootstocks, but no significance was found in the current study. This discrepancy may be due to SARDI using the trees as units whereas in the current study the 3 tree plots were considered as units.

There were differences between the replicates that were significant at the $p < 0.001$ level. This indicates that the measurement and experimental techniques were sufficiently sensitive to resolve small differences. It was therefore concluded that any difference between the rootstocks would have been small.

Table 26. Tree temperature from each rootstock

	Oct27.17	Nov11.17	Nov21.17	Dec12.17	Dec21.17	Jan4.18	Jan18.18	Feb1.18	Feb14.18	Feb28.18
Adafuel	30.4	18.9	34.9	21.5	32.8	36.0	40.0	20.5	23.0	26.8
Brights Hybrid	29.9	19.3	33.8	21.0	32.0	35.6	39.4	20.7	23.2	25.7
Cornerstone	29.6	19.9	35.2	22.9	32.6	35.9	38.7	21.9	23.4	26.8
Felinem	29.0	19.1	34.4	21.2	32.1	35.4	37.8	21.1	22.5	26.0
Garnem	29.9	19.2	35.0	21.7	32.2	36.0	39.0	21.0	22.9	26.1
GF557	28.9	19.1	34.5	22.1	32.6	35.6	38.1	21.2	22.8	25.7
GF677	29.2	19.0	34.1	21.7	32.3	35.5	38.1	20.9	22.5	25.4
GF749	28.8	19.0	33.8	21.1	32.2	35.3	39.0	21.0	22.8	26.2
Hansen 536	28.8	19.1	34.0	21.6	31.7	34.8	38.5	21.4	23.0	25.9
Krymsk 86	30.4	20.0	34.8	22.2	32.8	36.0	38.4	21.5	24.1	26.8
Monegro	29.4	19.2	34.2	21.5	32.3	35.0	38.3	21.0	22.5	26.1
Nemaguard	29.8	19.6	35.0	22.4	33.1	36.0	38.3	21.4	23.2	26.8
Spare	29.1	18.9	35.0	22.1	32.7	35.9	38.4	21.2	22.4	26.1
p value	0.164	0.500	0.149	0.091	0.860	0.703	0.412	0.324	0.570	0.418

Table 27. Temperature of canopy averaged across 10 measurement times

Rootstock	Average temperature
Adafuel	28.5
Brights Hybrid	28.1
Cornerstone	28.7
Felinem	27.8
Garnem	28.3
GF557	28.1
GF677	27.9
GF749	27.9
Hansen 536	27.9
Krymsk 86	28.7
Monegro	27.9
Nemaguard	28.5
Spare	28.2
P value	0.4

4.10 Nematode sampling data

The incidence of each of the six nematodes tested is shown in Table 28. There were no Five plant nematode species were recorded but the 'plant' nematode was not detected.

The quantitative data were subject to analysis of variance after a transform

$$Y = \log_{10} (X + k)$$

where k was taken as 0.02 being the minimum positive for the number of nematodes per gram of dry soil.

The pattern for incidence and amount of nematode present showed different patterns (Table 28 and Table 29). The highest levels were found in Hansen, Monegro and GF749.

Table 28. Incidence of nematodes on each rootstock.

	Pin Nematode (Paratylenchus)	Plant Parasitic Nematodes	Ring Nematode (Criconemella)	Root Knot Nematode (Meloidogyne)	Root Lesion Nematode (Pratylenchus)	Stubby Root Nematode (Paratrichodorus)
Adafuel	25%	0%	75%	25%	0%	50%
Brights Hybrid	0%	0%	75%	0%	25%	25%
Cornerstone	25%	0%	50%	0%	0%	25%
Felinem	0%	0%	50%	0%	0%	100%
Garnema	50%	0%	50%	0%	0%	75%
GF557	0%	0%	75%	0%	0%	100%
GF677	0%	0%	50%	0%	50%	100%
GF749	0%	0%	100%	25%	0%	100%
Hansen	50%	0%	25%	0%	0%	100%
Krymsk	0%	0%	100%	0%	25%	50%
Monegro	25%	0%	75%	0%	0%	100%
Nemaguard	50%	0%	75%	0%	25%	75%
Spare	25%	0%	75%	0%	25%	75%
Average	19%	0%	67%	4%	12%	75%

Table 29. Mean number of nematodes per gram of dry soil.

Rootstock	Pin Nematode (Paratylenchus)	Plant Parasitic Nematodes	Ring Nematode (Criconemella)	Root Knot Nematode (Meloidogyne)	Root Lesion Nematode (Pratylenchus)	Stubby Root Nematode (Paratrichodorus)
Adafuel	0.01	0	0.035	0.0925	0	0.025
Brights Hybrid	0	0	0.0325	0	0.295	0.005
Cornerstone	0.165	0	0.0175	0	0	0.005
Felinem	0	0	0.0225	0	0	0.055
Garnema	0.0375	0	0.035	0	0	0.045
GF557	0	0	0.045	0	0	0.0525
GF677	0	0	0.0275	0	0.1025	0.12
GF749	0	0	0.0275	0.075	0	0.335
Hansen	0.6775	0	0.005	0	0	0.4675
Krymsk	0	0	0.135	0	0.005	0.0125
Monegro	0.4725	0	0.035	0	0	0.45
Nemaguard	0.6825	0	0.0625	0	0.0075	0.195
Spare	0.67	0	0.05	0	0.005	0.115
P value	n.s.	NA	n.s.	n.s.	n.s.	< 0.001

Table 30. Analysis of variance table of stubby root nematode numbers

	Df	Sum of Sqs	Mean sq	F	Pr(>F)
Rootstock	12	8.307	0.692	6.66	0.000004
rep.mat	3	0.853	0.284	2.74	0.058
Residuals	36	3.740	0.104		

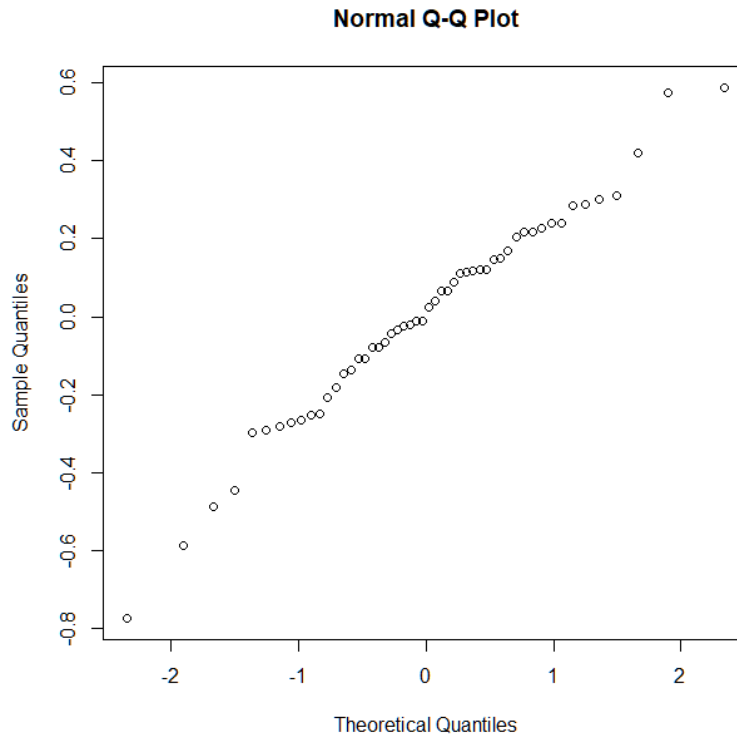


Figure 49. QQ plot of residuals from analysis of variance of 'Stubby' data after logarithmic transform.

5 Relationships between variables

Two important production variables in the study were yield (expressed as kg/ha of kernels) and kernel weight. Correlations were calculated for all combinations but only those involving that pair are reported here. The actual correlations and their statistical significance are given in Table 31. Selected relationships are shown in Figure 50.

There was a strong negative correlation between yield and kernel weight – where there was a high yield the kernel weight tended to be small. A result of that correlation was that where there was a positive correlation with yield, the correlation with kernel weight would have the opposite sign.

Tree height was correlated with yield (and negatively with kernel weight). Butt circumference was not correlated with yield.

The divalent ions – calcium and magnesium – were strongly positively correlated with yield. The petiole monovalent potassium and sodium concentrations were negatively correlated with yield. Petiole sulfur and chloride were also negatively correlated with yield.

There was no correlation between yield any soil nutrient measures nor was there any correlation between nematodes and yield.

Table 31. Significant correlations between yield and kernel rate and other measures.

	<i>Kg.ha</i>	<i>Kernal100</i>	<i>Kg.ha</i>	<i>Kernal100</i>
Kernal100	-0.516	1.000	0.000	NA
Butt16	0.288	-0.172	0.043	0.230
Height	0.392	-0.371	0.006	0.009
LAI	0.391	-0.274	0.006	0.055
Nitrate - N	0.299	-0.129	0.036	0.370
Potassium	-0.518	0.439	0.000	0.002
Calcium	0.576	-0.482	0.000	0.001
Magnesium	0.418	-0.421	0.003	0.003
Sodium	-0.332	0.181	0.020	0.206
Sulfur	-0.395	0.164	0.005	0.252
Chloride	-0.396	0.270	0.005	0.059

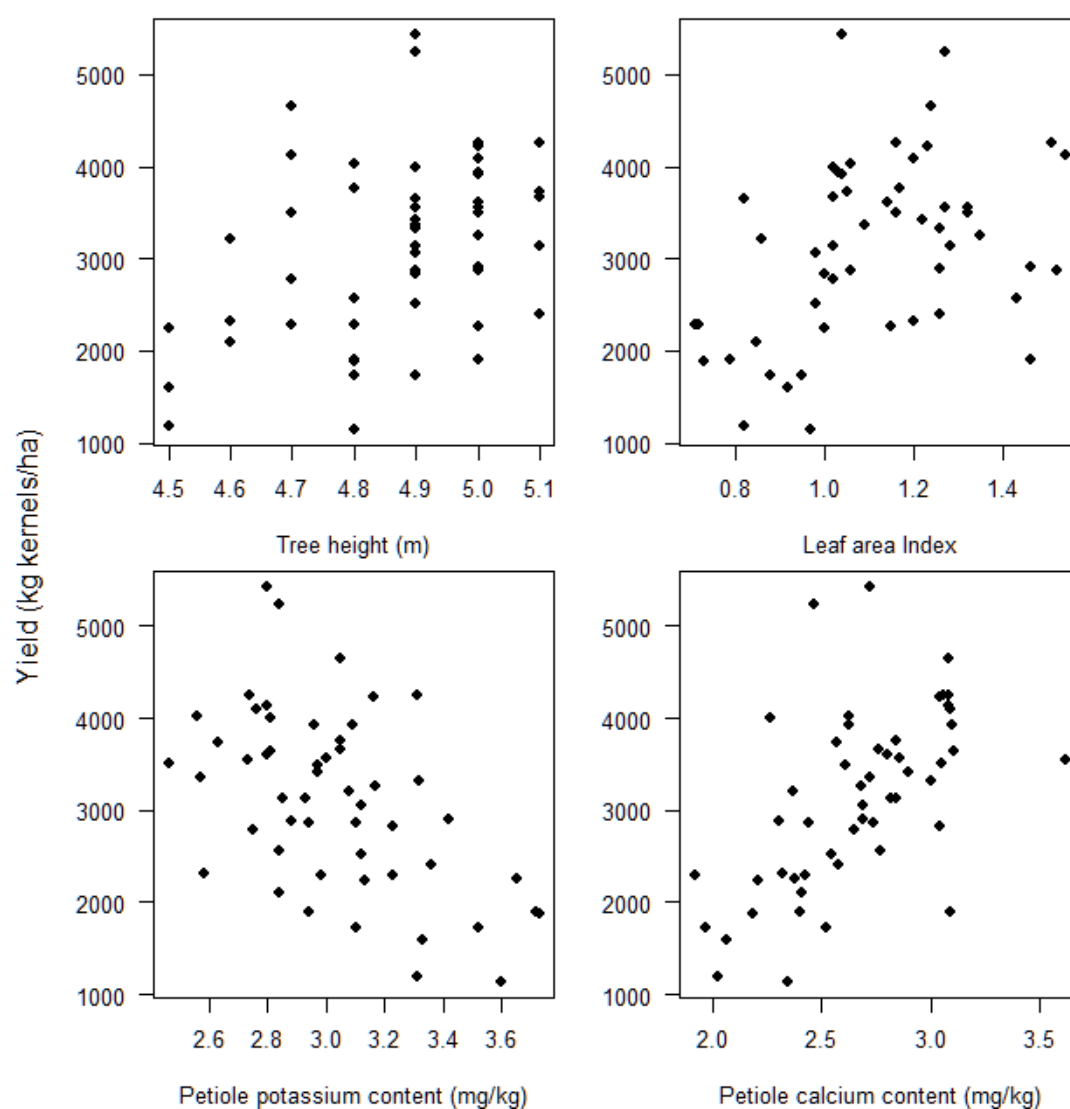


Figure 50. Relationships between tree height, leaf area index, petiole potassium and petiole calcium with yield.

All correlations

Table 32. Correlations between soil properties and petiole nutrient levels.

Petiole Concentration	Soil properties										
	pH.H ₂ O	pH.CaCl ₂	OC	Nitrate.N	Ammonia.N	Col.P	Tot.P	K	S	EC	TDS
Nitrate - N	0.21	0.22	-0.07	-0.05	0.19	-0.12	-0.21	0.21	0.01	0.14	0.15
Nitrogen	-0.09	-0.08	-0.18	0.02	0.13	0.10	-0.07	0.13	-0.01	-0.06	-0.06
Phosphorus	0.03	0.02	-0.04	0.01	-0.11	0.11	0.11	0.13	0.05	0.00	0.00
Potassium	-0.01	0.00	-0.09	-0.03	0.15	-0.08	-0.05	0.00	0.01	0.05	0.06
Calcium	0.38	0.41	0.21	-0.10	0.03	0.09	-0.09	0.24	0.10	0.25	0.26
Magnesium	0.12	0.08	0.11	-0.16	-0.03	-0.27	-0.09	0.00	-0.14	-0.12	-0.11
Sodium	-0.33	-0.33	0.06	0.08	-0.09	-0.23	0.00	-0.31	-0.12	-0.20	-0.20
Sulfur	0.10	0.08	0.02	-0.04	0.07	-0.22	-0.26	0.13	0.04	0.04	0.05
Boron	0.07	0.08	0.08	-0.06	-0.20	-0.25	-0.06	-0.10	-0.10	-0.02	-0.01
Copper	0.17	0.28	0.05	0.17	0.13	0.08	-0.27	0.40	0.55	0.56	0.56
Zinc	0.19	0.25	0.10	0.10	0.16	0.17	-0.03	0.19	0.24	0.30	0.30
Manganese	0.11	0.08	-0.11	-0.15	0.14	-0.06	-0.19	0.21	0.08	0.14	0.15
Iron	0.04	0.09	-0.06	-0.20	0.15	0.02	0.06	0.06	-0.01	0.09	0.09
Aluminium	-0.01	0.05	-0.19	0.16	-0.04	0.06	0.00	0.06	0.08	0.10	0.11
Molybdenum	-0.26	-0.26	0.08	-0.12	-0.06	0.00	0.06	-0.20	-0.12	-0.17	-0.17
Chloride	-0.39	-0.37	-0.14	0.26	-0.15	-0.11	0.10	-0.18	-0.05	-0.16	-0.16

6 References

Rueter, D and Robinson JB (1997). Plant analysis: An interpretation manual. Second Edition. CSIRO.

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Tree Nutrition

Leaf Analysis

The results of annual leaf nutrient analyses for each rootstock is provided below in a series of graphs for each element.

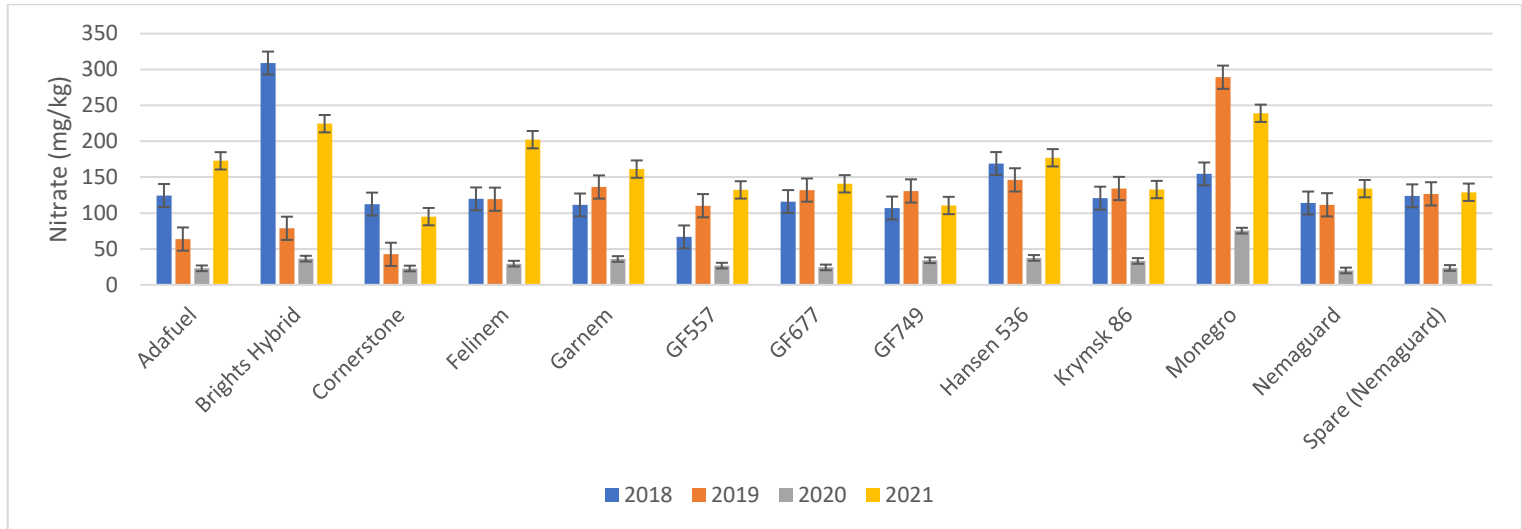


Figure H- 1: Mean petiole nitrate (mg/kg).

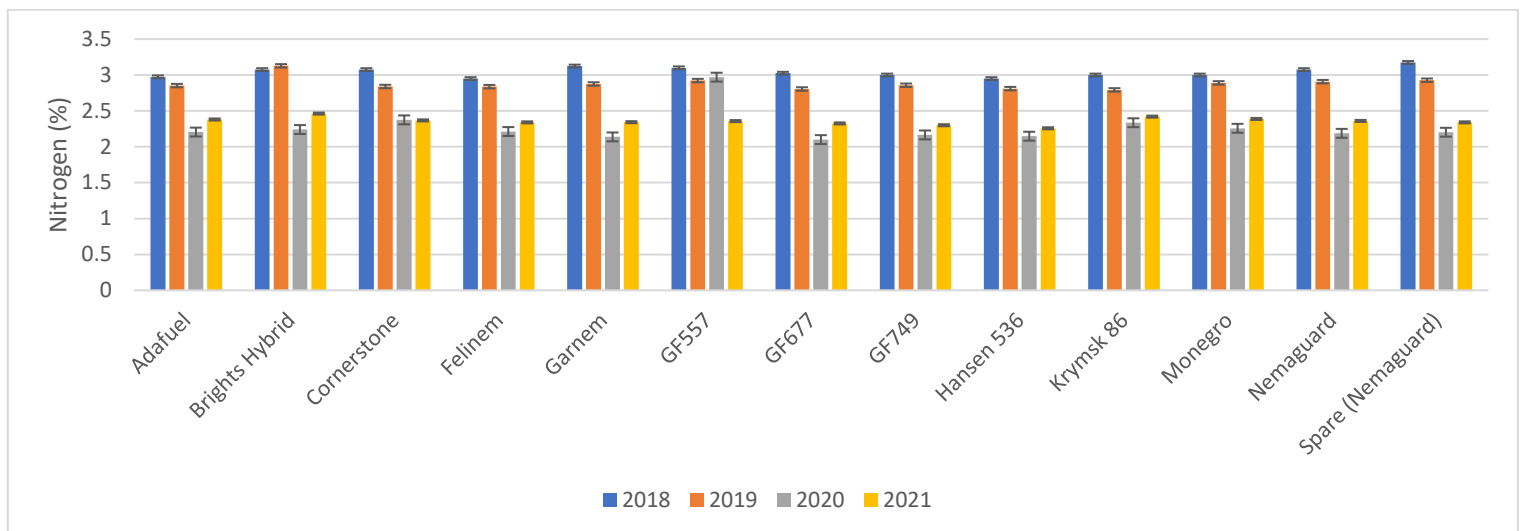


Figure H- 2: Mean petiole nitrogen percentage (%).

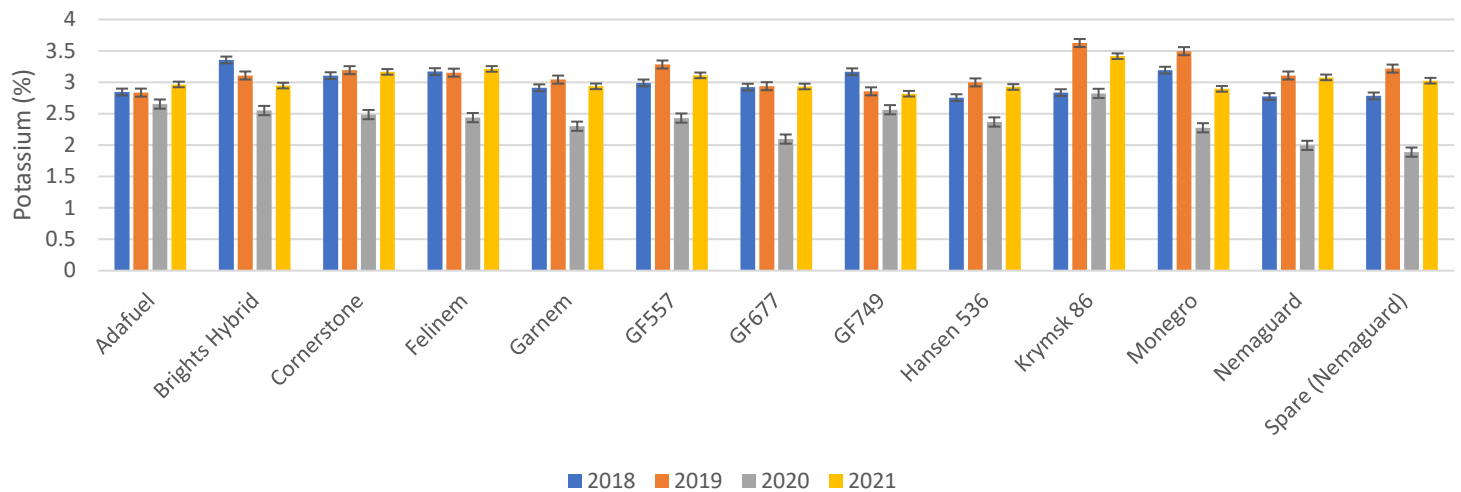


Figure H- 3: Mean petiole potassium percentage (%).

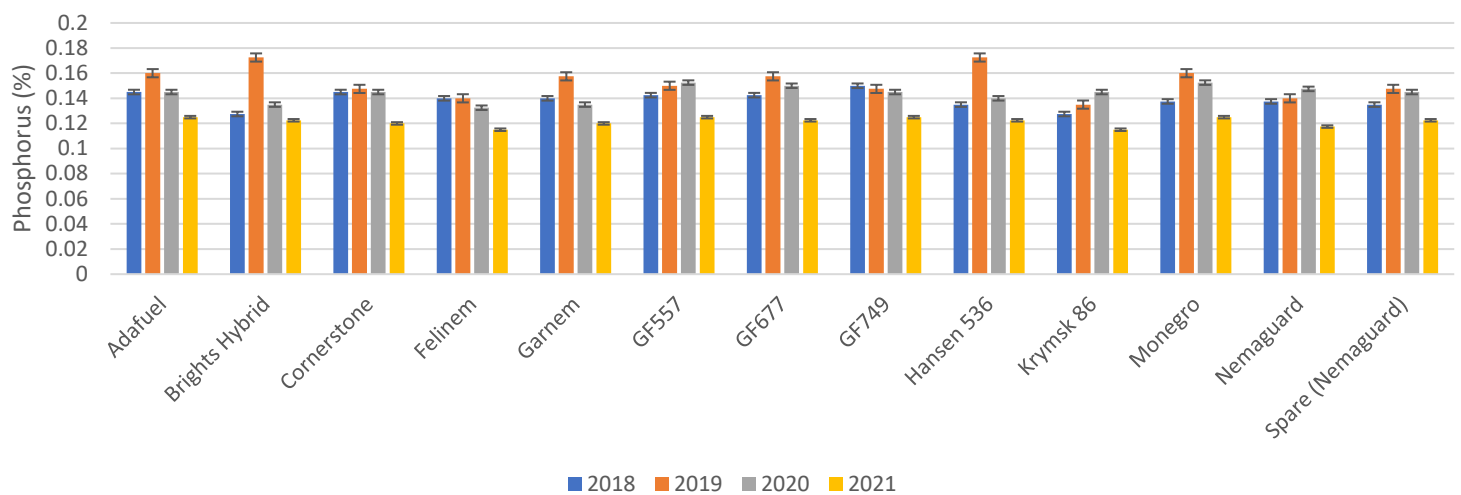


Figure H- 4: Mean petiole phosphorus percentage (%).

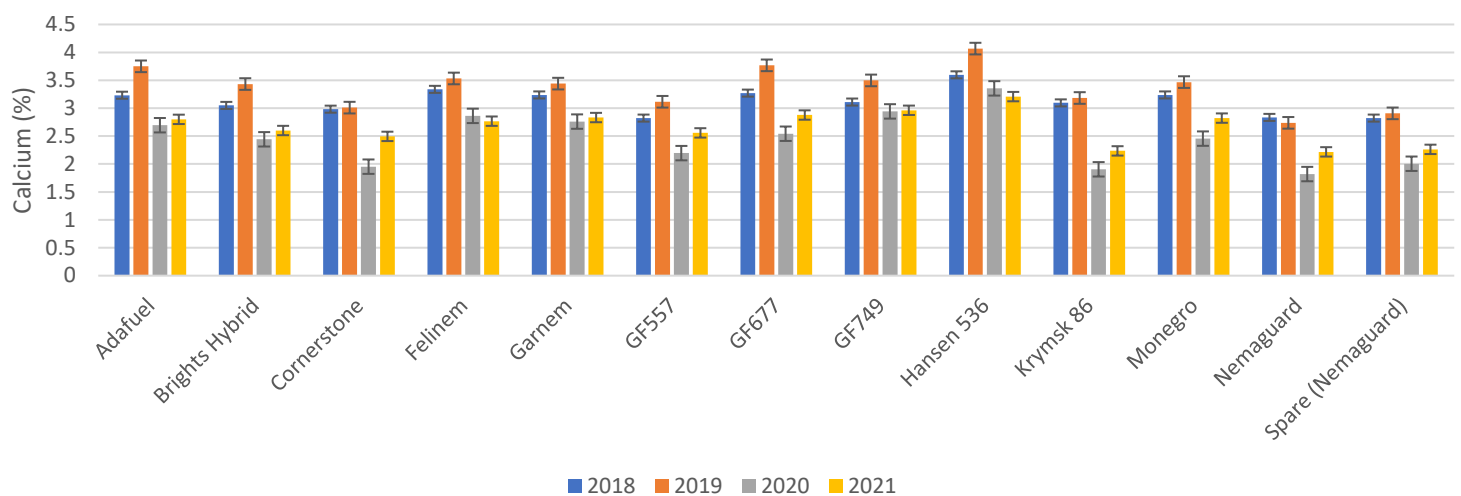


Figure H- 5: Mean petiole calcium percentage (%).

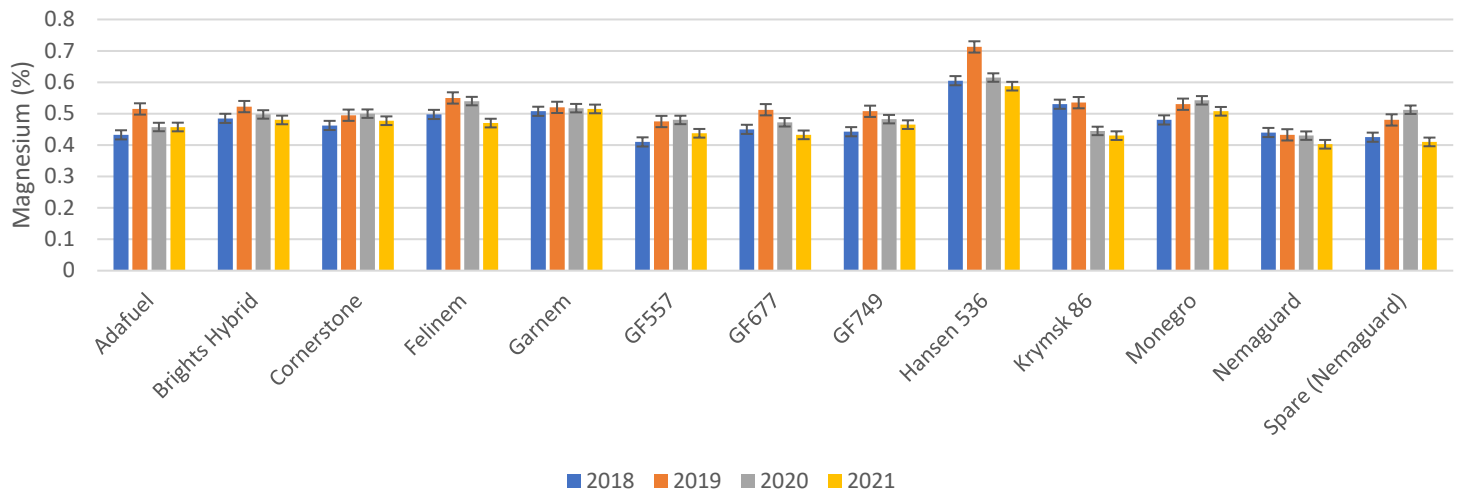


Figure H- 6: Mean petiole magnesium percentage (%).

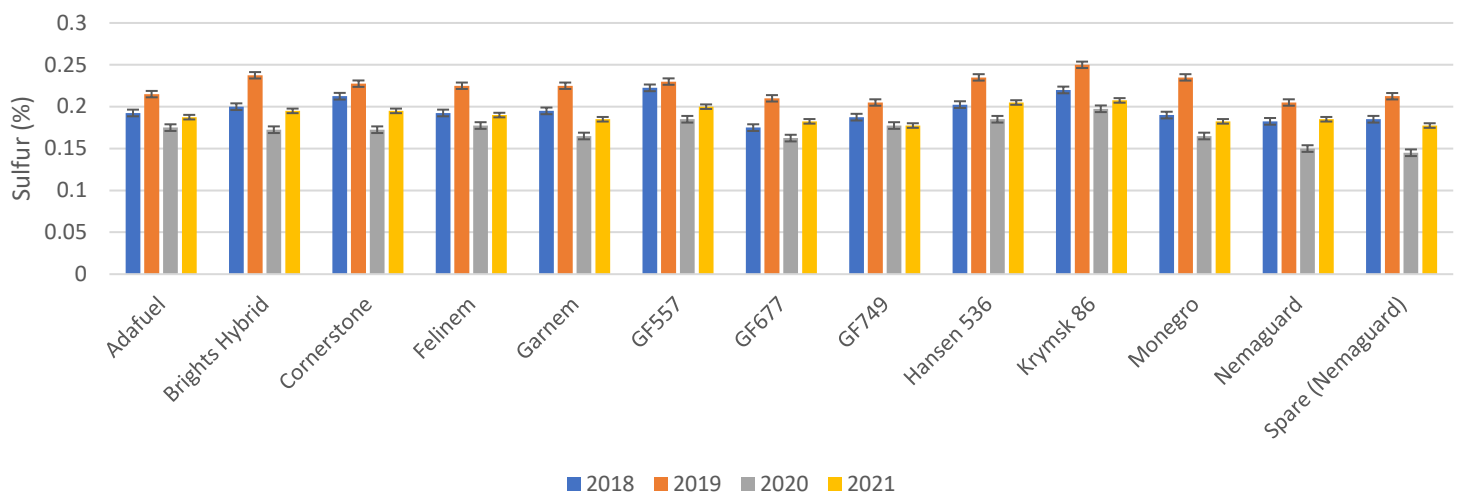


Figure H- 7: Mean petiole sulfur percentage (%).

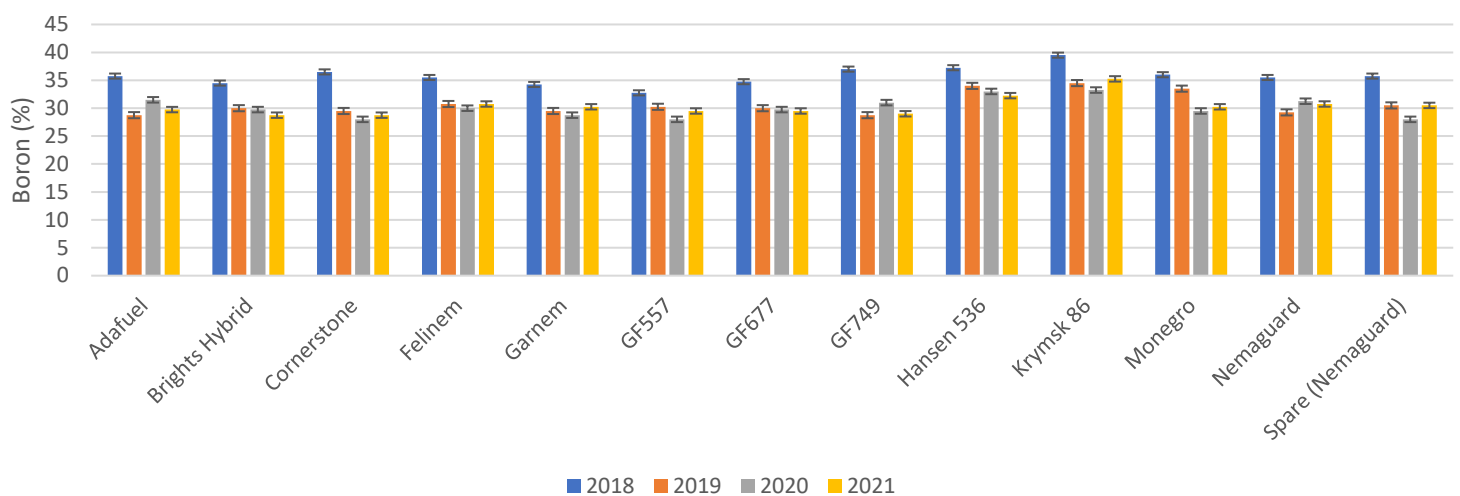


Figure H- 8: Mean petiole boron percentage (%).

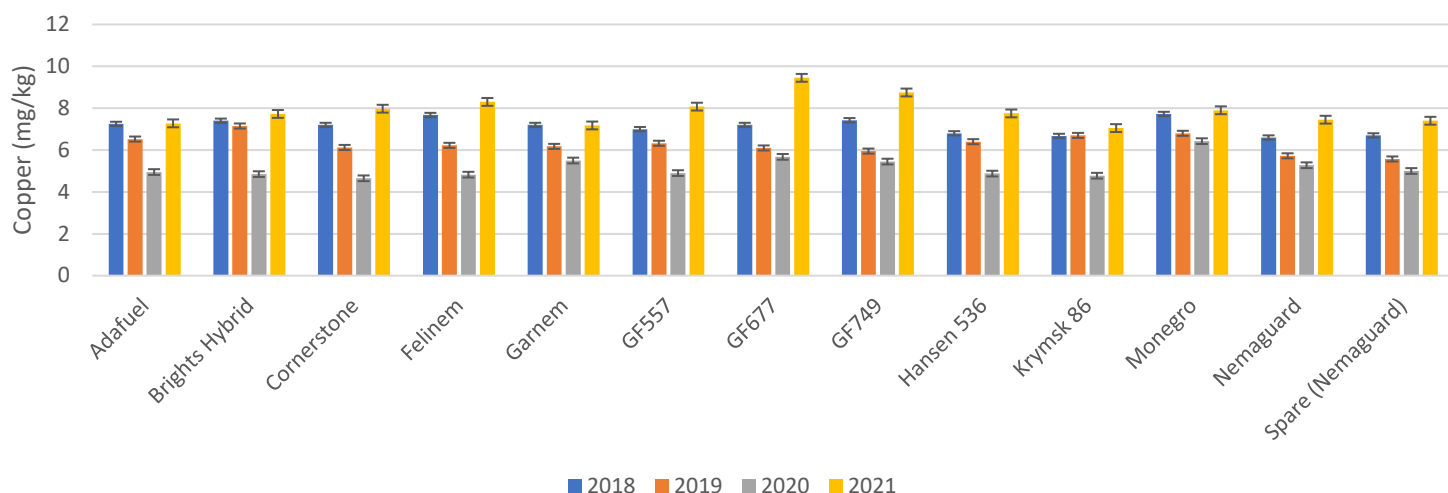


Figure H- 9: Mean petiole copper (mg/kg).

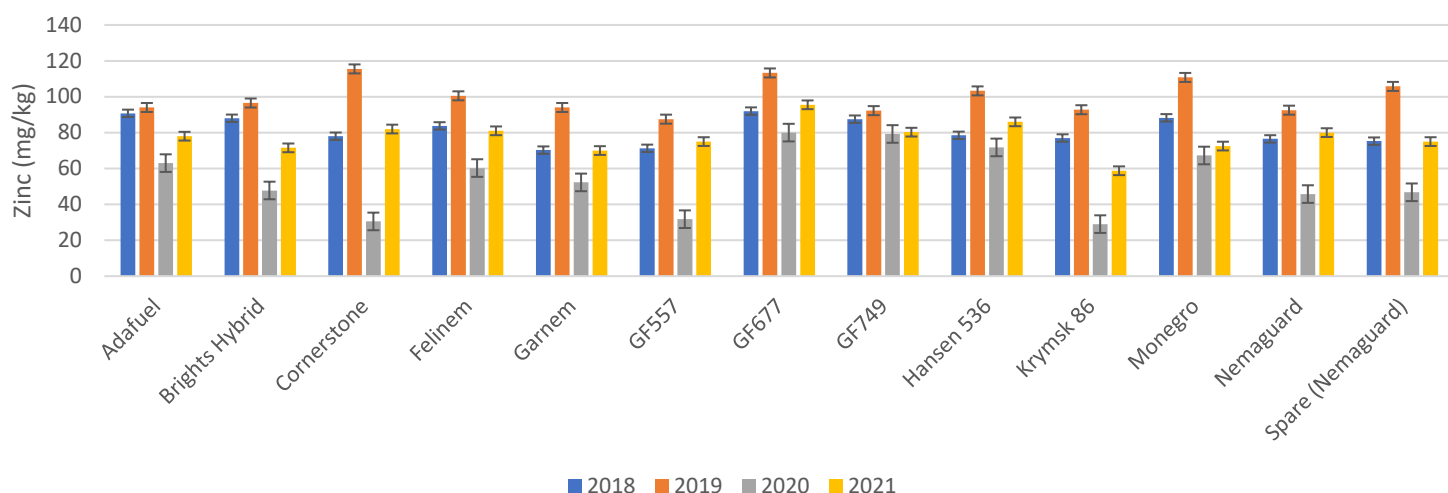


Figure H- 10: Mean petiole zinc (mg/kg).

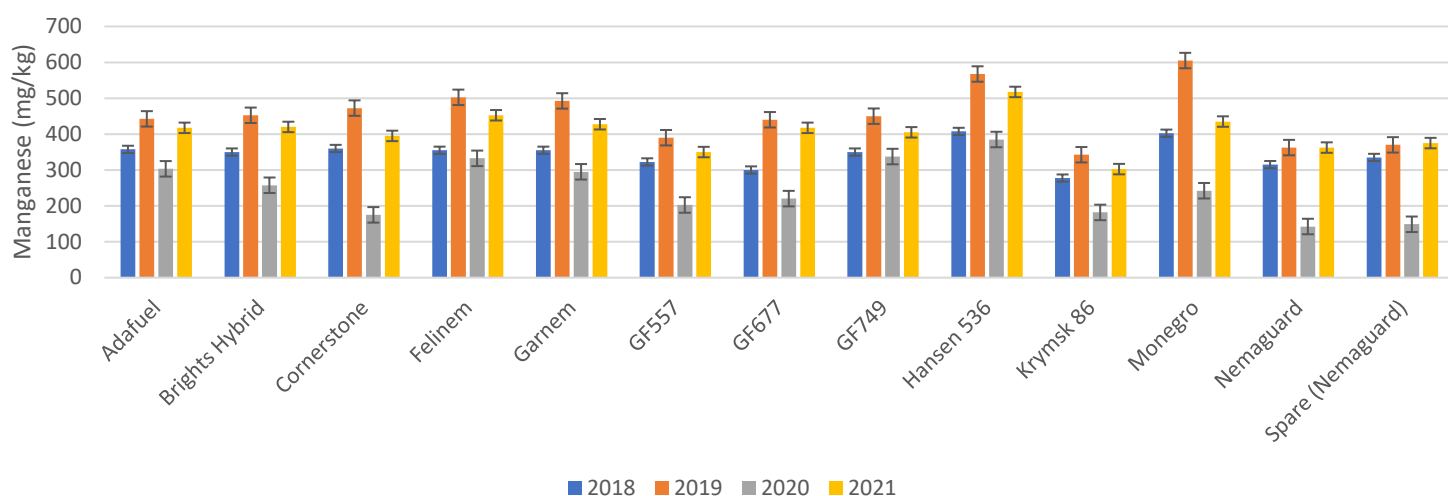


Figure H- 11: Mean petiole manganese (mg/kg).

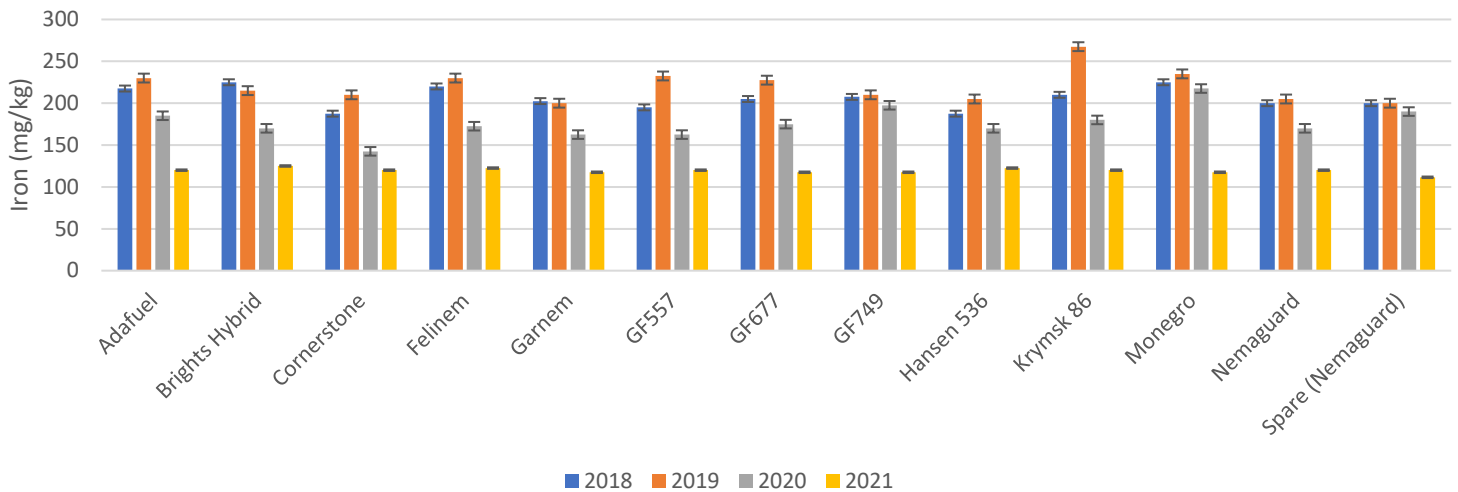


Figure H- 12: Mean petiole iron (mg/kg).

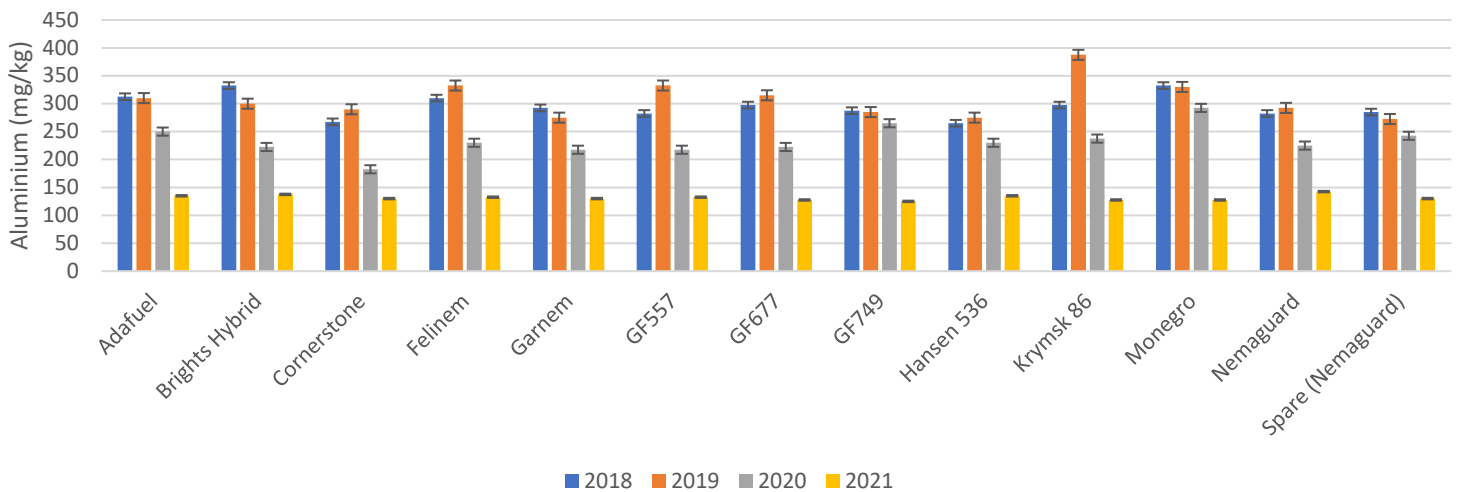


Figure H- 13: Mean petiole aluminium (mg/kg).

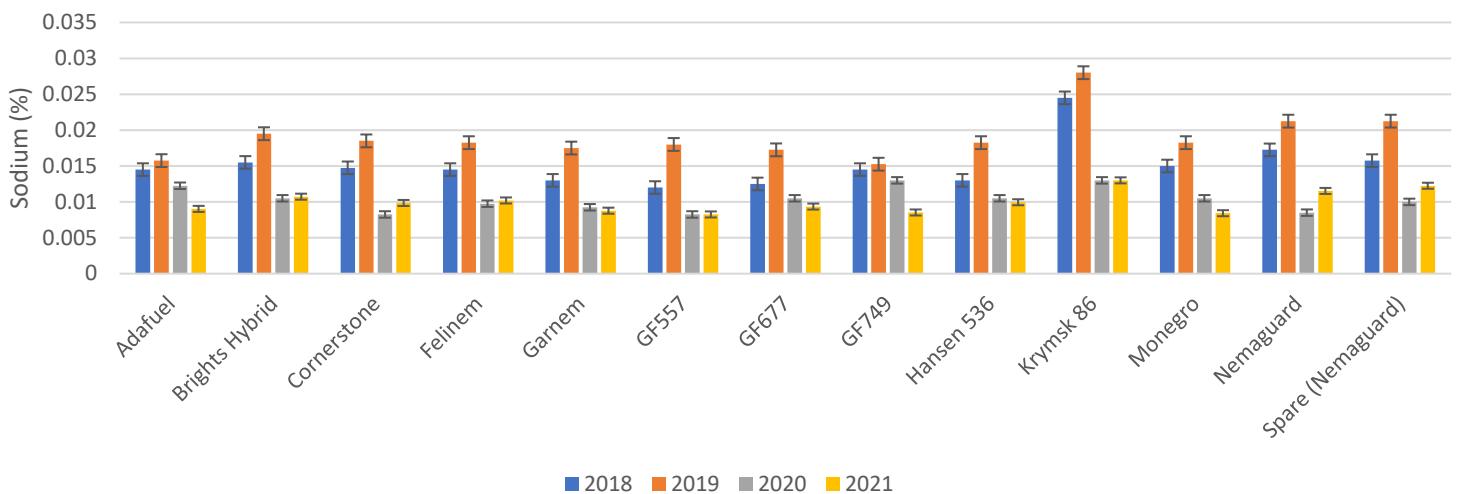


Figure H- 14: Mean petiole sodium percentage (%).

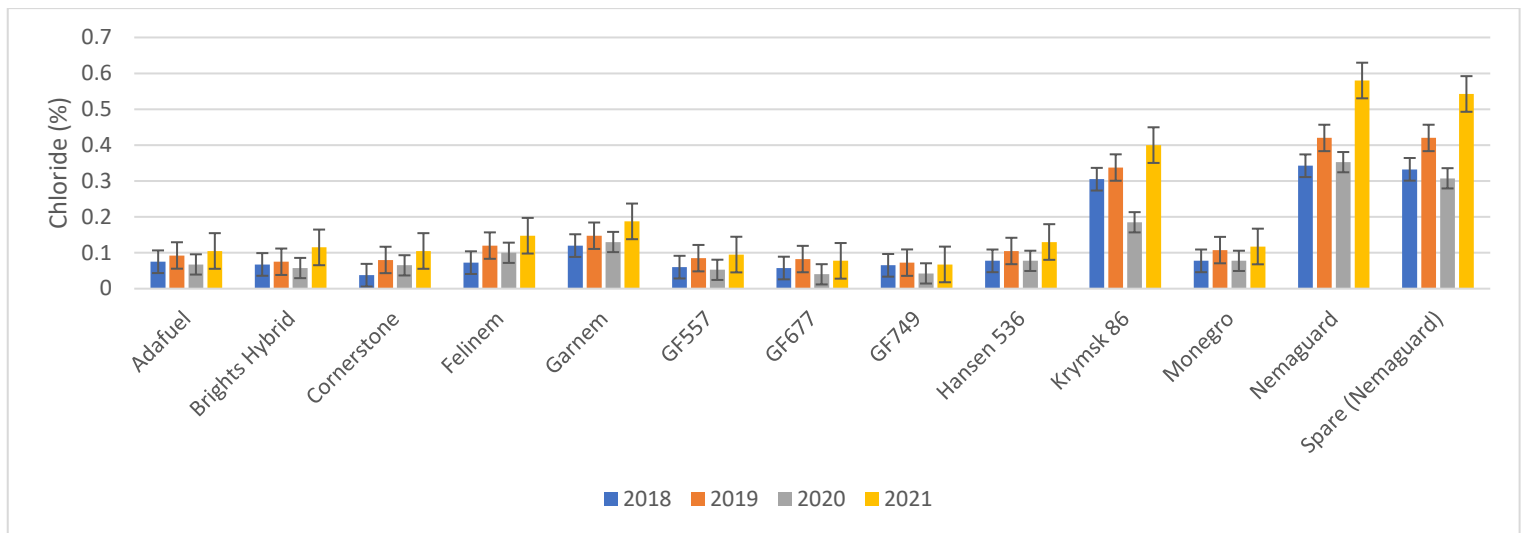


Figure H- 15: Mean petiole chloride percentage (%).

Soil Analysis

The result of annual soil nutrient analyses for each rootstock is provided below in a series of graphs for each soil characteristic.

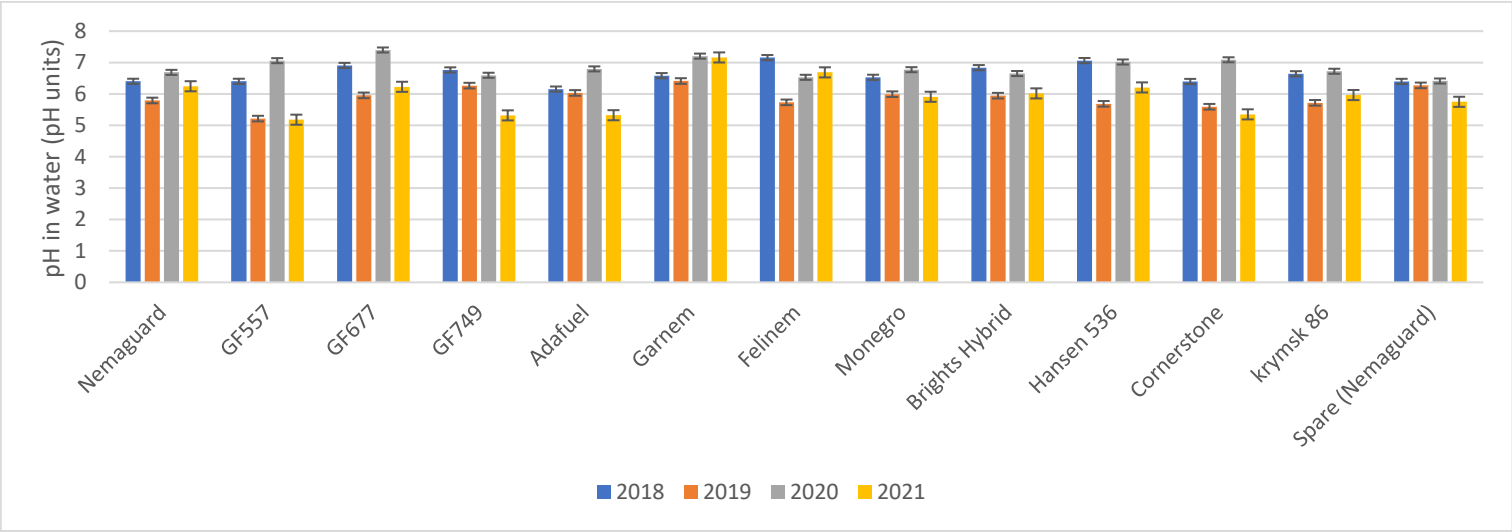


Figure H-16: Mean soil pH in water 1:5 (pH units).

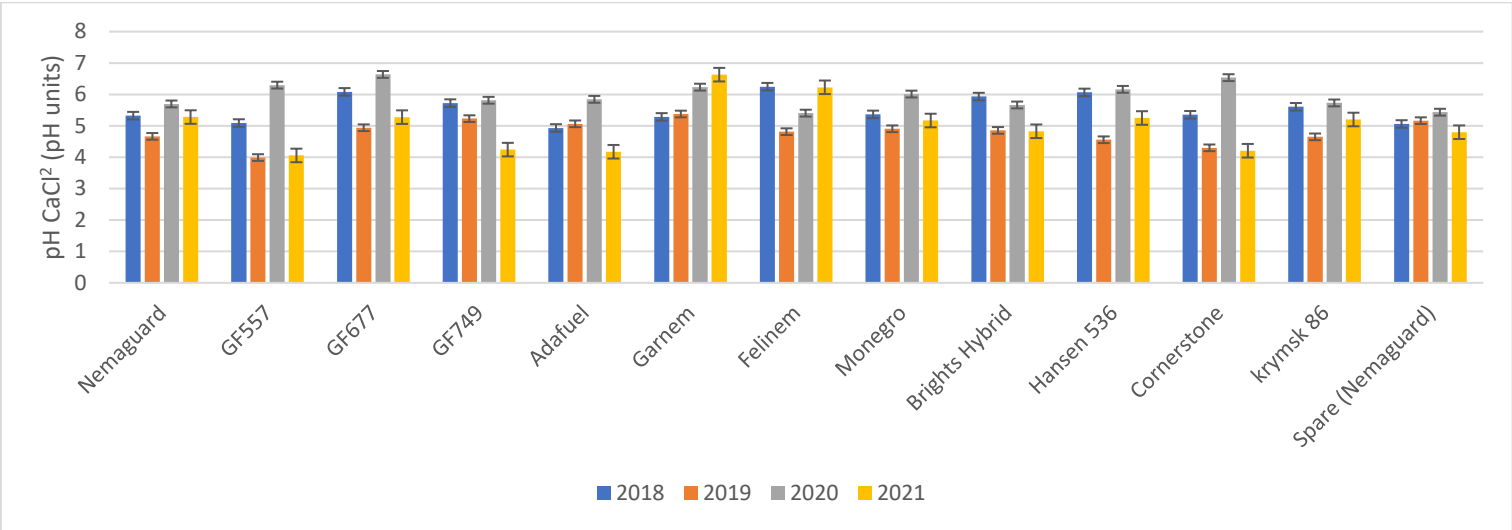


Figure H-17: Mean soil pH CaCl₂ following 4A1 (pH units).

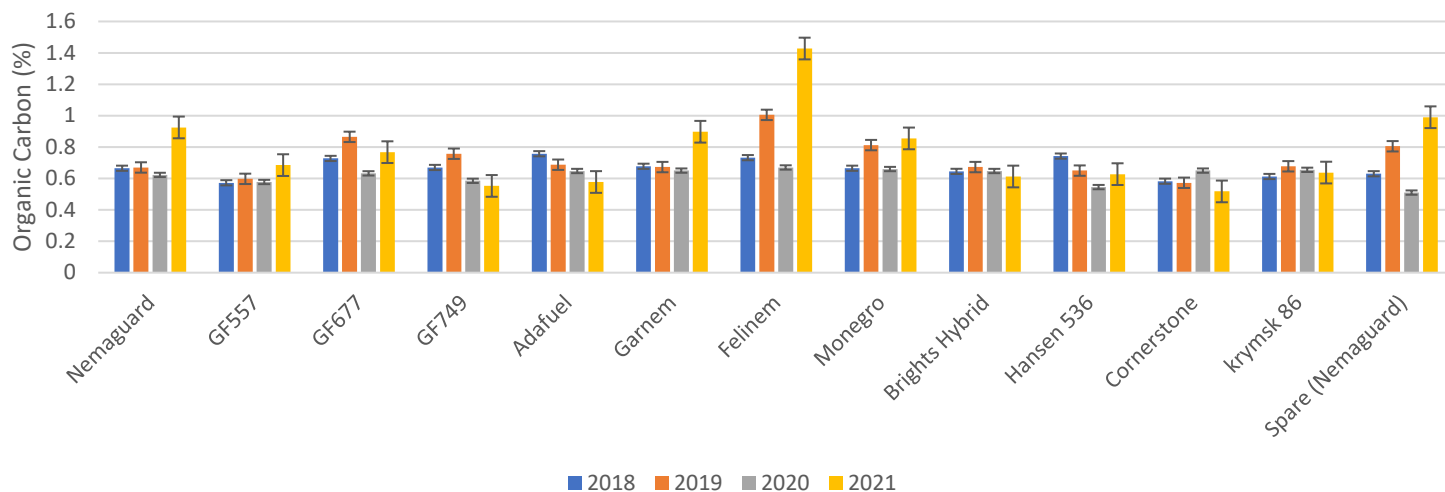


Figure H-18: Mean soil organic carbon (W&B) (%).

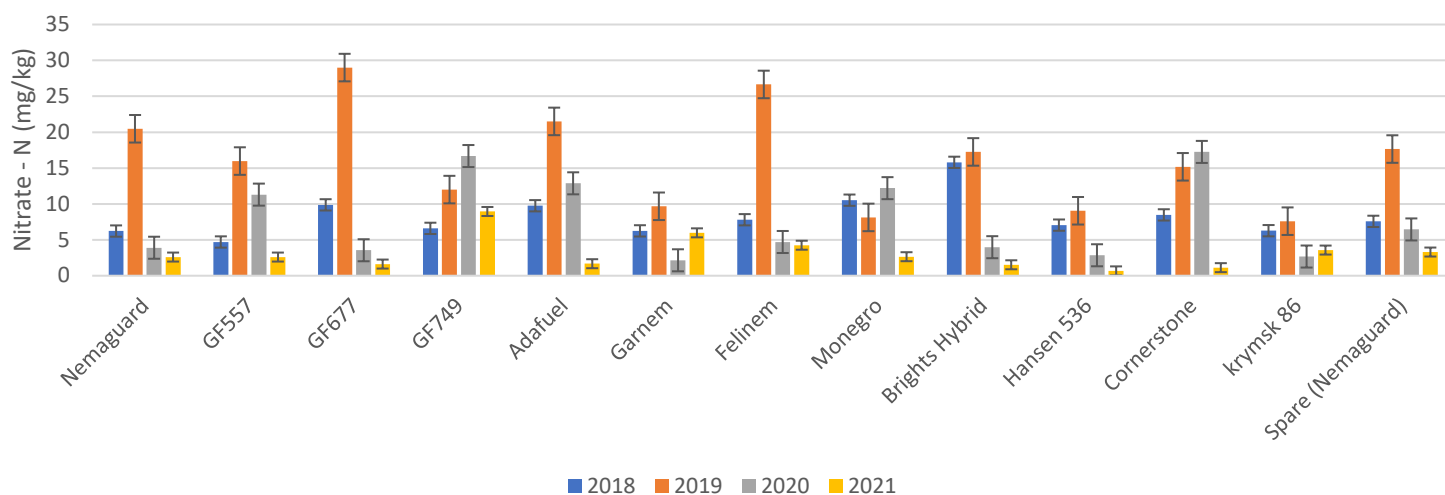


Figure H- 19: Mean soil nitrate - N (2M KCl) (mg/kg).

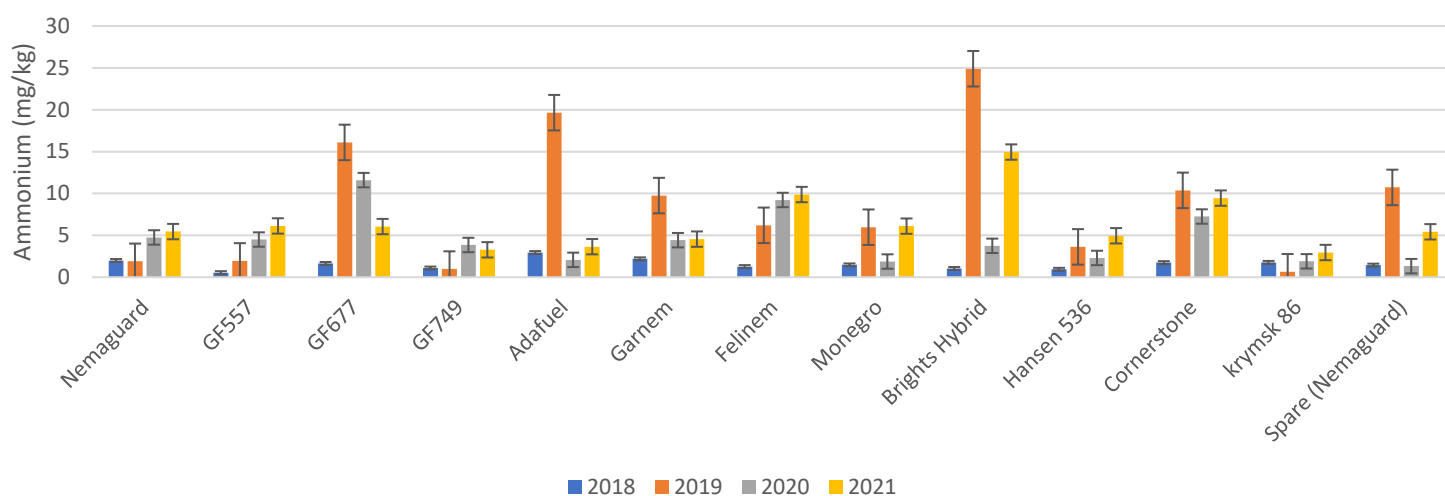


Figure H- 20: Mean soil ammonium - N (2M KCl) (mg/kg).

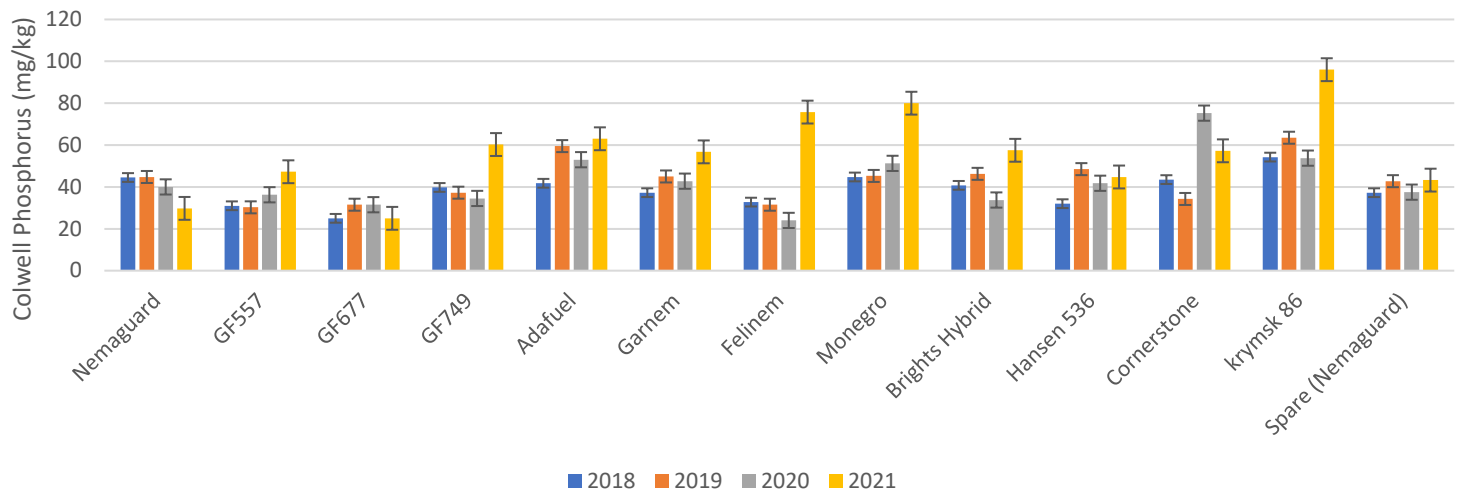


Figure H- 21: Mean soil Colwell Phosphorus (mg/kg).

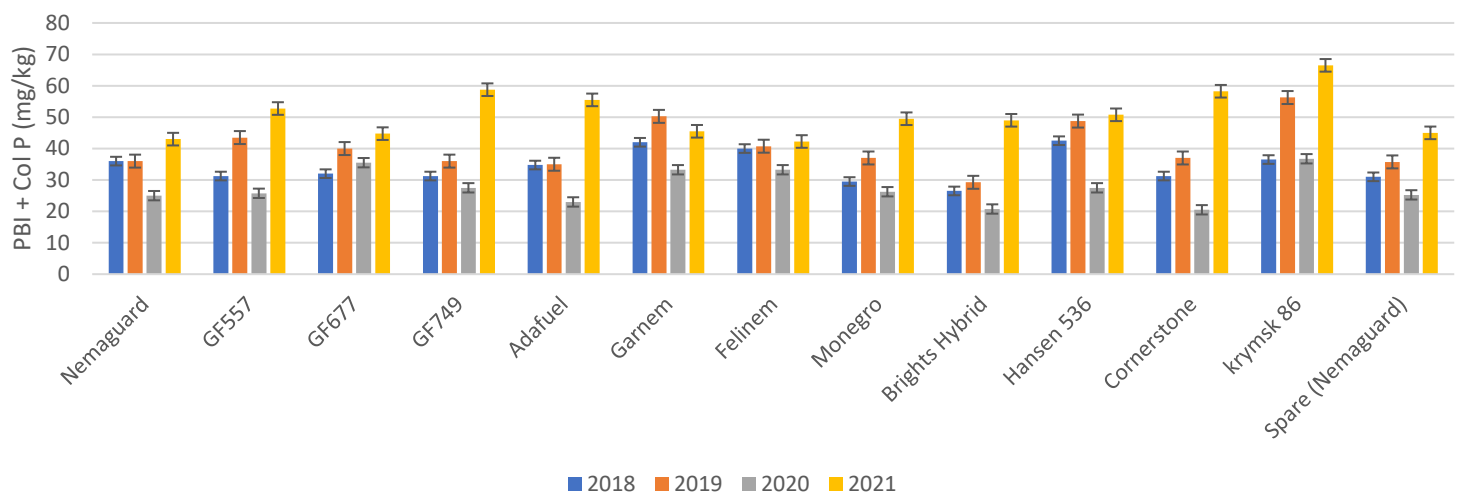


Figure H- 22: Mean soil PBI + Col P (mg/kg).

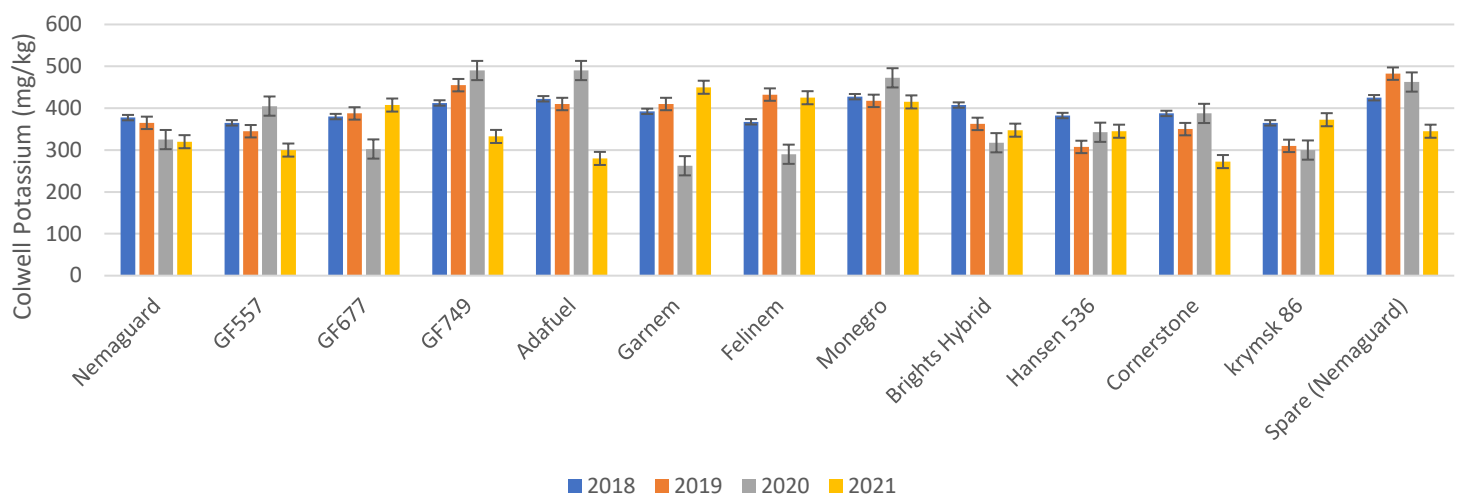


Figure H-23: Mean soil Colwell Potassium (mg/kg).

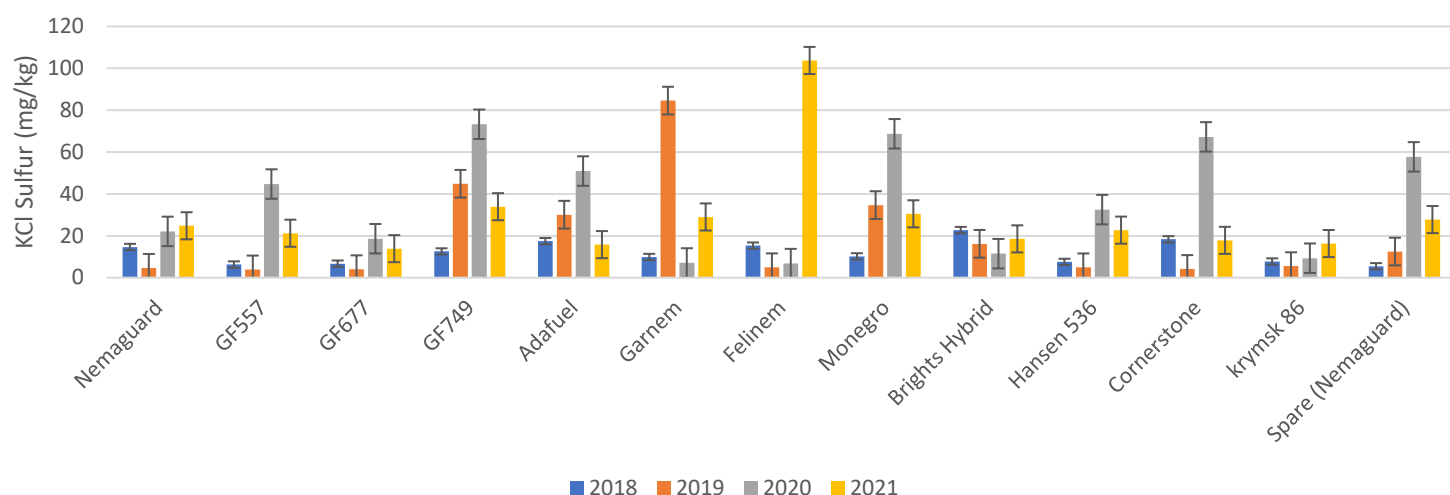


Figure H- 24: Mean soil KCl Sulfur (mg/kg).

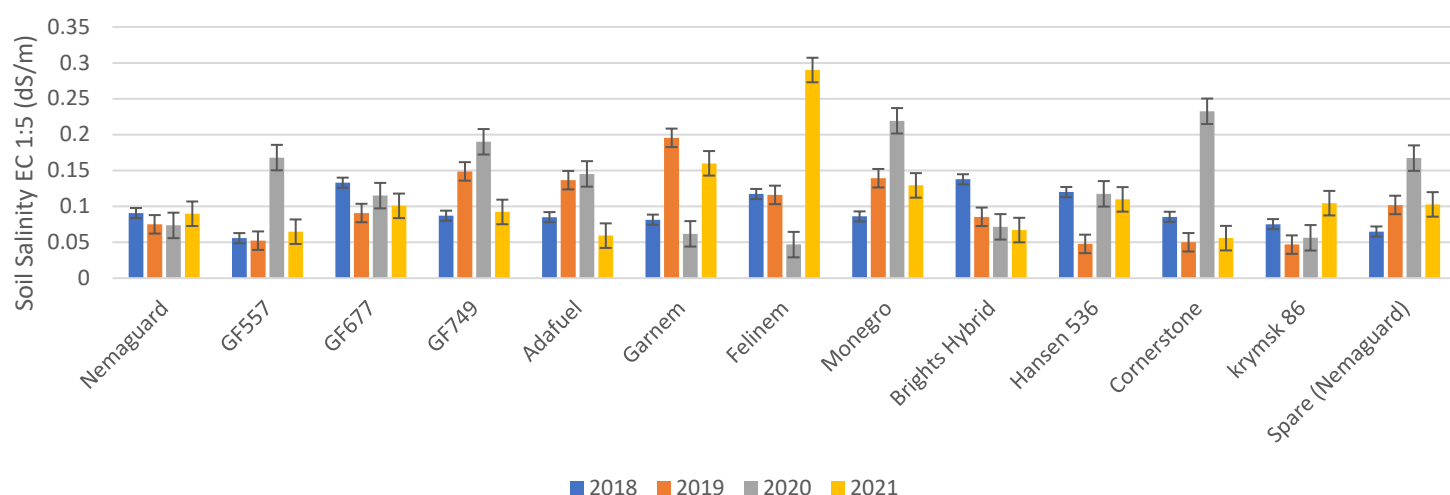


Figure H- 25: Mean soil salinity EC 1:5 (dS/m).

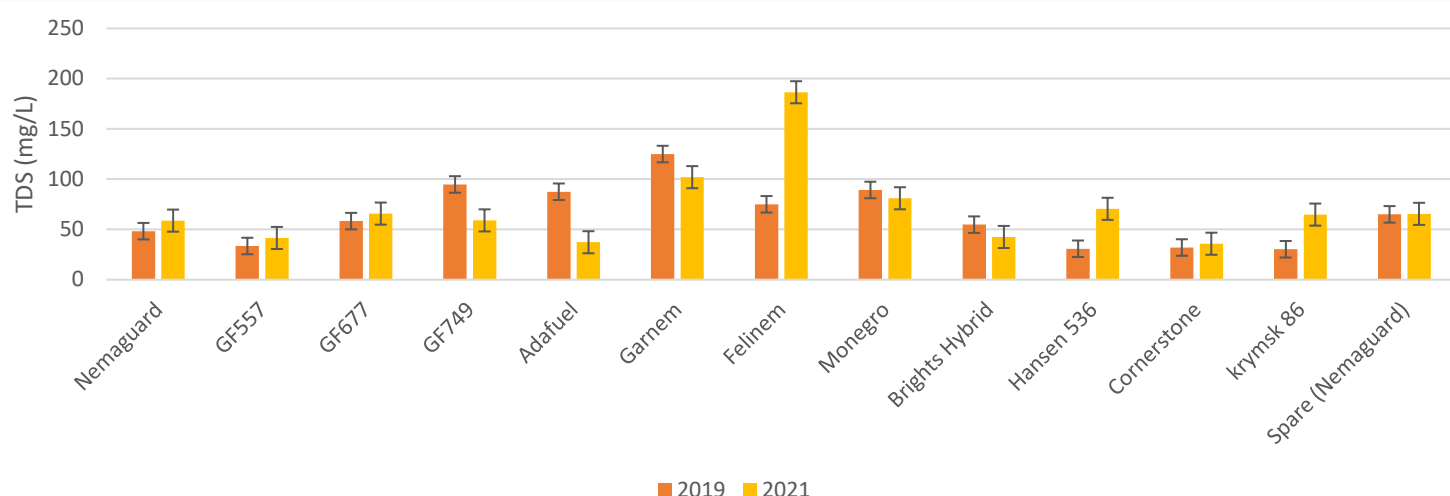


Figure H- 26: Mean soil total dissolved solids - TDS (mg/L) for 2019 and 2021.

AUSTRALIAN ALMOND FIELD DAY



EVALUATION OF PRUNUS ROOTSTOCKS

Fifteen rootstocks originating from the USA, France, Spain and Russia Planted in 2013. This trial has now produced two crops and underwent its first mechanical harvest in 2017. The trial site, located at Lindsay Point contains rootstocks that have been propagated, planted and grafted to common almond cultivars (i.e. Nonpareil, Carmel, Price and Peerless) - this handout contains yield results that have been produced to date.

YIELD

2015/16 HARVEST (HAND HARVESTED)

Rootstock	Observed Yield 2015-16			
	Avg Kernel/ Tree (kg)	Avg Kernel Size (g)	Avg Yield (kg/Ha)	Rank
Krymsk 86	1.08	1.29	370.31	10
Adafuel	0.82	1.25	280.01	12
Brights Hybrid	1.36	1.28	465.93	5
GF 557	1.11	1.27	380.23	9
GF 677	1.61	1.26	551.26	1
GF 749	1.36	1.28	466.33	4
Felinem	1.19	1.28	409.21	7
Monegro	1.36	1.29	464.65	6
Hansen 536	1.17	1.33	400.88	8
Cornerstone	0.37	1.33	125.12	13
Spare (Nemaguard)	1.40	1.28	479.26	3
Nemaguard	1.47	1.24	504.49	2
Garnem	1.06	1.37	362.83	11

CUMULATIVE YIELD

Rootstock	kg/Ha		
	2015/16	2016/17	Rank
Krymsk 86	370.31	1,023.18	13
Adafuel	280.01	1,365.59	8
Brights Hybrid	465.93	1,623.95	3
GF 557	380.23	1,249.92	11
GF 677	551.26	1,569.90	5
GF 749	466.33	1,597.16	4
Felinem	409.21	1,524.78	6
Monegro	464.65	1,775.90	1
Hansen 536	400.88	1,470.85	7
Cornerstone	125.12	1,257.56	10
Spare (Nemaguard)	479.26	1,364.34	9
Nemaguard	540.49	1,232.50	12
Garnem	362.83	1,668.10	2

YIELD

2016/17 HARVEST (MACHINE HARVESTED)

Rootstock	Observed Yield 2015-16				Potential Yield 2016-17		
	Avg Kernel/ Tree (kg)	Avg Kernel Size (g)	Avg Yield (kg/Ha)	Rank	Sticktights/ Tree (Kg)	Rank	Yield Potential (kg/Ha)
Krymsk 86	1.91	1.20	652.87	13	0.52	13	653.39
Adafuel	3.17	1.19	1,085.58	7	0.24	5	1085.82
Brights Hybrid	3.38	1.27	1,158.01	3	0.20	3	1158.21
GF 557	2.54	1.28	869.68	11	0.43	11	870.11
GF 677	2.97	1.30	1,018.64	9	0.28	6	1018.92
GF 749	3.30	1.15	1,130.84	5	0.09	2	1130.92
Felinem	3.26	1.20	1,115.57	6	0.23	4	1115.80
Monegro	3.83	1.17	1,311.25	1	0.33	9	1311.58
Hansen 536	3.12	1.25	1,069.97	8	0.31	7	1070.28
Cornerstone	3.31	1.20	1,132.43	4	0.49	12	1132.93
Spare (Nemaguard)	2.58	1.42	885.07	10	0.69	15	885.77
Nemaguard	2.13	1.27	728.01	12	0.59	14	728.61
Garnem	3.81	1.21	1,305.26	2	0.31	8	1305.58



Adafuel



Brights Hybrid



Cornerstone



Felinem



Garnem



GF557



GF677



GF749



Hansen 536



Krymsk 86



Monegro



Nemaguard

CHARACTERISTICS

Rootstock	Parentage	Intellectual Property		Pathogen Resistance					Soil Adaptation			Effects on the Variety		
		Plant Breeders Rights held	Root knot Nematode	Lesion Nematode	Ring Nematode/Bacterial Canker	Crown Gall	Armillaria	Phytophthora	Anchorage	Chlorosis	Compatibility	Vigour	Propagation by Cuttings	
Bright's	Peach x Almond	No	High	More Tolerant than Nemaguard	Susceptible	Susceptible	Susceptible	Susceptible		Tolerant	Good	High	Poor	
Cadaman (Avimag)	Wild Peach x Peach	Yes	High	Susceptible	Unknown	Susceptible	Susceptible	Unknown		Medium	Good	High	Poor	
Cornerstone	Peach x Almond	Yes	High	Susceptible	Susceptible	Susceptible	Susceptible	Susceptible		Tolerant	Good	High	Good	
Garnem	Peach x Almond	Yes	High	Medium / Susceptible	Unknown	Susceptible	Unknown	Susceptible		Tolerant	Good	High	Good	
Gf677 (Paramount)	Peach x Almond	No	Susceptible	Susceptible	Susceptible	Susceptible		Susceptible		Tolerant	Good	High	Poor	
Hansen 536	Peach x Almond	No	High	More Tolerant than Nemaguard	Susceptible	Susceptible	Susceptible	Susceptible		Tolerant	Good	High	Poor	
Krymsk (Kuban) 86	Peach x Plum	Yes	Susceptible	Medium	Susceptible	Medium	Unknown	Tolerant	V. Good	Medium	Good	Medium	Good	
Nemaguard	Wild Peach x Peach	No	High	Medium	Medium	Medium	Susceptible	Medium		Susceptible	Good	Medium	NA	

USEFUL RESOURCES

Almond Board of Australia - Fact Sheets

Tolerance of almond rootstocks to root-knot nematodes (2013)
<https://growing.australianalmonds.com.au/2015/02/12/tolerance-of-almond-rootstocks-to-root-knot-nematodes/>

MORE INFORMATION

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PROJECT CODE

AL16000 & AL16001

These projects have been funded by Horticulture Innovation Australia Limited using the almond research and development levy and funds from the Australian Government.

Acknowledgements:

The input and suggestions made by Australian almond processors, marketers and growers.

ABA Handout Field Days Rootstocks, UPDATED in April 2017

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ALL ABOUT ALMONDS

EVALUATION OF PRUNUS ROOTSTOCKS

ALMOND BOARD OF AUSTRALIA



TRIAL SUMMARY

This technical document presents the findings from the Evaluation of Prunus Rootstock project - AL16006 undertaken by the Almond Board of Australia (ABA). The aim of this trial was to evaluate the performance of prunus rootstocks under Australian growing environments. By improving our understanding of rootstock performance it will enable better decisions to be made about rootstock selection to suit growing conditions thereby improving profitability and sustainability. In 2021 76% (44,408 hectares) of Australian almond plantings are grafted to Nemaguard. While Nemaguard has several advantages, such as: nematode tolerance, easy propagation, relatively cheap, and moderately vigorous, it has some significant disadvantages such as: moderate vigour; moderate water and nutrient use efficiency; susceptibility to calcareous soils and lime induced chlorosis; susceptibility to root pathogenic disorders in a replant situation; and only moderate tolerance to salinity. Over the last decade there has been an increase in the availability of prunus rootstocks imported into Australia but there is limited information available on their performance in Australian soils and growing environments.

The rootstock evaluation trial site was established by the ABA at Lindsay Point, South Australia in 2013 (project AL11012) on a site previously planted to almonds that were approximately 40 years of age when removed. The trial was established on 3.74-hectares of typical Mallee soils with 30 to 60cm topsoil (loam-sand to sandy-clay-loam) overlying carbonate subsoils. Eleven alternative rootstocks were chosen for their high or medium vigour for comparison against Nemaguard. Rootstocks were sourced through commercially licensed nurseries, grafted to Nonpareil (50%), Carmel (25%) and Peerless (25%), and planted in a randomised block design with four replicates to enable statistical analysis. A 'spare' Nemaguard treatment was included to complete the trial layout. Trees were planted at a density of approximately 342 trees per hectare (7.3m row x 4m tree spacings) and managed using standard commercial management practices for irrigation and fertilizer applications across all replicates with additional foliar sprays and composted manure delved in. Performance measures were collected for the following traits: ease of propagation; flowering; production (seasonal and accumulated yield); vigour; tree habit; water stress; tree nutrition; fruit (crackout, size, weight); graft compatibility; suckering; iron chlorosis; nematode resistance; and fungal pathogen incidence.

This factsheet provides a summary of the observations from the rootstock evaluation trial and characteristics for each rootstock are provided in comparison to Nemaguard. Results are specific to the soil characteristics and management practices applied to the trial site. For more information, please refer to the final report available for download from Hort Innovation website ([LINK](#)).

Presented in Figure 1 below is the cumulative yield from 2016 to 2021. There were seven top performing rootstocks GF749, Monegro, Felinem, Garnem, Hansen 536, and Brights Hybrid producing similar cumulative yields that were not statistically different from each other. Of the top seven all but Brights Hybrid had significantly higher cumulative yields than Nemaguard. GF749 was significantly higher than both Nemaguard and spare Nemaguard. Nemaguard, Adafuel, Cornerstone (see note) and GF557 showed some differences between the high yielding seven but not for all rootstocks. All rootstocks produced yields significantly higher than Krymsk 86 for this site.

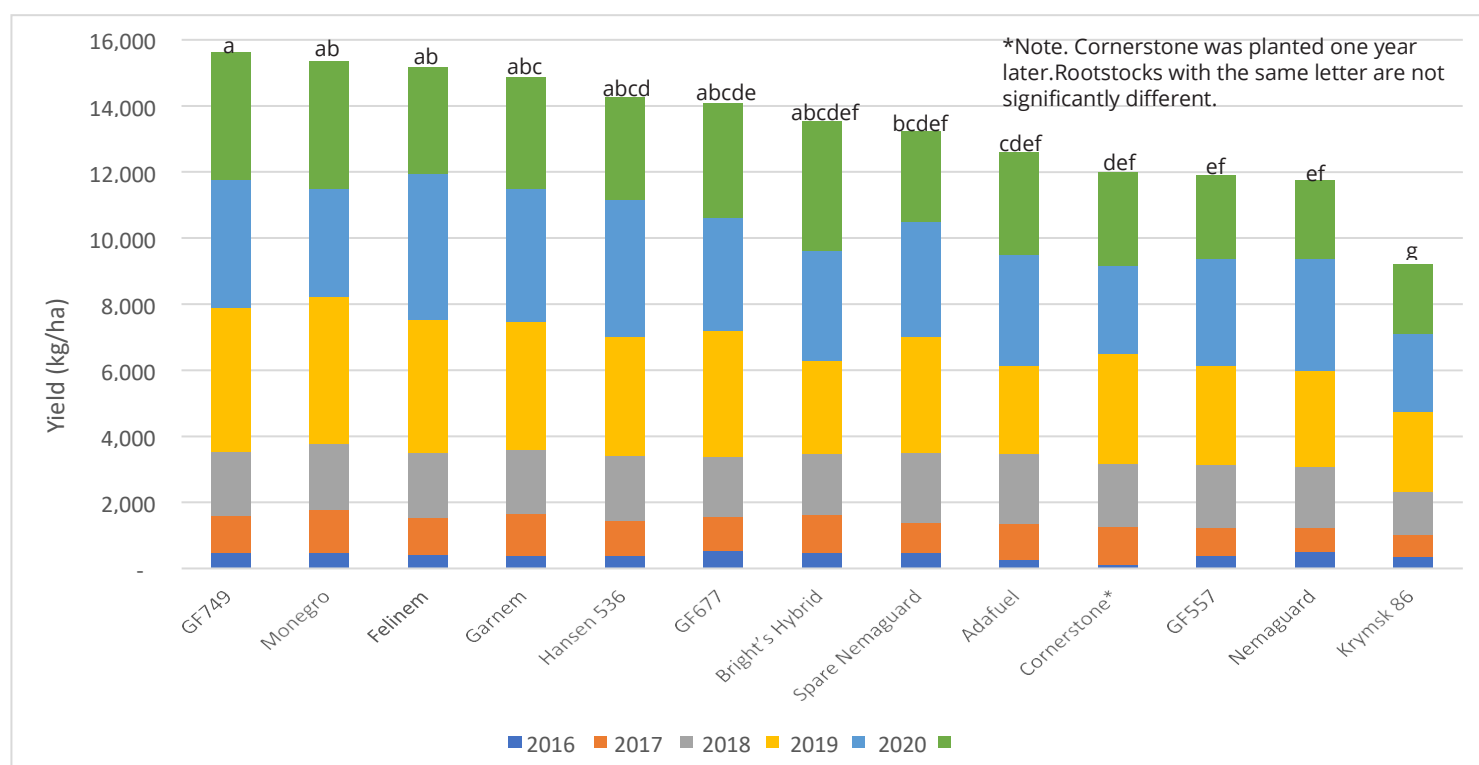


Figure 1. Cumulative yield (kg/ha). Note: Rootstocks that share the same letter do not differ at the 5% levels using Fishers protected Least Significant Difference (LSD).

Table 1 provides a summary of key measurements taken during the project listed in order of their cumulative yield as illustrated in Figure 1. Using trunk circumference (mm) as a measure of tree growth the production efficiency (kg/cm²) was calculated by dividing the average annual yield with the tree trunk area (yield / growth). In 2017 Adafuel, Cornerstone and GF557 had significantly higher production efficiencies compared to Garnem, Brights Hybrid, Nemaguard, Hansen 536 and Krymsk 86 rootstocks. However, the significance of these differences was lost after 2017 meaning trees with larger trunks were no more, or less, productive than trees with smaller trunks after their 4th leaf.

By 2020, GF749 (4.98m) and Garnem (4.98m) had produced significantly taller trees than Nemaguard (4.65m), Cornerstone (4.78m) and Krymsk 86 (4.78m) but not significantly taller than other rootstocks.

Note: Cornerstone was planted one season later than other rootstocks in 2014 and as a result only reached 7th leaf maturity and yield compared to other rootstocks reaching 8th leaf maturity and yield. These results were further complicated in that while these trees were younger, they received the same fertilizer and irrigation amounts as the older trees enabling tree growth and yields for Cornerstone to catch up to that of other rootstocks. These factors made it difficult to directly compare Cornerstone performance against other rootstocks in this trial.

Table 1. Summary observations.

Rootstock	2020 Trunk circumference (mm)	Fishers LSD*	2021 average yield (unadjusted) (kg/ha)	Cumulative yield (kg/ha)	Fishers LSD*	2017 Production efficiency (kg/cm ²)	Fishers LSD*	2020 average height (m)	Fishers LSD*
GF749	572.29	abc	3,846.56	15,597.21	a	0.077	ab	4.975	c
Monegro	608.75	cd	3,871.64	15,369.32	ab	0.084	ab	4.875	bc
Felinem	605.42	cd	3,211.19	15,168.62	ab	0.077	ab	4.925	bc
Garnem	572.1	abc	3,377.87	14,876.85	abc	0.061	bc	4.975	c
Hansen 536	619.58	d	3,103.80	14,276.15	abcd	0.040	c	4.900	bc
GF677	569.50	abc	3,464.41	14,088.51	abcde	0.080	ab	4.925	bc
Brights Hybrid	560.42	ab	3,914.46	13,519.39	abcdef	0.059	bc	4.925	bc
Spare Nemaguard	556.25	a	2,735.75	13,243.15	bcdef	0.070	ab	4.825	bc
Adafuel	600.21	bcd	3,106.40	12,587.77	cdef	0.095	a	4.925	bc
Cornerstone*	540.4	a	2,823.53	11,987.40	def	0.095	a	4.775	a
GF557	564.58	ab	2,520.11	11,885.96	ef	0.092	a	4.875	bc
Nemaguard	549.8	a	2,373	11,737.62	f	0.057	bc	4.650	a
Krymsk 86	568.8	abc	2,089	9,204	g	0.04	c	4.775	a
Standard Error		14	NA		1147		0.010		0.081
P value		<0.01	NA				0.008		0.012
LSD		40.2	NA		2321		0.028		0.164

*Note: Rootstocks that share the same letter do not differ at the 5% levels using Fishers protected LSD.

Leaf analyses indicated a significant correlation between yield and leaf calcium (Ca) and magnesium (Mg) levels. Rootstock with the highest uptake of both Ca and Mg were observed for Hansen 536, Garnem and Monegro. These rootstocks were in the top six highest yielding (cumulative yield) rootstocks with GF749 having high Ca and mid-range Mg levels. The lowest levels of leaf Ca and Mg were observed for the two Nemaguard rootstocks and Krymsk 86.

In 2021, there was a significant correlation between yield and leaf sodium with high sodium levels correlating with low yields. The lowest levels of leaf sodium were observed for GF557, Monegro and GF749 and the highest levels were observed in Krymsk and Nemaguard. Both Krymsk and Nemaguard have been found to be poor excluders of sodium and chloride and may have contributed to low yield performance even when soil salinities were below the level of 1.5dS/m considered to affect yield.

Flowering observations were recorded at each flowering stage including start, full bloom and end of flowering. The days of flowering are presented in Figure 2 compared to Nemaguard flowering dates showing the maximum and minimum number of days for each flowering stage. In general, some rootstocks appear to bring forward the start of flowering when compared with Nemaguard. For example, GF749 and Adafuel started flowering, on average, two days earlier, GF557 one day earlier, and Krymsk half a day earlier. Conversely, flowering start times appeared delayed for Felinem by 1.5 days and Hansen 536 by 0.75 days. Flowering periods were shorter for Krymsk 86 (22.5 days), GF557 and Adafuel (24.75days), and GF749 (25 days) and longer for Garnem (27days) and Monegro (27.25 days) when compared with Nemaguard (26 days). End of flowering appeared to be more variable for all rootstocks compared to Nemaguard. These observations were only taken for replicate 1 and were therefore not statistically analysed.

A hull split assessment was done in 2021 recording the timing of hull split for each rootstock with the number of fruit reaching stage 3 presented in Figure 3 and the number of fruit reaching stage 6 presented Figure 4. Nuts on Krymsk 86 matured rapidly reaching 97% stage 3 hull split significantly earlier (18 January 2021) than GF749, Monegro and Brights Hybrid. All rootstocks had reached 100% stage 3 hull split by the 25 January except for Brights Hybrid which had only 53% of nuts reaching 100% stage 3 hull split on the same day.

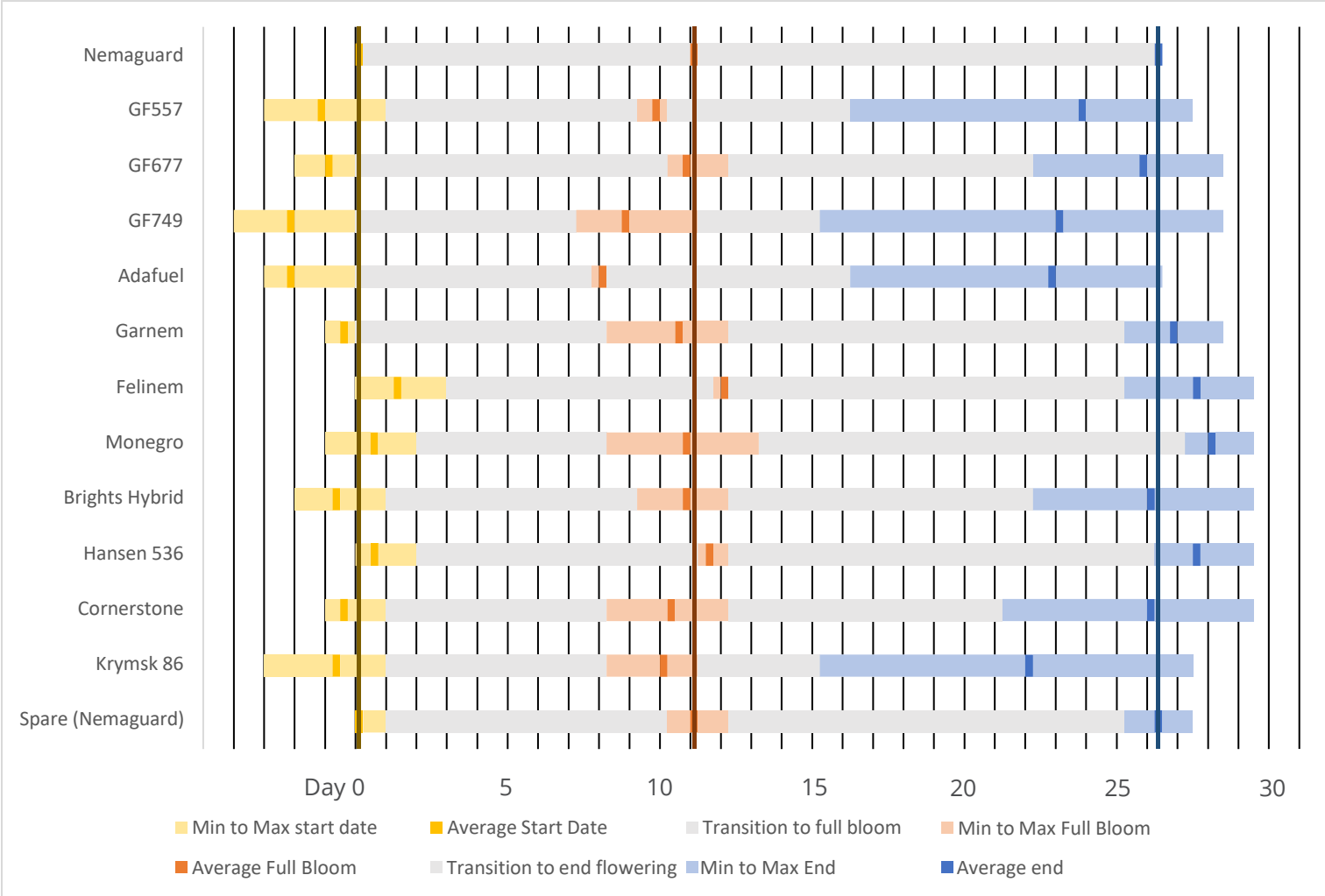


Figure 2. Flowering observations 2017 - 2020. Variation in flowering dates compared to Nemaguard.

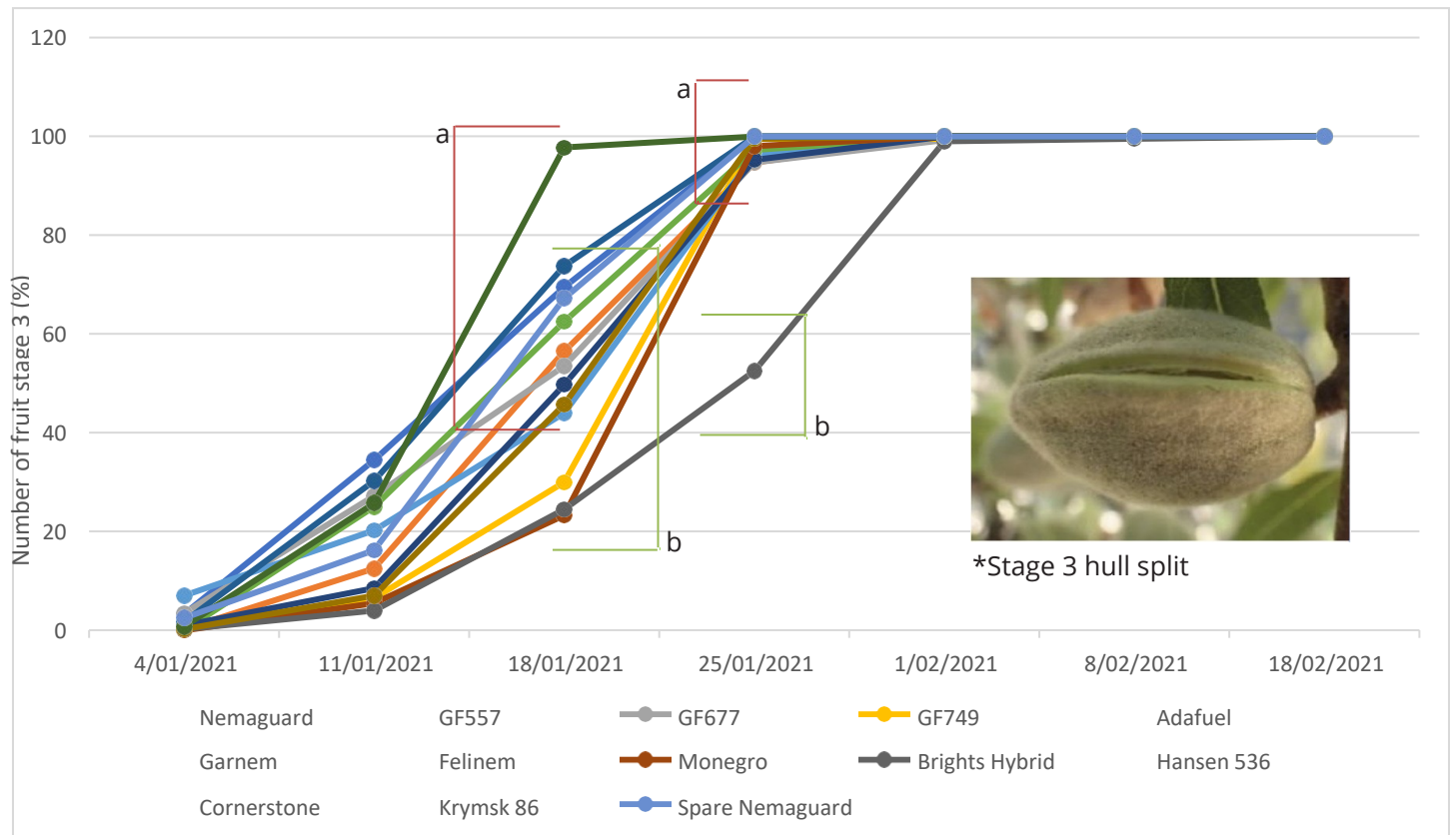


Figure 3. Percentage of hull split at stage 3 or beyond (2021 only).

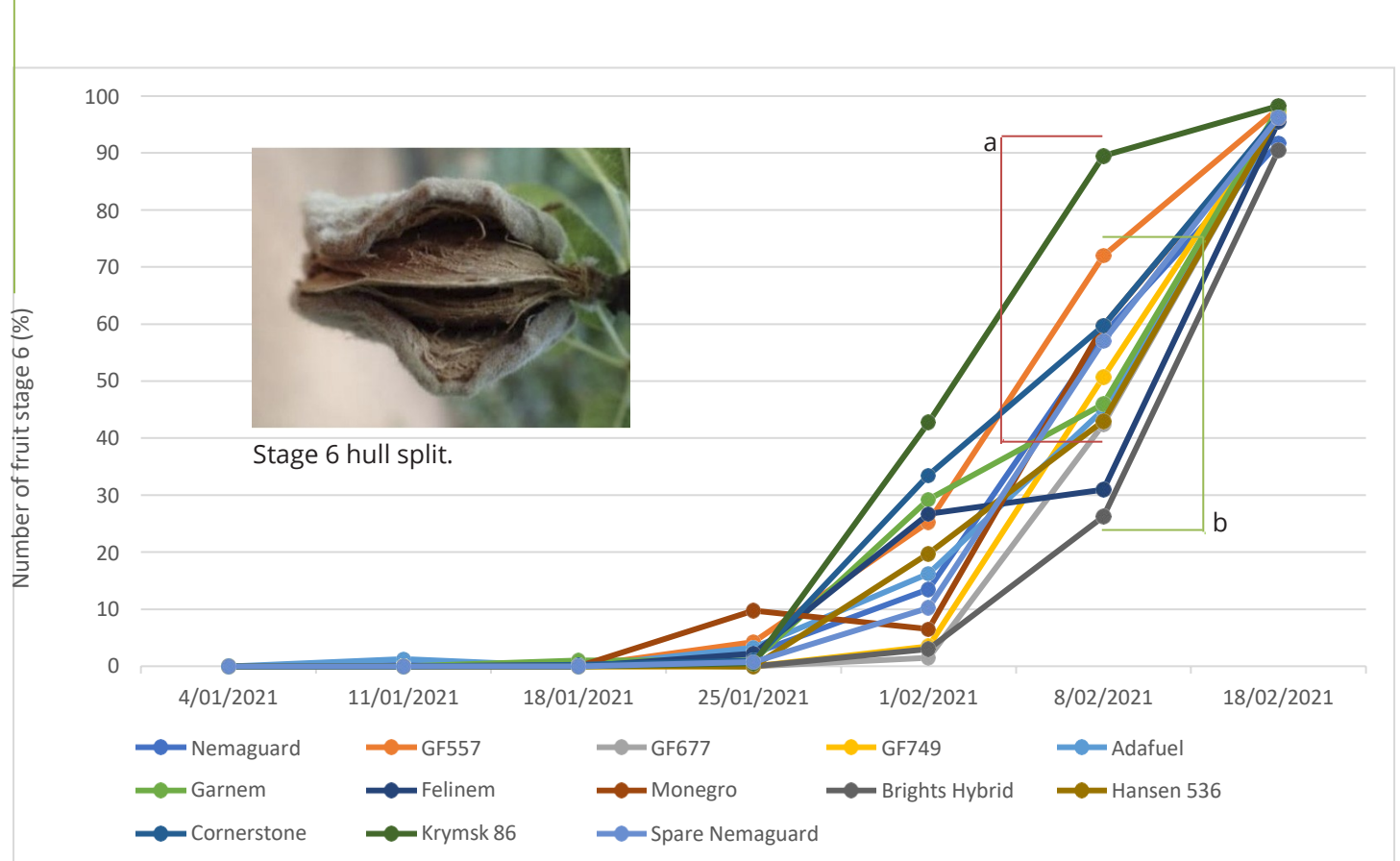


Figure 4. Percentage of hull split at stage 6 or beyond (2021 only).

Performance summary

GF749 was among the top seven highest performing rootstocks in terms of cumulative yield. Results are specific to the soil characteristics and management practices applied to the trial site. GF749 was able to produce consistently high yields with a good balance between canopy growth and crop production. There was some variability between replicates and ongoing monitoring will be important to see if these trends continue. GF749 has medium to high susceptibility to one or more species of root-knot nematodes and future monitoring will determine if increased nematode populations at this site will impact future yields.

Key observations

Tree Habit

Using trunk circumference as an indicator of tree growth, Nonpareil trees grown on GF749 had similar average growth (572mm) compared with Nemaguard (547mm, Figure 5).

Trees grown on GF749 produced one of the taller canopies averaging a height of 4.98m, significantly higher than Nemaguard 4.65m but similar to spare Nemaguard 4.83m. Visual observations suggest that while the inner scaffold has pushed canopy growth the canopy remained open in its 8th leaf enabling good light interception (Figure 8).

Production

GF749 produced consistently high yields each season for mature crops compared with Nemaguard (Table 2). Between 2019 and 2021 (6th to 8th leaf) there was only one outlying yield that was below 2,000kg/ha in 2020 for Replicate 3 (Figure 6).

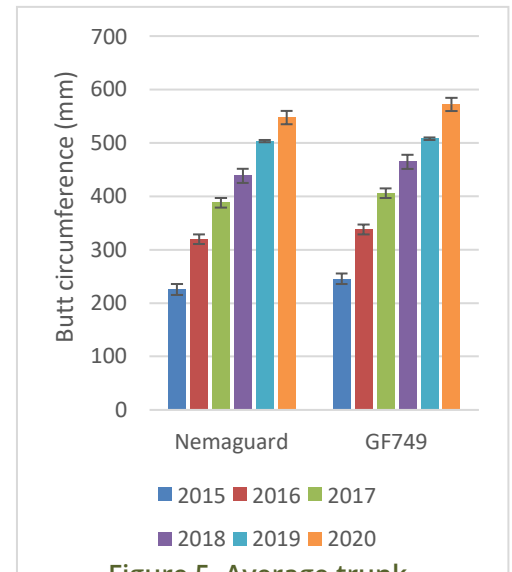


Figure 5. Average trunk circumference.

Table 2. Average annual yields (kg/ha).

Rootstock	2016	2017	2018	2019	2020	2021	Cumulative
GF749	469	1,133	1,939	4,355	3,855	3,847	15,597
Nemaguard	508	731	1,831	2,919	3,377	2,373	11,738

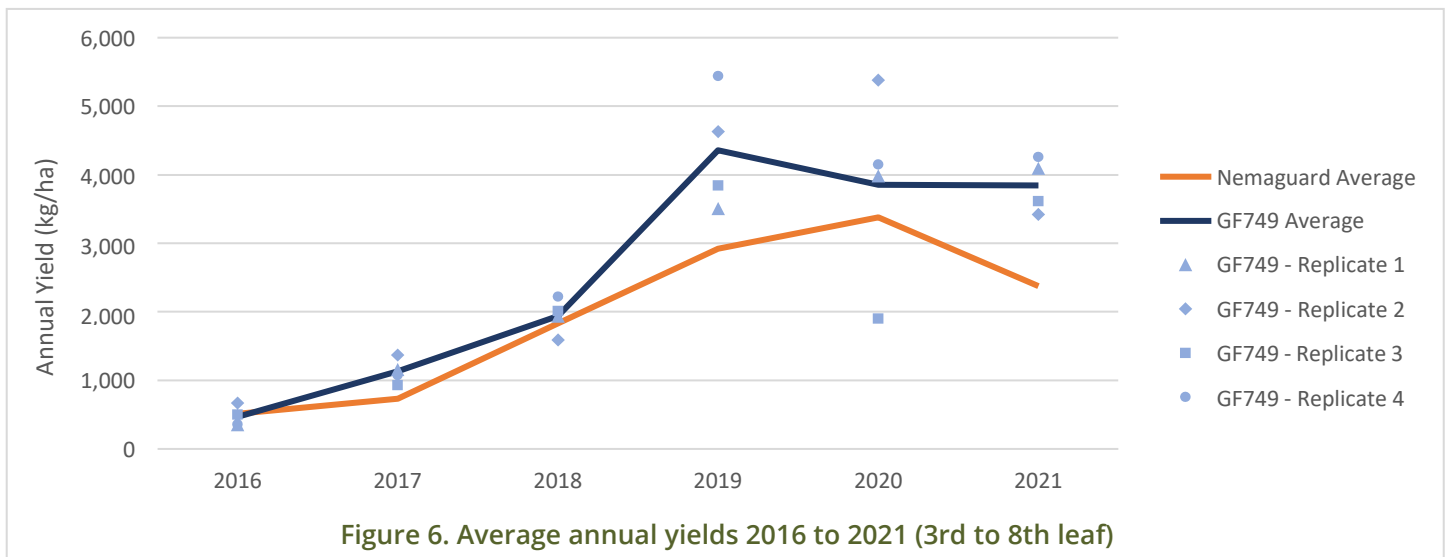


Figure 6. Average annual yields 2016 to 2021 (3rd to 8th leaf)

Rootstock characteristics

Investigations into root-knot susceptibility for rootstocks in Australia indicate GF749 has medium to high susceptibility to root-knot nematode *M. incongnita* and *M. javanica* and should be avoided where high nematode pressures are expected. In 2021 trial plots indicated a moderate population of root-knot nematode. Continued monitoring will help to determine any increase in nematode population and how this impacts yield.

GF749 brought forward the start of flowering by 2 days on average and reached full bloom earlier than Nemaguard. GF749 had low levels of leaf sodium suggesting it has good salt tolerance excluding sodium and chloride from the soil.

Table 3. Rootstock characteristics.

Root knot Nematode	Lesion Nematode	Ring Nematode	Crown Gall	Armillaria	Phytophthora	Salt exclusion	Chlorosis	Vigour	Propagation by cuttings
Characteristics are unpublished for GF749.									



Figure 7. Juvenile tree - 2017.



Figure 8. Mature tree - 2021.



Figure 9. Graft union - 2021.

Performance summary

Spanish bred Monegro (GN-9) was among the top seven highest performing rootstocks in terms of cumulative yield. Results are specific to the soil characteristics and management practices applied to this trial site. Monegro rootstock produced strong early growth with a higher canopy growing into the available space. Yields were higher than Nemaguard up to their 6th leaf. Some variability in seasonal yield was observed in their 7th leaf. Monegro has medium to high susceptibility to one or more species of root-knot nematodes and should be avoided where high nematode populations are expected. Monegro had low levels of leaf sodium suggesting it has good salt tolerance.

Key observations

Tree Habit

Using trunk circumference as an indicator of tree growth, Nonpareil trees grown on Monegro had significantly higher average growth (608.75mm) compared with Nemaguard (550mm) in 2020 (Figure 10).

Monegro trees had strong early growth producing taller trees (4.54m) with the second widest canopy in 2017 (4.94m) and a slightly more spreading canopy. By 2021 the rootstock filled the available canopy space with tree height (4.88m) significantly higher than Nemaguard (4.65m) but similar to the spare Nemaguard height 4.83m (Figure 13).

Production

Monegro produced consistently strong early yields (Table 4) across the four replicates with yields over 4 t/ha up to the 6th leaf in 2019 (Figure 11). In 2020 the average yield dropped due to lower yields in replicates 2 (2,423kg/ha) and 3 (1,897kg/ha).

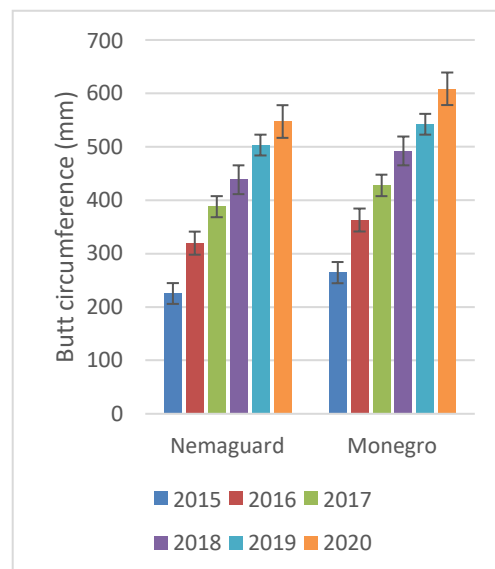


Figure 10. Average trunk circumference.

Table 4. Average annual yields (kg/ha).

Rootstock	2016	2017	2018	2019	2020	2021	Cumulative
Monegro	468	1,308	2,010	4,446	3,265	3,872	15,369
Nemaguard	508	731	1,831	2,919	3,377	2,373	11,738

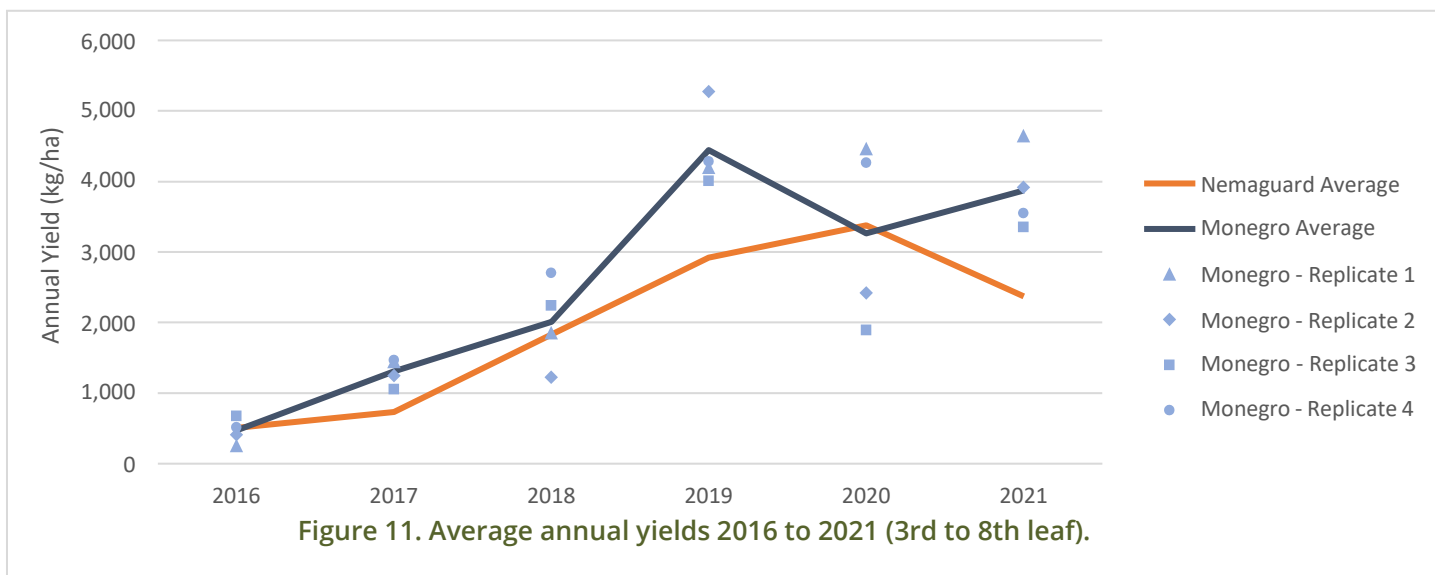


Figure 11. Average annual yields 2016 to 2021 (3rd to 8th leaf).

Rootstock characteristics

Literature states that Monegro has strong drought tolerance which will be an important feature for industry to cope with predicted drier growing climates. Investigations into root-knot susceptibility for rootstocks in Australia showed Monegro had a medium to high susceptibility to root-knot nematode *M. incongnita* and *M. javanica* and root lesion nematode *Pratylenchus vulnus* and should be avoided where high nematode pressures are expected. Monegro had low levels of leaf sodium suggesting it has good salt tolerance, able to exclude sodium and chloride from the soil.

Table 5. Rootstock characteristics.

Root knot Nematode	Lesion Nematode	Ring Nematode	Crown Gall	Armillaria	Phytophthora	Salt exclusion	Chlorosis	Vigour	Propagation bycuttings
Susceptible	Susceptible		Susceptible			Tolerant	Tolerant		Good



Figure 12. Juvenile tree - 2017.



Figure 13. Mature tree - 2021.



Figure 14. Graft union - 2021.

Performance summary

Spanish bred Felinem (GN-22) was among the top seven highest performing rootstocks in terms of cumulative yield. Results are specific to the soil characteristics and management practices applied to this trial site. Felinem produced a tree with higher growth characteristics including trunk circumference and canopy size than Nemaguard. Further monitoring will be needed to determine the effect of canopy growth on light interception and tree yield. Felinem delayed all stages of flowering start, full bloom and end of flowering compared with Nemaguard.

Key observations

Tree Habit

Using trunk circumference as an indicator of tree growth, Nonpareil trees grown on Felinem had one of the larger trunk circumferences (605mm) and was significantly higher than Nemaguard and spare Nemaguard (Figure 15).

In 2020 Nonpareil trees grown on Felinem were among the largest trees in the trial for width (6.42m) and height (4.93m) readily occupying the available growing space (Figure 18).

Production

Some variability within replicates was observed for seasonal yields and some decline in yield noted in the 8th leaf. Ongoing monitoring of seasonal yields will help establish any tendency towards biennial bearing.

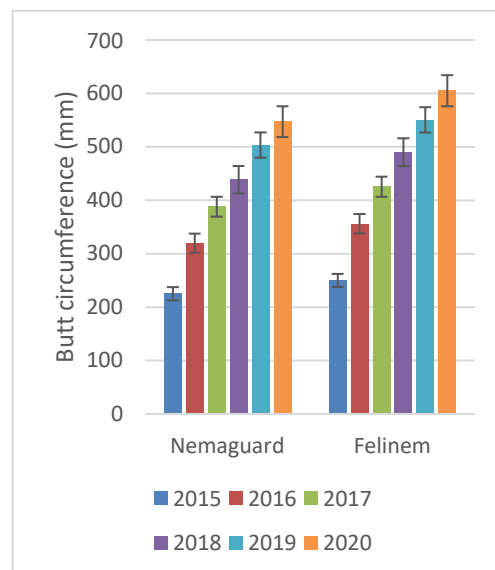


Figure 15. Average trunk circumference.

Table 6. Average annual yields (kg/ha).

Rootstock	2016	2017	2018	2019	2020	2021	Cumulative
Felinem	415	1,127	1,962	4,009	4,445	3,211	15,169
Nemaguard	508	731	1,831	2,919	3,377	2,373	11,738

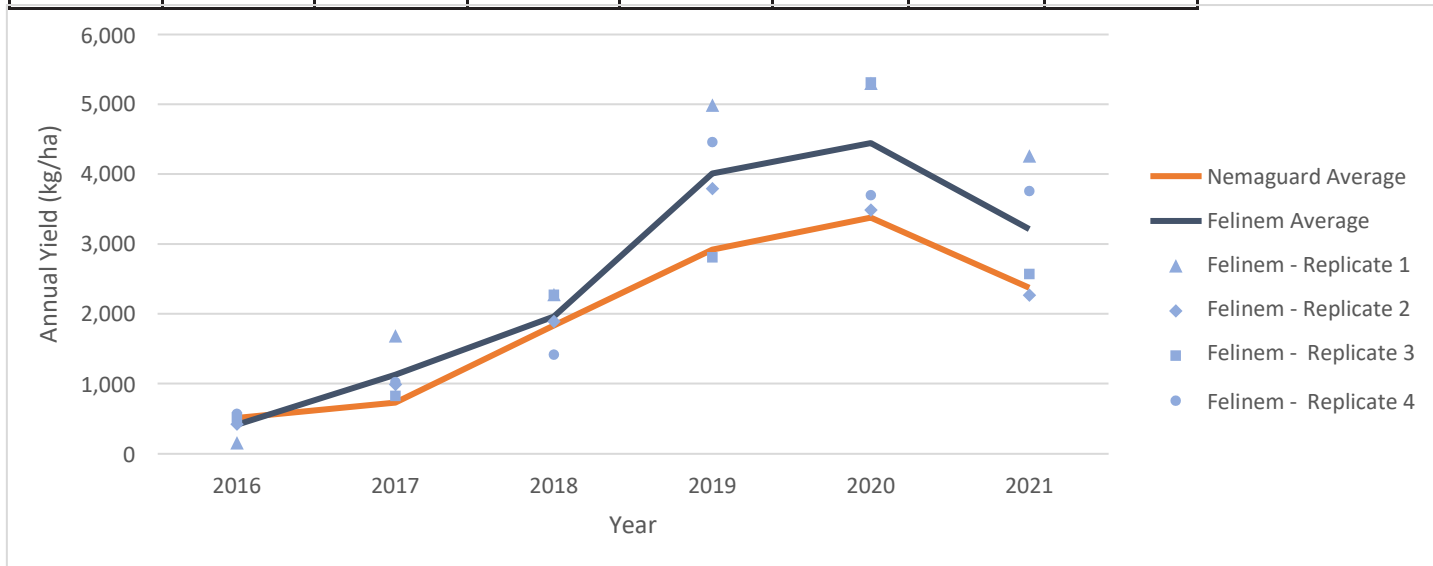


Figure 16. Average annual yields 2016 to 2021 (3rd to 8th leaf).

Rootstock characteristics

On average Felinem delayed the start of flowering by 1.5 days and full bloom and end of flowering were also later than Nemaguard (Figure 2).

Table 7. Rootstock characteristics.

Root knot Nematode	Lesion Nematode	Ring Nematode	Crown Gall	Armillaria	Phytophthora	Salt exclusion	Chlorosis	Vigour	Propagation by cuttings
Moderate resistance	Moderate resistance		Susceptible			Unknown	Tolerant		Good



Figure 17. Juvenile tree - 2017.



Figure 18. Mature tree - 2021.



Figure 19. Graft union - 2021.

Performance summary

Spanish bred Garnem (GN-15) was among the top seven highest performing rootstocks in terms of cumulative yield. Results are specific to the soil characteristics and management practices applied to this trial site. Garnem resulted in vigorous trees with a spreading habit that were significantly higher than Nemaguard. Of the top seven rootstocks Garnem rootstock is commercially available as a grafted tree in Australia.

Key observations

Tree Habit

Using trunk circumference as an indicator of tree growth, Nonpareil trees grown on Garnem (572mm) were not significantly different from Nemaguard (550mm) or spare Nemaguard (556mm) (Figure 20). Statistical analysis undertaken in years 2016, 2018 and 2020 applied some adjustment to account for a tree death in Replicate 3.

Garnem produced the largest trees in the trial significantly higher (4.98m) than Nemaguard (4.65m) but not significantly different from spare Nemaguard (4.83m). The trees had a spreading canopy that readily filled the available canopy space by 8th leaf.

Production

Seasonal yields for Garnem had little variability each year, except in 2020 where some variability was observed between replicates (Figure 21). Average seasonal yields followed a similar trend to Nemaguard with a slight decline in 8th leaf.

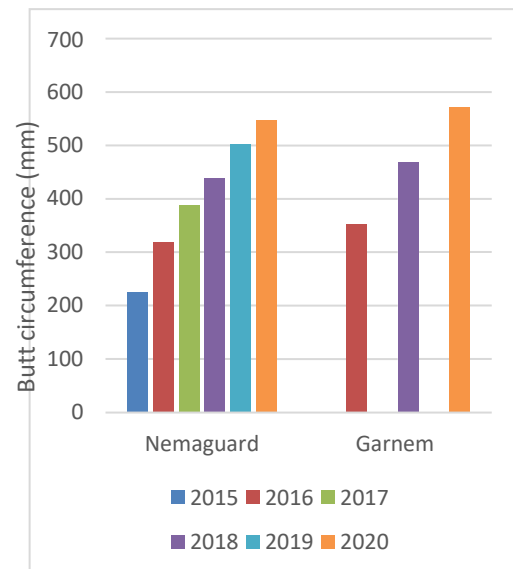


Figure 20. Statistically adjusted trunk circumference.

Table 8. Average annual yields (kg/ha).

Rootstock	2016	2017	2018	2019	2020	2021	Cumulative
Garnem	365	1,301	1,936	3,859	4,038	3,378	14,877
Nemaguard	508	731	1,831	2,919	3,377	2,373	11,738

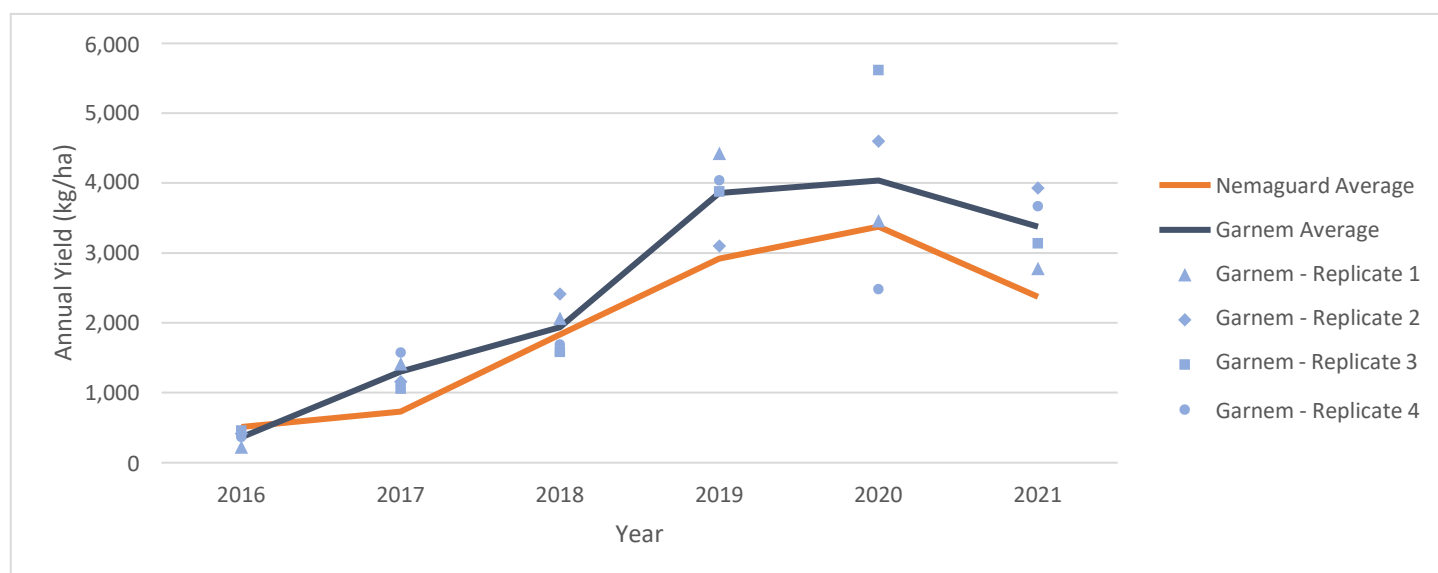


Figure 21. Average annual yields 2016 to 2021 (3rd to 8th leaf).

Rootstock characteristics

While susceptible to root-lesion nematode, only low populations of ring nematode were recorded in this trial and their impact on Garnem is unknown.

Table 9. Rootstock characteristics.

Root knot Nematode	Lesion Nematode	Ring Nematode	Crown Gall	Armillaria	Phytophthora	Salt exclusion	Chlorosis	Vigour	Propagation by cuttings
High resistance	Medium / Susceptible	Unknown	Susceptible	Unknown	Susceptible	Excluder	Tolerant	High	Good



Figure 22. Juvenile tree - 2017.



Figure 23. Mature tree - 2021.



Figure 24. Graft union - 2021.

Performance summary

Hansen 536 was among the top seven highest performing rootstocks in terms of cumulative yield. Results are specific to the soil characteristics and management practices applied to this trial site. Hansen 536 produced trees with the largest trunk circumference and one of the larger tree canopies in the trial. Average annual yields followed a similar trend as Nemaguard. Hansen 536 had significantly higher leaf calcium (Ca) and magnesium (Mg) levels which correlated with other rootstocks with higher yields. Earlier start of flowering by 0.75 days was observed for Hansen 536 compared to Nemaguard.

Key observations

Tree Habit

Using trunk circumference as an indicator of tree growth, Nonpareil trees grown on Hansen (619.6mm) were significantly larger than Nemaguard (549.8mm) in 2020 (Figure 25) and significantly larger than all other rootstocks (Table 1).

Hansen produced one of the larger canopies, 5.83m wide and 4.9m high, significantly higher than Nemaguard (4.65m) but not significantly higher than spareNemaguard (4.83m). Early canopy areas and light interception were higher for Hansen 536 than Krymsk 86 but not significantly different than other rootstocks. These differences were lost by 2021.

Production

Hansen 536 larger canopy growth has assisted in producing average seasonal yields slightly higher than Nemaguard each year resulting in a cumulative yield significantly higher than Nemaguard. As seen in Figure 26 average seasonal yields follow a similar trend to that of Nemaguard.

Strong early growth meant Hansen 536 had a low production efficiency (0.04kg/cm²) not significantly different from the production efficiency for Nemaguard (0.057kg/cm²). Differences in production efficiency were no longer observed in 2020.

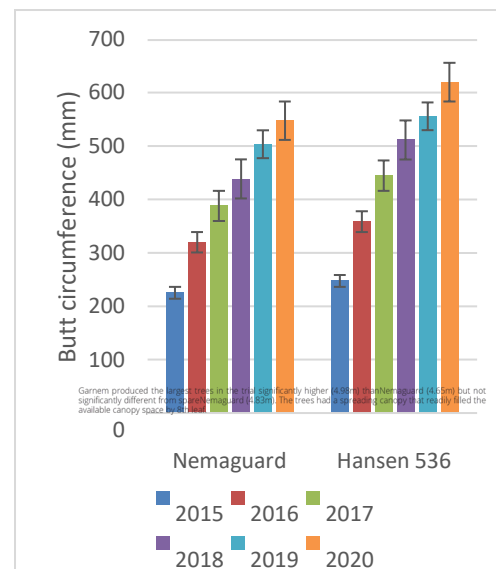


Figure 25. Average trunk circumference.

Table 10. Average annual yields (kg/ha).

Rootstock	2016	2017	2018	2019	2020	2021	Cumulative
Hansen 536	401	1,062	1,940	3,618	4,151	3,104	14,276
Nemaguard	508	731	1,831	2,919	3,377	2,373	11,738

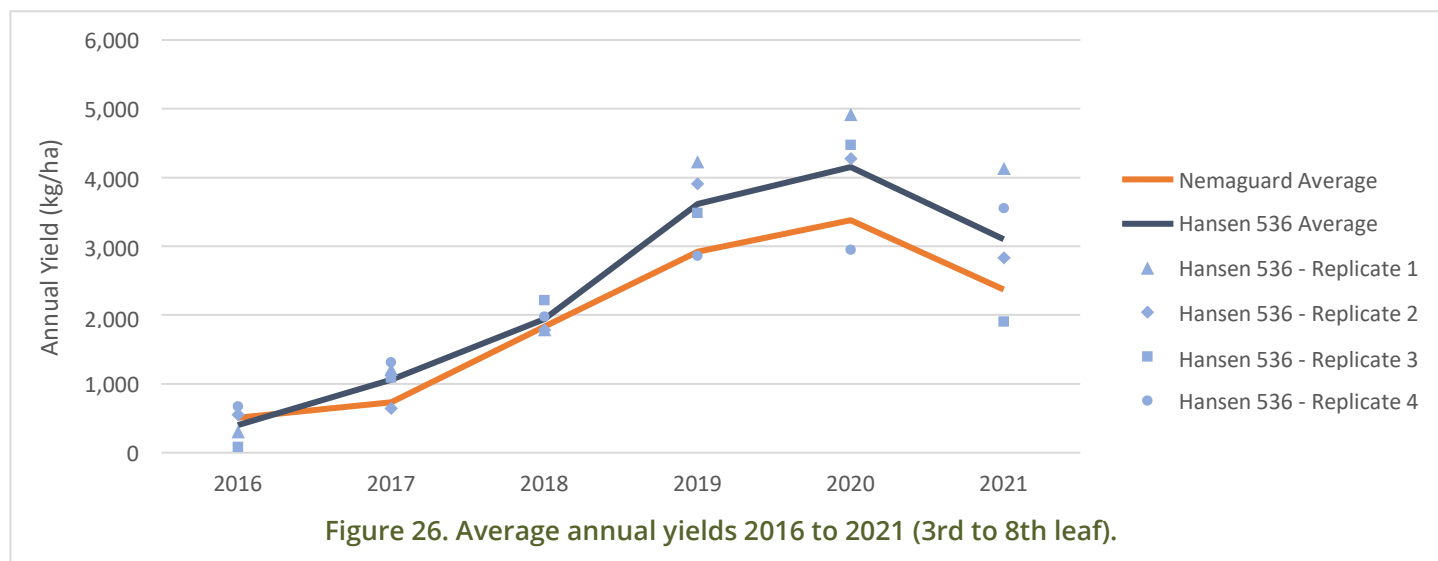


Figure 26. Average annual yields 2016 to 2021 (3rd to 8th leaf).

Rootstock characteristics

Leaf analyses indicated a highly significant correlation between yield and leaf calcium (Ca) and magnesium (Mg) levels with Hansen 536 having the highest uptake of both Ca and Mg.

On average Hansen 536 delayed the start of flowering by 0.75 days with full bloom and end of flowering also slightly later than Nemaguard (Figure 2).

Table 11. Rootstock characteristics.

Root knot Nematode	Lesion Nematode	Ring Nematode	Crown Gall	Armillaria	Phytophthora	Salt exclusion	Chlorosis	Vigour	Propagation by cuttings
High resistance	More tolerant than Nemaguard	Susceptible	Susceptible	Susceptible	Susceptible	Resistant/ Excluder	Tolerant	High	Poor



Figure 27. Juvenile tree - 2017.



Figure 28. Mature tree - 2021.



Figure 29. Graft union - 2021.

Performance summary

GF677 was among the top seven highest performing rootstocks in terms of cumulative yield. Results are specific to the soil characteristics and management practices applied to this trial site. GF677 produced trees with similar trunk circumferences to Nemaguard and tree canopies were upright with open upper canopies. GF677 is susceptible to root-knot nematode and low levels detected in the trial will need to be monitored to determine if these populations increase and what effect (if any) they have on future yields. Of the top seven rootstocks GF677 rootstock is commercially available as a grafted tree in Australia.

Key observations

Tree Habit

Using trunk circumference as an indicator of tree growth, Nonpareil trees grown on GF677 (570mm) were not significantly larger than Nemaguard (549.8mm) in 2020.

In 2020, GF677 produced upright tree canopies (Figure 33) that were narrower (4.72m) than their height (4.93m) and significantly higher than Nemaguard (4.65m) but not significantly higher than the spare Nemaguard (4.83m). The upper part of the canopy is slightly less dense than the lower parts, leaving room for more growth in the future years.

Early canopy areas and light interception (canopy densities) were higher for GF677 than Krymsk 86 but not significantly different than other rootstocks. These differences were lost by 8th leaf.

Production

GF677 produced seasonal yields that were similar and slightly higher than Nemaguard each year resulting in a cumulative yield significantly higher than Nemaguard but similar to spare Nemaguard (Table 1), achieving over 3 tonnes per hectare by 2019. In 2020 an outlying yield was observed in Replicate 4 reducing the average annual yield harvested in that year.

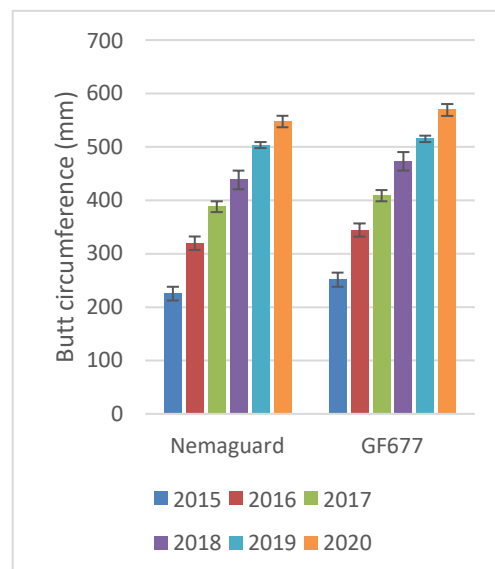


Figure 30. Average trunk circumference.

Table 12. Average annual yields (kg/ha).

Rootstock	2016	2017	2018	2019	2020	2021	Cumulative
GF677	549	1,010	1,829	3,803	3,433	3,464	14,089
Nemaguard	508	731	1,831	2,919	3,377	2,373	11,738

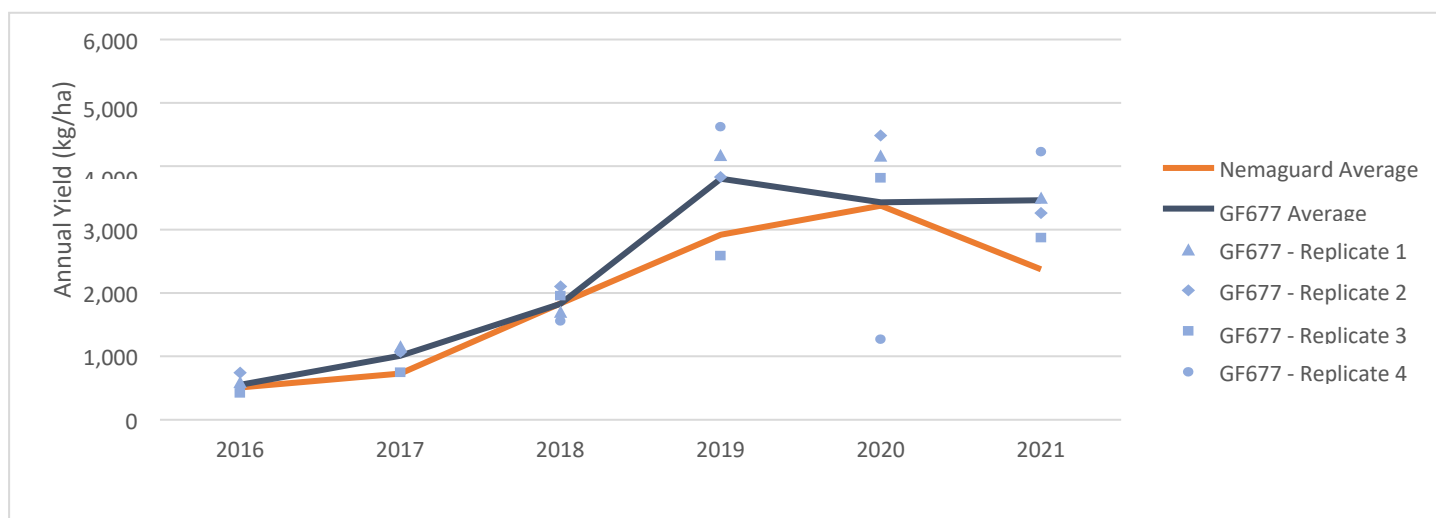


Figure 31. Average annual yields 2016 to 2021 (3rd to 8th leaf).

Rootstock characteristics

Root knot nematode was observed in the soil at low levels for GF677. Given GF677 is susceptible to root-knot nematode continued monitoring will determine if population increases at this site impact on future yield.

Table 13. Rootstock characteristics.

Root knot Nematode	Lesion Nematode	Ring Nematode	Crown Gall	Armillaria	Phytophthora	Salt exclusion	Chlorosis	Vigour	Propagation by cuttings
Susceptible	Susceptible	Susceptible	Susceptible		Susceptible	Excluder	Tolerant	High	Poor



Figure 32. Juvenile tree - 2017.



Figure 33. Mature tree - 2021.



Figure 34. Graft union - 2021.

Performance summary

Bright's Hybrid was among the top seven highest performing rootstocks in terms of cumulative yield. Results are specific to the soil characteristics and management practices applied to this trial site. Early canopy growth produced yields that were similar to Nemaguard and steadily increased each year. Bright's Hybrid had a significant delay in nut maturity where only 53% of nuts had reached stage 3 hull split by 25th January 2021 where all other rootstocks had reached 100% by the same day. Of the top seven rootstocks Brights Hybrid is one that is commercially available as a grafted tree in Australia.

Key observations

Tree Habit

Using trunk circumference as an indicator of tree growth, Nonpareil trees grown on Brights Hybrid (560.4mm) were not significantly larger than Nemaguard (549.8mm) in 2020.

In 2020, Brights Hybrid produced tree canopies that were 5.74m wide and 4.93m tall, and significantly higher than Nemaguard (4.65m) but not significantly higher than the spare Nemaguard (4.83m).

Canopy areas and light interception were higher for Brights Hybrid than Krymsk 86 but not significantly different than other rootstocks. These differences were lost by 8th leaf.

The lower canopy had quite dense growth with sparse limb growth into the upper canopy (Figure 38).

Production

Bright's Hybrid showed a steady increase in average seasonal yield over time unlike many other rootstocks where the average annual yield in 2020 and / or 2021 declined below 2019 levels.

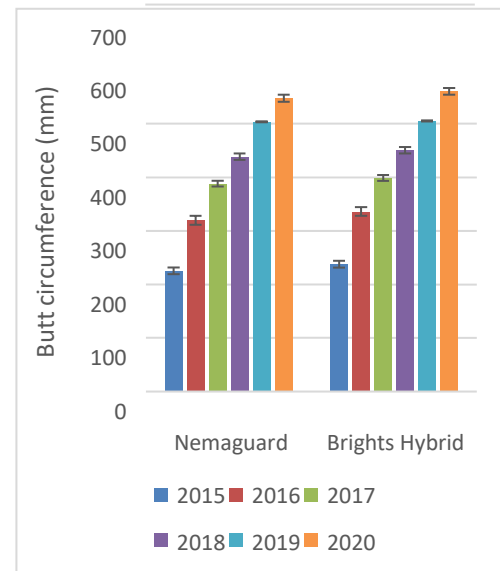


Figure 35. Average trunk circumference.

Table 14. Average annual yields (kg/ha)

Rootstock	2016	2017	2018	2019	2020	2021	Cumulative
Bright's Hybrid	469	1,156	1,826	2,840	3,314	3,914	13,519
Nemaguard	508	731	1,831	2,919	3,377	2,373	11,738

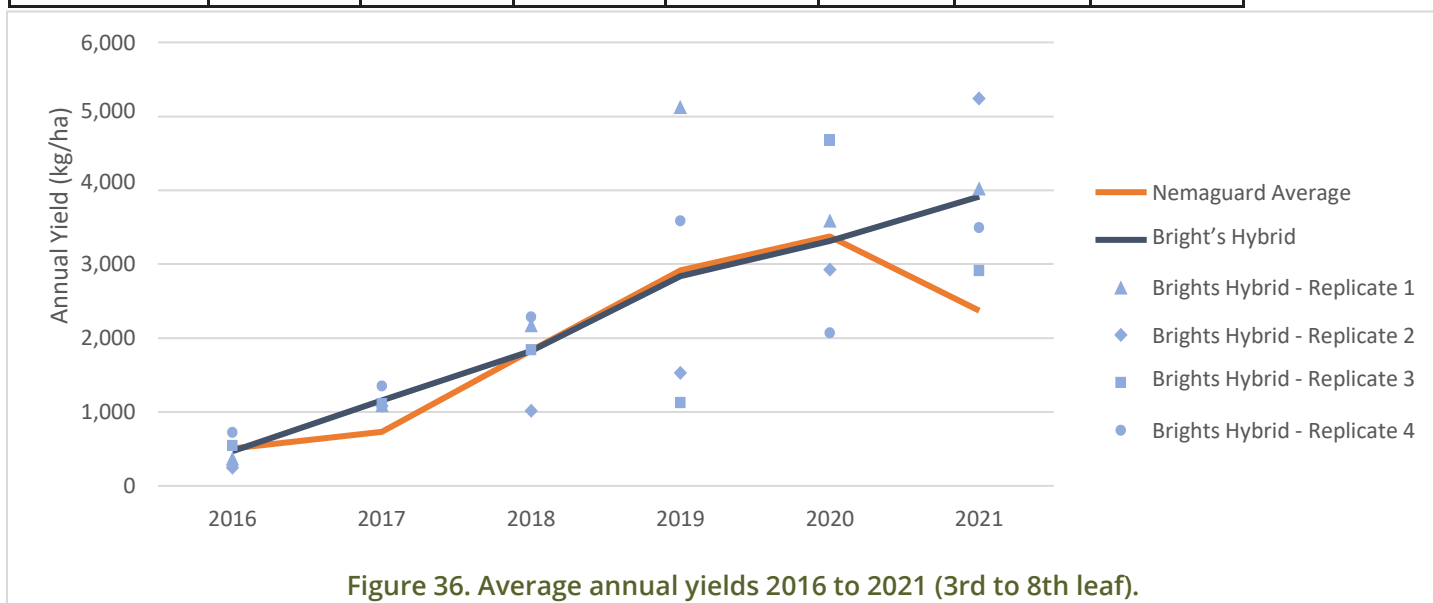


Figure 36. Average annual yields 2016 to 2021 (3rd to 8th leaf).

Rootstock characteristics

Bright's Hybrid had a significant delay in nut maturity where only 53% of nuts had reached stage 3 hull split by 25th January 2021 where all other rootstocks had reached 100% by the same day. This delay was not evident in progressing to stage 6 where all rootstocks had reached 100% stage 6 by 18th February.

Table 15. Rootstock characteristics.

Root knot Nematode	Lesion Nematode	Ring Nematode	Crown Gall	Armillaria	Phytophthora	Salt exclusion	Chlorosis	Vigour	Propagation by cuttings
High resistance	More Tolerant than Nemaguard	Susceptible	Susceptible	Susceptible	Susceptible	Tolerant/ Excluder	Tolerant	High	Poor



Figure 37. Juvenile tree - 2017.



Figure 38. Mature tree - 2021.



Figure 39. Graft union - 2021.

Performance summary

Nemaguard was not among the top seven highest performing rootstocks in terms of cumulative yield but had similar yields to Brights Hybrid, Adafuel, Cornerstone (planted one year later) and GF557. Cumulative yield was significantly higher for Nemaguard than Krymsk 86 for this trial site and management practices. Leaf analysis showed low levels of Ca and Mg and high levels of leaf sodium may have contributed to low yield performance.

Key observations

Tree Habit

Using trunk circumference as an indicator of tree growth, Nonpareil trees grown on Nemaguard (549.8mm) were similar to Spare Nemaguard (556.25mm) in 2020 and were significantly smaller than Adafuel (600.2mm), Monegro (608.8mm), Felinem (605.4mm) and Hansen 536 (619.6mm) but not other rootstocks.

In 2020, Nemaguard produced smaller tree canopies with heights of 4.65m (4.78m wide) and together with spareNemaguard, of similar height 4.83m (4.9m wide), ranked in the bottom four tree heights. Visually the rootstock promoted strong light interception through the spacing of the canopy (Figure 43).

Production

Seasonal yields on Nemaguard were typically mid-range with some rootstocks achieving higher yields e.g. GF749, Monegro, Felinem, Hansen 536, Garnem, GF677 and others less e.g. Krymsk 86, and GF557. While earlier yields for Adafuel and Brights Hybrid were similar to Nemaguard they may surpass Nemaguard in future years if their upward trajectory continues.

Figure 41 shows the variability that makes up the average yields for Nemaguard and spare Nemaguard.

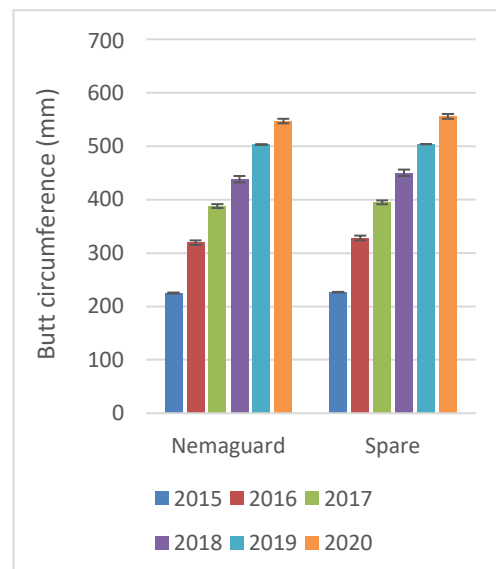


Figure 40. Average trunk circumference.

Table 16. Average annual yields (kg/ha).

Rootstock	2016	2017	2018	2019	2020	2021	Cumulative
Spare Nemaguard	482	893	2,144	3,486	3,502	2,736	13,243
Nemaguard	508	731	1,831	2,919	3,377	2,373	11,738

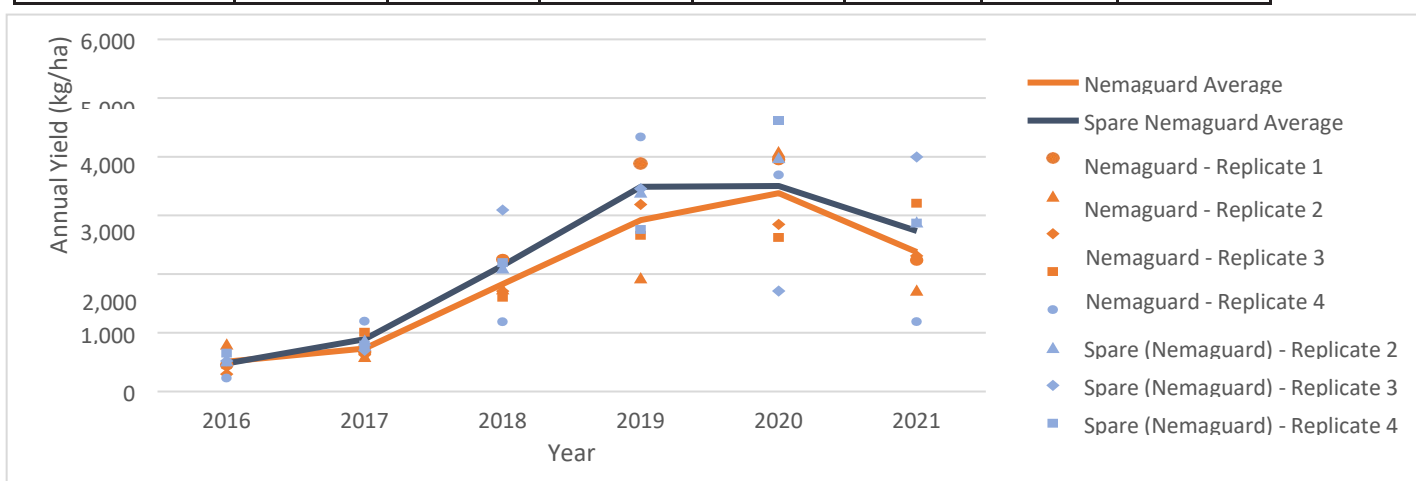


Figure 41. Average annual yields 2016 to 2021 (3rd to 8th leaf).

Rootstock characteristics

In 2021 leaf analysis indicated a significant correlation between yield and leaf Ca and Mg levels with the two Nemaguard rootstocks having the lowest leaf Ca and Mg levels. Similarly, there was a significant correlation between yield and leaf sodium with high sodium levels correlating with low yields. The highest levels were observed in Krymsk and Nemaguard. Both Krymsk and Nemaguard have been found to be poor excluders of sodium and chloride and may have contributed to low yield performance even when soil salinities were below the level considered to affect yield (1.5dS/m).

Table 17. Rootstock characteristics.

Root knot Nematode	Lesion Nematode	Ring Nematode	Crown Gall	Armillaria	Phytophthora	Salt exclusion	Chlorosis	Vigour	Propagation by cuttings
High	Medium	Medium	Medium	Susceptible	Medium	Sensitive	Susceptible	Medium	NA



Figure 42. Juvenile tree - 2017.



Figure 43. Mature tree - 2021.



Figure 44. Graft union - 2021.

Performance summary

While Adafuel produced larger trees and high production efficiencies early (2017) this did not translate into cumulative yields that were significantly higher than Nemaguard, potentially due to variability within the trial. Root-knot nematode was detected on Adafuel rootstock in moderate levels and Adafuel is reported to have low to medium susceptibility. Adafuel brought forward flowering start dates and flowering duration compared to Nemaguard.

Key observations

Tree Habit

Using trunk circumference as an indicator of tree growth, Nonpareil trees grown on Adafuel (600.2mm) were significantly larger than Nemaguard (549.8mm) and had similar circumferences as high performing rootstocks Monegro (608.8mm), Felinem (605.4mm) and Hansen 536 (619.6mm).

In 2020, Adafuel produced strong canopy growth of 4.56m wide with heights (4.93m) significantly higher than Nemaguard (4.65m) but not significantly higher than the spareNemaguard (4.83m). Most growth was in the lower part of the canopy with some limbs extending apically in the upper canopy.

Production

Seasonal yields on Adafuel were similar to Nemaguard (Table 18). Early high production efficiency seen in 2017 did not translate into significantly higher cumulative yield than Nemaguard potentially due to the variability within the trial. In 2019, Replicate 2 did not have harvest data therefore the average annual yield was based on 3 data sets. An outlying low yield in Replicate 3 in 2020 combined with a declining trend in Replicate 1 meant the cumulative yield by 2021 was not significantly higher than Nemaguard.

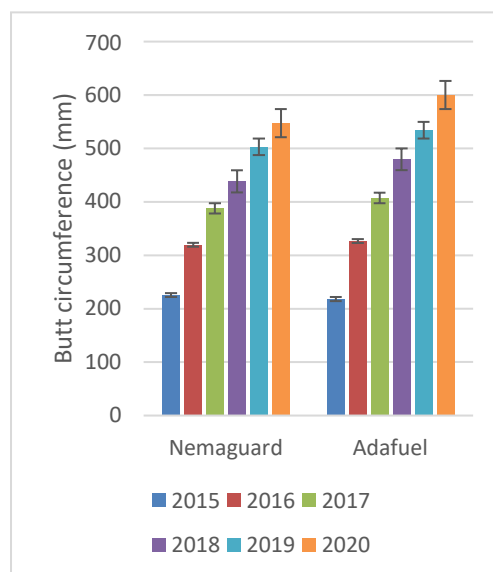


Figure 45. Average trunk circumference.

Table 18. Average annual yields (kg/ha).

Rootstock	2016	2017	2018	2019	2020	2021	Cumulative
Adafuel	274	1,074	2,127	2,648	3,357	3,106	12,588
Nemaguard	508	731	1,831	2,919	3,377	2,373	11,738

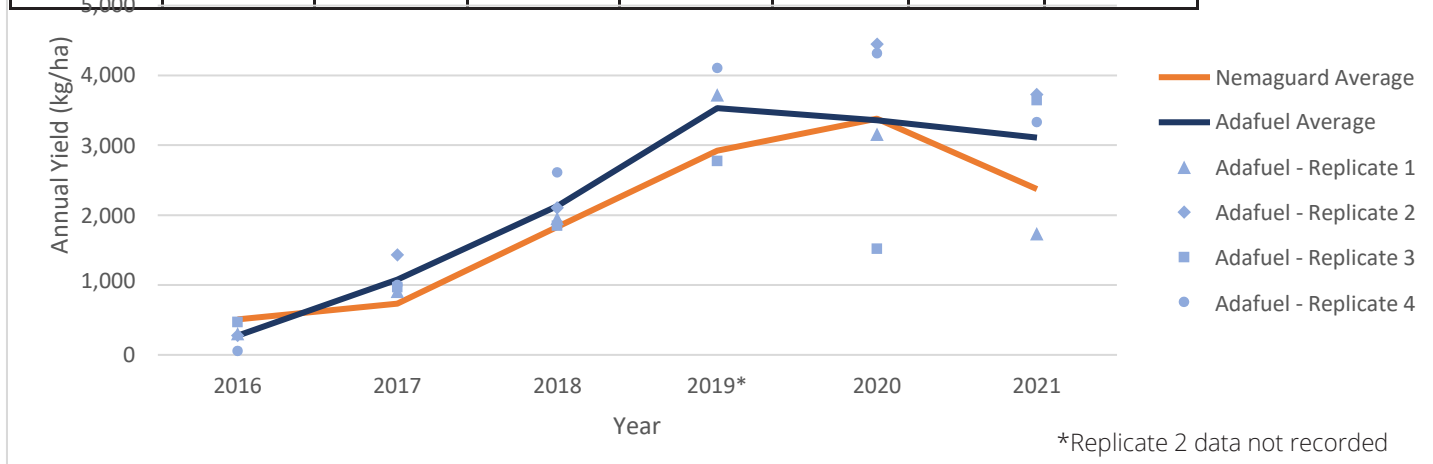


Figure 46. Average annual yields 2016 to 2021 (3rd to 8th leaf).

Rootstock characteristics

Root Knot was detected on Adafuel rootstock in moderate levels and Adafuel is reported to have low to medium susceptibility. On average Adafuel brought forward the start of flowering two days earlier than Nemaguard with a shorter flowering period from 26 days to 24.75 days (Figure 2).

Table 19. Rootstock characteristics.

Root knot Nematode	Lesion Nematode	Ring Nematode	Crown Gall	Armillaria	Phytophthora	Salt exclusion	Chlorosis	Vigour	Propagation by cuttings
Characteristics are unpublished for Adafuel.									



Figure 47. Juvenile tree - 2017.



Figure 48. Mature tree - 2021.



Figure 49. Graft union - 2021.

Performance summary

Cornerstone was planted one year later in this trial making it difficult to make direct comparisons with other rootstocks. The delayed planting was further complicated in that they received the same fertilizer and irrigation amounts as the trees 12 months older enabling growth and yields to catch up to that of other rootstocks. By 3rd leaf Cornerstone's average annual yield was higher than Nemaguard and after 7 years growth produced a similar cumulative yield to Nemaguard that had 8 years growth.

Key observations

Tree Habit

Despite being planted one year later, Nonpareil trees grown on Cornerstone had strong growth and by 2020 (540.4mm) had similar trunk circumferences as Nemaguard (549.8mm).

In 2020, Cornerstone had one of the smaller canopies with heights (4.78m) similar to Nemaguard (4.65m) but not significantly smaller than the spare Nemaguard (4.83m).

Production

In 2017 Cornerstone had significantly higher production efficiency (0.095kg/cm²) than Nemaguard (0.057kg/cm²) the significance between rootstocks was lost after 2017.

Despite being planted 12 months later Cornerstone produced annual average yields higher than Nemaguard in all years except for 2016 and 2020. After 7 years growth Cornerstone achieved a similar cumulative yield to Nemaguard that had 8 years growth.

Table 20. Average annual yields (kg/ha).

Rootstock	2016	2017	2018	2019	2020	2021	Cumulative
Cornerstone*	123	1,132	1,931	3,309	2,669	2,824	11,987
Nemaguard	508	731	1,831	2,919	3,377	2,373	11,738

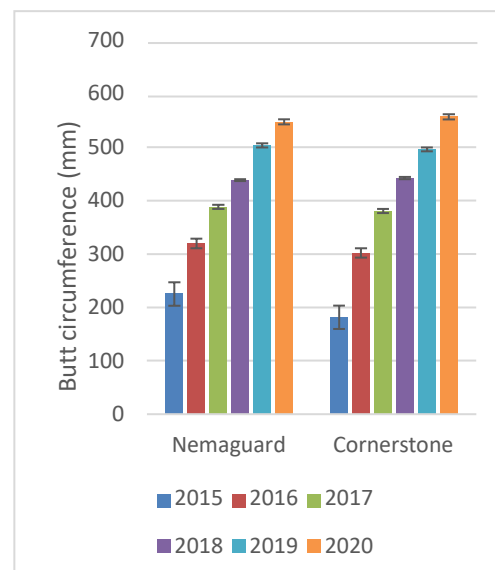


Figure 50. Average trunk circumference.

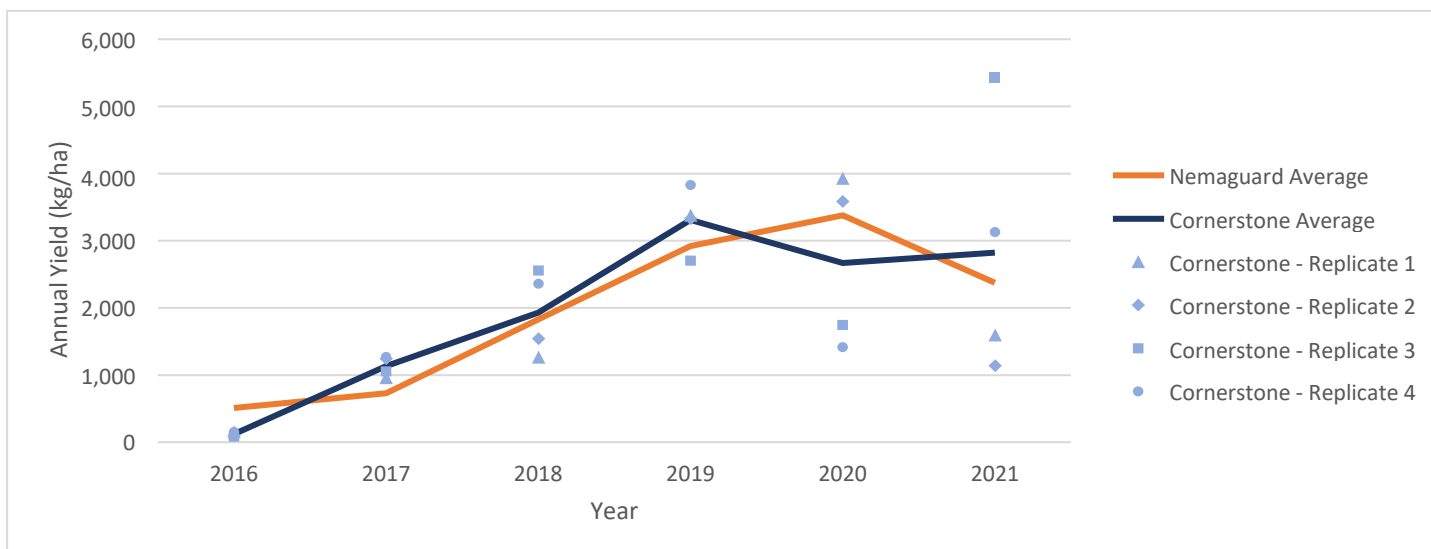


Figure 51. Average annual yields 2016 to 2021 (3rd to 8th leaf)

Rootstock characteristics

Low levels of ring nematode were detected and requires ongoing monitoring. On average earlier flowering was observed for Adafuel bringing forward the start of flowering by two days. Full bloom and end of flowering were also earlier than Nemaguard (Figure 2).

Table 21. Rootstock characteristics.

Root knot Nematode	Lesion Nematode	Ring Nematode	Crown Gall	Armillaria	Phytophthora	Salt exclusion	Chlorosis	Vigour	Propagation by cuttings
High	Susceptible	Susceptible	Susceptible	Susceptible	Susceptible	Excluder	Tolerant	High	Good



Figure 52. Juvenile tree - 2017.



Figure 53. Mature tree - 2021.



Figure 54. Graft union - 2021.

Performance summary

GF557 produced trees that were similar to Nemaguard in terms of canopy size, seasonal yields and cumulative yield. Root knot nematode was detected in soils at low levels and will require monitoring to determine any yield impacts given GF557 is susceptible to root-knot nematode. GF557 had low levels of leaf sodium suggesting it has good salt tolerance. GF557 brought forward the start of flowering by one day and shortened the flowering period to 24.75 days compared to Nemaguard (26 days).

Key observations

Tree Habit

Using trunk circumference as an indicator of tree growth, Nonpareil trees grown on GF557 (564.6mm) were similar in size as Nemaguard (549.8mm) and spare Nemaguard (556.3mm).

By 2020, trees grown on GF557 (4.88m) were significantly higher than Nemaguard (4.65m) but not significantly higher than spare Nemaguard (4.83m). Canopy growth was evenly distributed in the upper and lower canopy without apically dominant limbs (Figure 58).

Production

GF557 had similar average annual yield and cumulative yield as Nemaguard (Table 22).

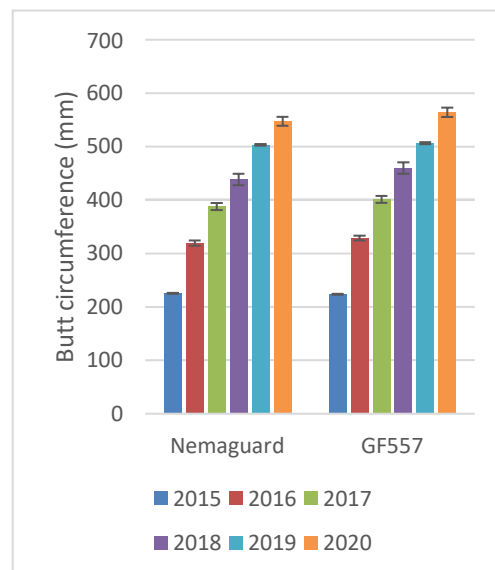


Figure 55. Average trunk circumference.

Table 22. Average annual yields (kg/ha).

Rootstock	2016	2017	2018	2019	2020	2021	Cumulative
GF557	379	871	1,884	3,013	3,219	2,520	11,886
Nemaguard	508	731	1,831	2,919	3,377	2,373	11,738

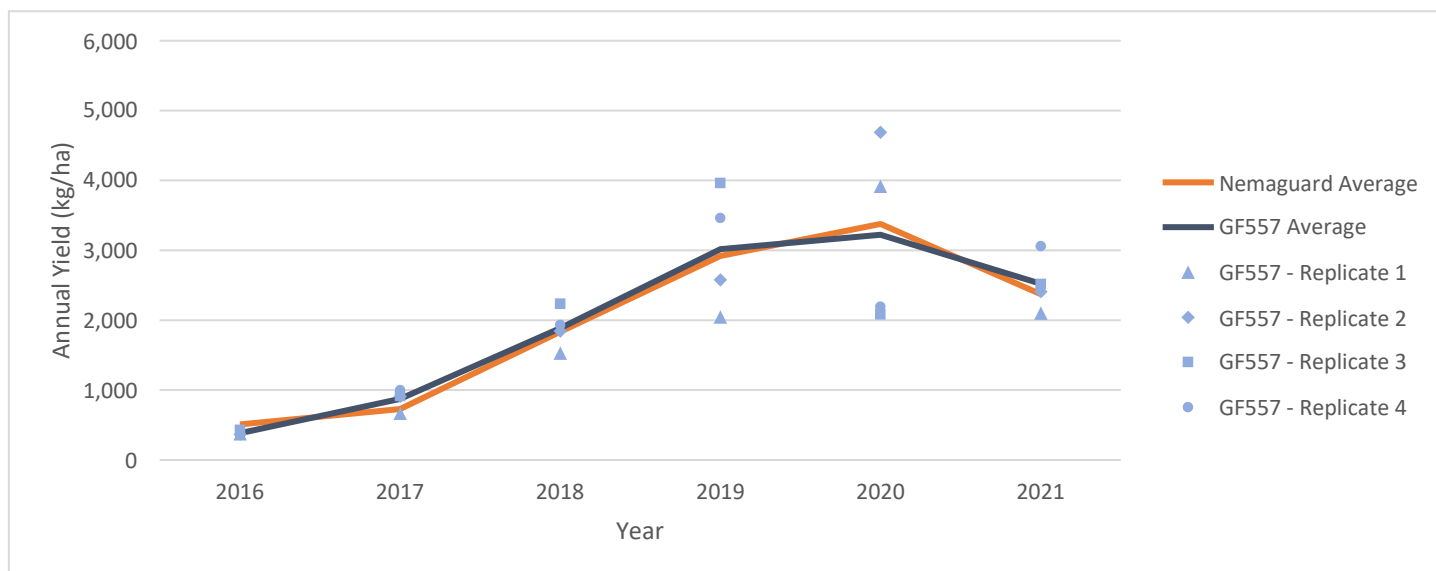


Figure 56. Average annual yields 2016 to 2021 (3rd to 8th leaf).

Rootstock characteristics

Root knot nematode was detected in soils at low levels. Given GF557 is susceptible to root-knot nematode continued monitoring would determine if populations increase and their impact on yield. GF557 had low levels of leaf sodium suggesting it has good salt tolerance, able to exclude sodium and chloride from the soil. GF557 brought forward the start of flowering by one day and shortened the flowering period to 24.75 days compared to Nemaguard (26 days).

Table 23. Rootstock characteristics.

Root knot Nematode	Lesion Nematode	Ring Nematode	Crown Gall	Armillaria	Phytophthora	Salt exclusion	Chlorosis	Vigour	Propagation by cuttings
Susceptible	Characteristics are unpublished for GF557.								



Figure 57. Juvenile tree - 2017.



Figure 58. Mature tree - 2021.



Figure 59. Graft union - 2021.

Performance summary

Krymsk 86 was the lowest performing rootstocks within the trial producing trees with similar trunk circumference, height and canopy area to Nemaguard however yields were significantly lower than Nemaguard and all other rootstocks. These results are specific to the soil characteristics and management practices applied to this trial site. Leaf analysis showed low levels of Ca and Mg and high levels of leaf sodium may have contributed to low yield performance. Krymsk 86 brought forward the start of flowering (0.5 days) and reduced flowering periods by 3.5 days compared to Nemaguard. Fruit on Krymsk 86 reached stage 3 hull split earlier than Nemaguard.

Key observations

Tree Habit

Using trunk circumference as an indicator of tree growth, Nonpareil trees grown on Krymsk 86 (568.8mm) had similar growth compared to Nemaguard (549.8mm) and spare Nemaguard (556.3mm) but was significantly smaller than Hansen 536 (619.6mm).

In 2020, Krymsk 86 produced small trees with height (4.87m) similar to Nemaguard (4.65m) and Cornerstone (12 months younger) and significantly smaller than all other rootstocks.

Canopy area measures in 2018 indicated that Krymsk 86 had a significantly smaller canopy area than most rootstocks but not significantly different from Nemaguard, GF557 and Felinem. Strong apical limb growth was observed for some limbs with much of the available space between trees remaining in 2021 (Figure 63).

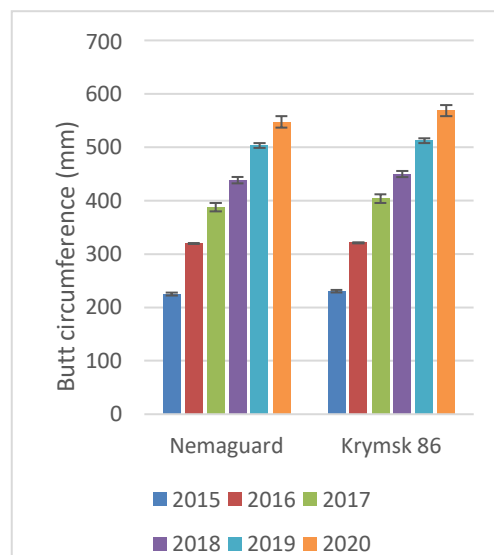


Figure 60. Average trunk circumference.

Production

Average annual yields for Krymsk 86 were consistently less than Nemaguard resulting in a cumulative yield significantly lower than Nemaguard and all other rootstocks (Table 24).

Table 24. Average annual yields (kg/ha).

Rootstock	2016	2017	2018	2019	2020	2021	Cumulative
Krymsk 86	370	651	1,299	2,403	2,392	2,089	9,204
Nemaguard	508	731	1,831	2,919	3,377	2,373	11,738

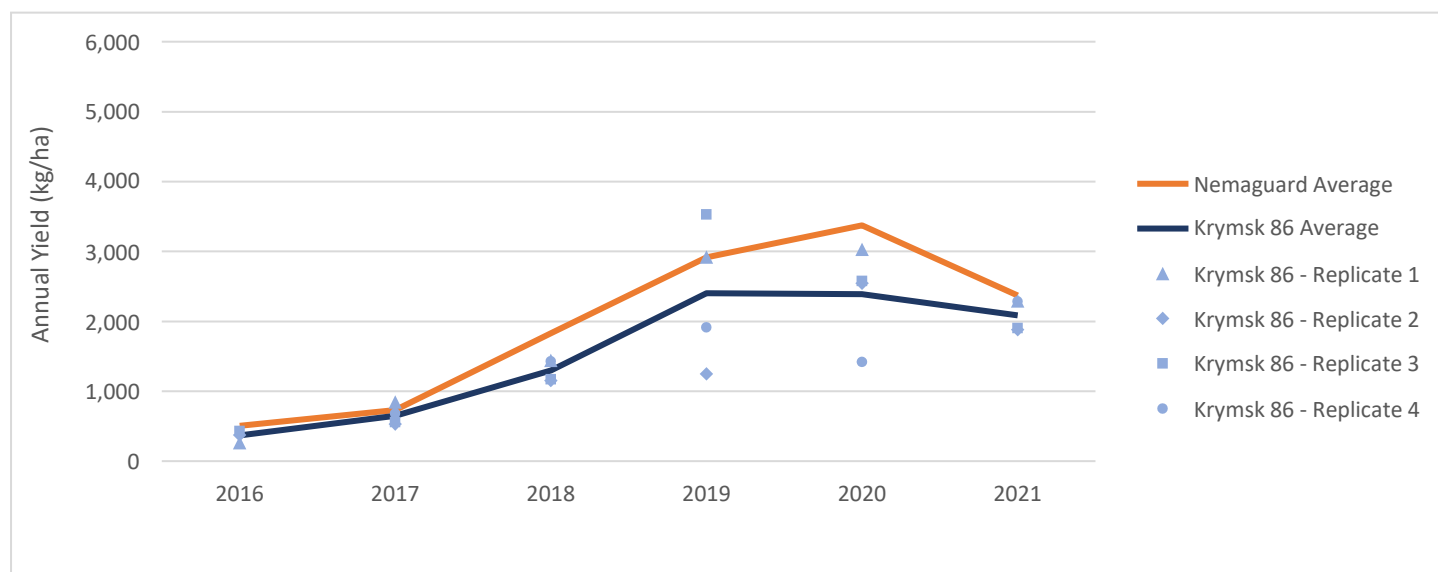


Figure 61. Average annual yields 2016 to 2021 (3rd to 8th leaf).

Rootstock characteristics

In 2021 leaf analysis indicated a significant correlation between yield and leaf Ca and Mg levels with trees grown on Krymsk 86 and Nemaguard having the lowest leaf Ca and Mg levels. Similarly, there was a significant correlation between yield and leaf sodium with high sodium levels correlating with low yields. The highest levels were observed in Krymsk 86 and Nemaguard. Both Krymsk 86 and Nemaguard have been found to be poor excluders of sodium and chloride and may have contributed to low yield performance even when soil salinities were below the level considered to affect yield (1.5dS/m).

Moderate level of Ring Nematode were observed in the soil around Krymsk 86. Ring Nematode is known to increase the susceptibility to bacterial cankers and will require monitoring to determine if the nematode population increases and its effect on tree growth and yield.

Fruit on Krymsk 86 reached stage 3 hull split earlier than Nemaguard with 98% of the fruit reaching stage 3 by January 18 compared to Nemaguard having only 74% of fruit reaching stage 3 on the same date.

Krymsk brought flowering forward by half a day and reduced the flowering period to 22.5 days compared with Nemaguard’s average flowering period of 26 days.

Table 25. Rootstock characteristics

Root knot Nematode	Lesion Nematode	Ring Nematode	Crown Gall	Armillaria	Phytophthora	Salt exclusion	Chlorosis	Vigour	Propagation by cuttings
Susceptible	Medium	Susceptible	Medium	Unknown	Tolerant	Sensitive	Medium	Medium	Good



Figure 62. Juvenile tree - 2017.



Figure 63. Mature tree - 2021.



Figure 64. Graft union - 2021.