Project title:	East Malling Rootstock Breeding Club (EMRBC)
Project number:	TF 224
Project leader:	Felicidad Fernández, NIAB EMR
Report:	Annual report, 2017-2018
Previous report:	EMRC (TF224) 2016-2017
Key staff:	Felicidad Fernández Amanda Karlström
Location of project:	East Malling, Kent
Industry Representative:	Nigel Kitney, H L Hutchinson Ltd
Date project commenced:	1 April 2015
Date project completed (or expected completion date):	31 March 2020

DISCLAIMER

While the Agriculture and Horticulture Development Board seeks to ensure that the information contained within this document is accurate at the time of printing, no warranty is given in respect thereof and, to the maximum extent permitted by law the Agriculture and Horticulture Development Board accepts no liability for loss, damage or injury howsoever caused (including that caused by negligence) or suffered directly or indirectly in relation to information and opinions contained in or omitted from this document.

[The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.]

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

Felicidad Fernández Fernández

Plant Breeder and Molecular Geneticist

NIAB EMR

Signature   Date: 4 June 2018

Report authorised by:

Richard Harrison

Head of Department

NIAB EMR

Signature   Date: 4 June 2018

CONTENTS

GROWER SUMMARY

Headline

NIAB EMR continues to breed and select improved rootstocks for apple and pear. Trials with our own selections, as well as material from other breeding programmes, are also ongoing. This project (2015-2020) encompasses the work covered in former project TF 182 (breeding) and TF 172a&b (trialling). A number of trials have been completed in 2017-18 and new ones are coming on-stream.

Background

Improved rootstocks are essential for profitable and sustainable production in tree-fruit crops. Factors important to growers include dwarfing (to reduce the cost of pruning and picking), induction of precocious and reliable cropping, freedom from suckers, good anchorage and resistance to pests and diseases. Ease of propagation and good scion-stock compatibility are also important in the nursery.

In 2008, EMR (now NIAB EMR), the HDC (now AHDB Horticulture) and the International New Varieties Network (INN) launched a Rootstock Club (EMRC) to breed, develop, distribute and commercialise new rootstock breeding material from East Malling, world-wide.

For UK growers, the AHDB involvement in the development of new rootstocks from NIAB EMR's programme will ensure material will be available to UK levy payers. The AHDB helps to 'steer' breeding objectives to meet the specific requirements of UK growers and ensures that appropriate newly selected rootstocks are trialled further before release to the UK industry.

INN has members in the USA, Chile, South Africa, Australia, New Zealand and throughout Europe. In each country, members can produce virus-free (VF) certified rootstocks and premium quality VF certified finished trees. INN members will arrange, evaluate and select from their own trials to identify those rootstocks best suited to each country's specific growing conditions.

The EMRC aims to develop a range of apple, pear and quince rootstocks to suit different growing conditions. Breeding objectives include:

- new dwarfing and semi-dwarfing stocks for apple and pear
- improved scion-graft compatibility, in particular for pear
- increased precocity and productivity
- increased fire-blight and/or woolly apple aphid resistance
- enhanced tolerance to replant disease

Summary of progress

Preliminary trials:

- The apple trial planted in 2012 (RF 185 trial) was completed and grubbed in 2017-18. It comprised four selections from the family M.306 (AR86-120 x M.20). These rootstocks are quite different in vigour and performance but none of them was found to be a significant improvement over the commercial rootstocks in the trial. This is compounded by their susceptibility to woolly apple aphid and lack of fire blight resistance genes. The most dwarfing of these selections will be retained as a possible parent.
- Winter records were taken for the pear trial planted in 2014 (RF187) but a spring frost in 2017 caused a complete loss of what would have been this trial's first harvest.

Second stage trials:

- The conventional trial planted in 2010 (EE207), where five new selections were being evaluated with Braeburn and Gala for a vigour range between M.27 and M.26, was also completed during the reporting period. None of the rootstocks was a major improvement of the commercial standard, but a couple of them could be of interest if compared to standards on the M.116 range. All five selections are all still under trial with INN in the continent so no firm decisions have been taken on their future.
- The low-input orchard planted also planted in 2010 (VF224), where four selections being trialled are evaluated with Red Falstaff, was also completed. AR10-3-9 continued to perform very similarly to M.116 in the UK and probably slightly better in some of the continental trials but it offers no additional pest or disease resistance, whilst R80 is probably the most promising selection on the group. All four selections are still under trial with INN in the continent so no firm decisions have been taken on their future.
- The 2014 trial evaluating Canadian apple rootstocks started to show interesting differences on both vigour and productivity traits but it is too early to draw any conclusions.
- A new apple rootstock trial was planted in 2017 as part of a EUFRIN co-ordinated initiative across 19 sites in Europe. Six NIAB EMR advanced selections are included.

Crossing programme

- Eleven apple and four pear crosses were carried out in spring 2017 with nearly 4,000 flowers hand-pollinated but, due to a late spring frost, only 965 apple and 335 pear viable seeds could obtained from seven and two crosses respectively.

- Nearly 4,200 seeds from nine crosses were sown in winter 2016-17 to raise 2,561 new apple seedlings from eight families.

Selection

- Field records (vigour, crop load and suckering) were taken on existing apple and pear populations.
- Forty-two preliminary selections were made from the population of seedlings populations planted in 2011 (21 apple and 21 pear). These have now been cut down to initiate propagation in 2018-19.

Pest and disease screening

- Fire blight screening in Agroscope (CH) confirmed AR835-11, AR839-9 and AR486-1 can be classed as of low to medium susceptibility. AR801-11 and AR682-6 were classed as of medium susceptibility but should be retested and AR628-2 was found to be highly susceptible.
- *P. cactorum* and woolly apple aphid screening (WAA) were hampered by insufficient number of hardwood cutting of many genotypes of interest but some characterisation of seedlings was possible for WAA

Financial Benefits

Although this is a very long-term project, there are major financial advantages to the development and selection of rootstocks with improved agronomic performance including reduced pruning and picking costs and the ability to grow material with reduced pest and disease susceptibility and AHDB support to this projects ensures that UK growers will have access to new UK-bred rootstocks.

Action Points

None at this point.

SCIENCE SECTION

Introduction

Improved rootstocks are essential for profitable and sustainable production in tree-fruit crops. Factors important to growers include dwarfing (to reduce the cost of pruning and picking), induction of precocious and reliable cropping, freedom from suckers, good anchorage and resistance to pests and diseases. Ease of propagation and good scion-stock compatibility are also important in the nursery. Whilst there are few international breeding programmes generating tree-fruit rootstocks, NIAB EMR involvement in rootstock development dates back to its foundation with the subsequent release of the world-famous series of apple rootstocks; M. (Malling) and M.M. (Malling-Merton in collaboration with the, as was, John Innes Horticultural Institution).

In 2008, EMR (now NIAB EMR), the AHDB tree fruit panel and the International New Varieties Network (INN) launched a Rootstock Club (EMRC) to breed, develop, distribute and commercialise new rootstock breeding material from EMR, world-wide. The programme has been renewed several times since and current funding incorporating breeding, preliminary trialling and UK second stage trials runs until 2020.

For UK growers, the AHDB also acts as the UK licensee for the EMRC with the intention of making new rootstocks released from EMR's programme, widely available to UK levy payers. AHDB also helps to 'steer' breeding objectives to meet the specific requirements of the UK growers and ensures that newly selected rootstocks are trialled further before release to the UK industry.

INN has members in the USA, Chile, South Africa, Australia, New Zealand and in the EU (represented by EVI). In each country, members can produce virus-free (VF) certified rootstocks and premium quality VF certified finished trees. INN members will arrange, evaluate and select from their own trials to identify those rootstocks best suited to each country's specific growing conditions.

It is not unusual for new rootstock to take 30-35 years. Selection of parental material, crossing, seedling selection and first stage trialling, which are carried out at NIAB EMR, takes around 10 years. Promising material is then propagated and released for HDC-funded trials in the UK and INN-funded trials at appropriate sites around the rest of the world. As trial results accumulate, validating which selections are most promising, these rootstocks are then propagated to build up sufficient material for distribution before it is possible to co-ordinate effective world-wide release.

The EMRC will complete the evaluation of apple, pear and quince rootstock material developed by the former APBC currently in the pipeline, with the aim to identify a range of apple, pear and quince rootstocks with desirable size control, precocity and productivity, with resistance to diseases and pests where applicable.

Aims and objectives

The EMRC aims to develop a range of apple, pear and quince rootstocks to suit different growing conditions. Breeding objectives include:

- new dwarfing and semi-dwarfing stocks for apple and pear
- improved scion-graft compatibility, in particular for pear
- increased precocity and productivity
- increased fire-blight and/or woolly apple aphid resistance
- enhanced tolerance to replant disease

Materials and methods

The breeding programme is an ongoing effort of which different steps are briefly described below. More detailed methodology is included in the relevant part of the yearly update if necessary.

Preliminary trials

After one or two years of growth in pots, selections are grafted with a common scion (currently 'Gala' for apples and 'Conference' for pears) and established in replicated trials that include standard commercial rootstocks for control purposes.

In these trials tree vigour is assessed by the measurement of tree volume (in the form of either the number and length of shoots for trees <3 years old, or the height and spread of the tree crown for older trees) and by the recording of trunk girth at 15 cm above ground level; where appropriate, fresh weights at the time of grubbing are also recorded as a measure of relative vigour.

Total yields and yields of class one fruit (>65 mm and 55-65 mm) are measured for each tree and cumulative yields and yield efficiencies (kg per cm^2 of cross section) are calculated. Records are taken on tree health, graft compatibility and anchorage.

Traditionally, rootstock trials at NIAB EMR have not been pruned other than to remove suckers after recording. However, this has not led to the best agronomical evaluation of the new selections. After discussions with the EMRC executive management committee and the HDC tree fruit panel, it was decided to correctively prune ongoing trials in February 2015 and to follow a conservative pruning strategy more in line with commercial orchard practice thereafter. This year, pruning weights were recorded in April 2018.

The best selections after this preliminary evaluation are subsequently propagated to enter the second stage trials funded by AHDB Horticulture under this same project (TF224) in the UK and by INN overseas.

Second stage trials (previously under AHDB Horticulture project TF172a&b)

They are performed as above but usually with greater level of replication as more material is available per genotype and, in the case of apple, can involve more than one scion cultivar. During the reporting year, three second state apple trials were evaluated (EE207 involving NIAB EMR genotypes in conventional growing conditions, VF224 involving NIAB EMR genotypes under low-input conditions and the recently planted SP250 that will assess

Statistical analysis of trial data

All statistical analyses were conducted in the software R (https://www.R-project.org).

The differences between rootstocks for traits measured in 2017 in all trials except ‘SP250’ were analysed with ANOVA (native R-function: ‘aov’). Rootstock and block were included as factors in the analysis of all trials, whereas scion and scion:rootstock interaction only were included in the analysis of the trial EE207.

Differences between rootstocks in the trial ‘SP250’ were analysed using a mixed linear model.

The normality of the residuals from the model were checked through a Shapiro-Wilk normality test (function: ‘shapiro.test’) and Q-Q-plots. Traits which had non-normally distributed residuals were either log or square root-transformed for numeric and integer traits, respectively. A few traits did not have normally distributed residuals after transformation and differences between rootstocks were therefore analysed with a Kruskal-Wallis test (function: ‘kruskal.test’).

A linear mixed-effect model approach was used to analyse yield and yield efficiency data for all trial years of the three trials (RF185, EE207 and VF224) that were terminated in spring 2018. The analysis was conducted using the ‘lmer’ function in the R package ‘lme4’. In the mixed-effect model, rootstock and scion (in the case of EE207) were included as fixed effects, whereas year, rootstock:year interaction and block were included as random effects. The best linear unbiased estimate of yield and yield efficiency was obtained from the fixed effect of rootstock from the same model.

Breeding activities:

Crossing

Parental genotypes that carry one or more phenotypic traits of interest are selected and a crossing programme is designed aiming to combine those desirable characteristic into the resulting seedlings. Controlled crosses are carried out in spring: first, the anthers of the intended male parent are extracted from unopened blossoms to avoid cross contamination and placed in Petri dishes until the dehisce releasing their pollen. Pollen is stored in a desiccator at 3°C remaining viable for up to 4 years. Secondly, petals are removed from the flowers of the intended female (balloon stage) and pollen of the chosen male placed on the receptive stigmas. Fruits are then left to develop and ripen naturally and seeds are carefully extracted after harvest.

Fresh seeds are washed and soaked in water for 2-3 days with daily rinses to remove germination-inhibiting compounds. They are then air-dried and stored at 3°C for until the following January.

Raising seedling populations

Seeds are stratified in the cold-store (between 2 and 4°C) in trays of moist compost and perlite mix for 16 weeks. After this period, seed trays clearly labelled with progeny numbers are placed in a glasshouse (at ~18°C) for germination. Individual seedlings are potted and labelled as they become large enough to handle safely and grown on for around two months. In their first summer, seedlings are planted out in the field and left to establish for a whole growing season.

Field evaluation of rootstock seedlings

In the first winter, 1-year-old bare-rooted plants of commercial standards rootstocks are interspersed in the seedling population as controls. Rootstocks ‘M.27’, ‘M.9’, ‘M.26’ and ‘M.M.106’ are used for apple populations and quince rootstock ‘EMA’ and ‘EMC’ are used in the pear populations. Seedlings are budded with a common scion 12-13 months after planting and the controls are bench grafted the winter after that and planted in the field during the second summer in the field of the seedling population.

Records on bud take and production of suckers are taken in the first two years of the population and, thereafter, for the three to four years, seedlings are evaluated with regards to vigour and suckering. As the common scion comes into fruit, crop load and fruit size are recorded and any other differences attributable to the rootstocks (e.g. incidence of bitter-pit) are noted if significant as is pest and disease incidence (in the suckers or crown) and any other detrimental characteristic observed (e.g. burr-knots, brittle wood, poor anchorage, etc.). The most promising seedlings on each population are selected for propagation, usually five or six years after planting.

Propagation

Interesting seedlings are selected and marked out with tape in the field during the summer and cut back below the budding union the following autumn. To encourage growth of shoots from the rootstock and their subsequent rooting, stumps are earthed-up with compost in the spring and again during the summer. Leaf samples of each selection are taken at this stage to allow future DNA identification. Pest and disease incidence of the stocks is recorded during the summer and unhealthy selections can be discarded (e.g. severe mildew infection or infestation by woolly apple aphid on families segregating for resistance)

Hardwood cuttings (ideally ~30 cm in length) are taken of these selections at the beginning of December and dipped in 0.5% (Indole-3-butryic acid) IBA solution for 5 s prior to insertion into a heated cutting bin to a depth of 6 to 8 cm. The cutting bin consists of 30 cm layer of a 1:1 mixture of peat and fine bark over a 5 cm layer of coarse sand. A soil warming cable maintains bed temperature at 25^{o}C. Air temperature is cooled via ventilation to outside. Cuttings are left until rooted and then potted into 2 L pots, in late January or early February and grown on in unheated glasshouse. Ease of propagation is also a key selection criterion and recalcitrant selections are discarded.

Pest and disease resistance screening

Fire-blight (FB)

Shoots of four selections were sent to Agroscope (CH) to be entered on their routine screening. Genotypes were grafted on rootstock M9vf T337 in rose pots (35.5 cm pot height, 7 cm in diameter, 12 replicate trees per genotype). ‘Gala Galaxy’ was included as a susceptible control, ‘Enterprise’ as a resistant control. Grafted genotypes were grown up during five weeks in a greenhouse (temperature: 16-24°C, humidity: 65%).

After 5 weeks, the plants were transferred to the security greenhouse GX. Plants with minimum shoot length of 14 cm were inoculated on early May 2016 as described by Momol et al. (1998). Inoculum *Erwinia amylovora* (Swiss strains FAW 610 Rif, specified concentration = 109 cfu/ml-1) was introduced to the shoot tip by inserting a syringe of 0.7mm diameter (22 gauge) through the stem just above the youngest unfolded leaf. The length of the optical fire blight-free shoot part as well as the length of necrotic lesion (cm) was measured 7, 14 and 21 days after inoculation. To estimate susceptibility, percent lesion length (lesion length divided by shoot length) was calculated for each time point. Unfortunately, Agroscope will not be offering this service in future and it is unclear how future testing will be carried out in apple. On a positive note, INRA Angers might be able to include pear genotypes into their screening from 2018.

Woolly apple aphid (WAA)

Colonies of *Eriosoma lanigenum* (WAA) collected from the field in Kent are used to challenge rooted cuttings in the glasshouse. Aphids are added to each tree 2-3 time during July and August. Scoring is carried out at the end of the growing season. Individuals will be considered resistant if WAA failed to establish colonies and susceptible if they have succeeded. Genotypes considered resistant will usually be re-tested in a second season for confirmation as will any selection presenting conflicting results amongst replicates.

Phytophthora cactorum:

Due to insufficient hardwood cuttings, it was not possible to carry out an effective screening for *P. cactorum* in 2017.

In winter 2018, in addition to continuing the development of a GH pot-based test for determining susceptibility to *P. cactorum*, we have also started collaborating with colleagues to develop and validate a cut shoot test inoculation which if successful, would allow us to test a large number of genotypes more easily.

Results

Preliminary Trials

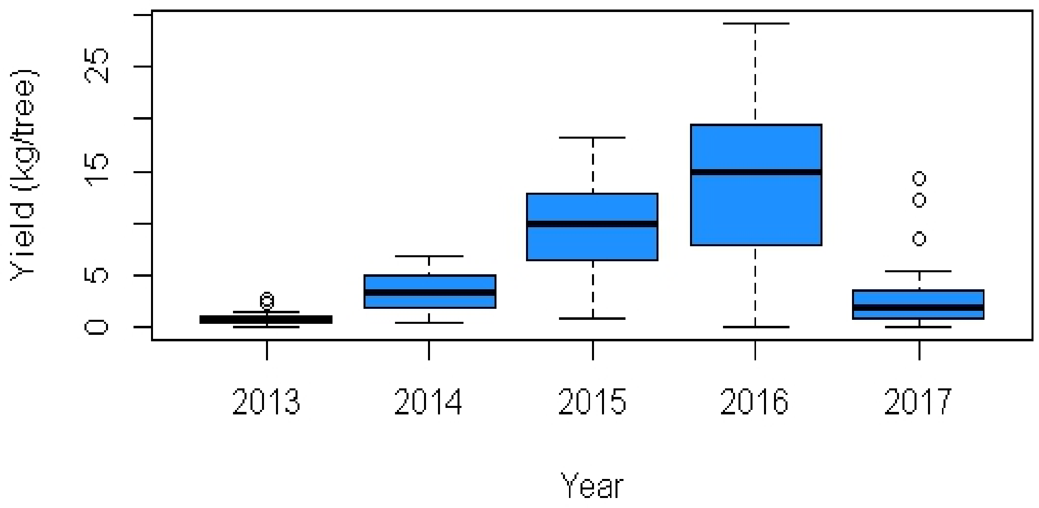
Apple trial, 'Royal Gala' (RF185)

This trial was planted in 2012 and ended in spring 2018. All rootstocks were grown with 'Royal Gala' as a common scion under conventional orchard management. M9, M116 and MM106 were included as standards.

The fruit was harvested, graded and weighed in September 2017. As seen in figure 1, the mean fruit yield across all rootstocks was lower than previous years. This was likely due to a late frost which particularly affected this plot due to its location in the farm. The girth and volume of the trees were measured in January 2018. The final weight of the trees was measured on 29 March 2018 when the trees were cut just above the graft union and immediately weighed in the field.

The likelihood ratio test for yield and yield efficiency per trunk cross section area (TCA) showed a highly significant effect of rootstock and year for both traits, but no interaction between the two. This indicates that the rootstocks in this trial did not induce biannual bearing.

Figure 1. Fruit yield per tree across all rootstocks in the RF185 trial for the years 2013-2017.



M.306-6

M.306-6 was one of the most vigorous rootstocks in this trial (Table 2). The TCA, tree volume and tree weight at grubbing were larger than for all three standards. The TCA and tree weight for M306-6 were significantly ($p<0.05$) different from M.9. M.306-6 also had the highest yield and yield efficiency of all trialled rootstocks in 2017 as well as the highest unbiased estimate (BLUE) of fruit yield per tree (Table 3). However, the unbiased estimate for yield efficiency across all years was lower for M306-6 than for M.9. Overall, considering this selection is susceptible to woolly apple aphid (WAA) and carries no genes for fire blight (FB) resistance it offers no substantial improvement on existing commercial rootstocks and it is of no interest for further trialling or as a parental genotype.

M.306-20

M.306-20 was the most vigorous rootstock within the trial, with a mean tree volume of 16 m3 and a mean tree weight of 8.89 kg. Together with M.306-6 it was the highest yielding rootstock both in 2017 (6.60 kg/tree) and across all years (8.4 kg/tree,). Although the yield efficiency of M.306-20 was higher than all three standards in 2017, the unbiased yield efficiency per TCA of this selection was lower than M.9 and similar to the two other standards (Table 3). The proportion of small fruit (≤65mm) produced by this rootstock (70%) was too high and along with its vigour made it uninteresting for further trials or breeding.

M.306-79

M.306-79 is very similar to M.9 in terms of vigour and precocity. It had a similar, but slightly larger, tree volume and TCA to M.9. The yield and yield efficiency (both expressed as yield per TCA and per tree volume) was higher for M.306-79 compared to M.9 in 2017, although this was not statistically significant. Also the unbiased estimate of yield across all the trial years was slightly higher for M.306-79 compared to M.9 but with no additional pest or disease resistances it offers little interest for further trials or breeding.

M.306-189

M.306-189 was the least vigorous rootstock in the trial with a mean TCA and tree volume of approximately 40% of that of M.9. The unbiased estimate mean yield efficiency of this rootstock selection was the same as that of M.9. The median harvest index of M.306-189 (Figure 2) was the same as for M.9, although M.9 showed less variation in this trait. This genotype is susceptible to WAA and due to its parentage will carry no FB resistance genes but it might be a useful parent for dwarfing; therefore it will be retained and genotyped for markers linked to dwarfing and compared to M.9 and M.27. It will also be assessed for its precocity coming into flower as a scion and its response to crown rot (*P. cactorum*).

Table 1. Mean and standard error of yield (kg/tree) and number of fruit per tree for each size class and bitter pit incidence in 2017 for four apple rootstock selections and three standard varieties. Letters that are different indicate significant differences at p≤0.05

Rootstock	Fruit yield (kg/tree)				Number of fruit per tree				Bitter pit
	≤65 mm	65-75 mm	≥75 mm	Total	≤65mm	65-75 mm	≥75 mm	Total	
M306-6	2.39 (± 0.8)*a*	4.73 (±1.7)	0.11 (±0.10)	7.21 (±0.4) *a*	24 (±8)	35 (±13)	1 (±1)	60 (±20)	1(±0)
M306-20	3.90 (±2.7) *a*	2.95 (±1.4)	0.05 (±0.05)	6.60 (±0.2) *ab*	43 (±31)	23 (±10)	0 (±0)	66(±31)	1(±0)
M306-79	0.26 (±0.2) *a*	1.62 (±0.3)	0.05(±0.05)	1.92 (±3.1) *ab*	3 (±2)	21 (±11)	0 (±0)	24(±9)	1(±0)
M306-189	0.10(±0.0) *a*	0.28 (±0.2)	0.05(±0.05)	0.44 (±2.5) *b*	1 (±0)	2 (±1)	0 (±0)	3(±2)	1(±0)
M9	0.16 (±0.1) *a*	0.92 (±0.3)	0.13 (±0.08)	1.20 (±0.2) *ab*	2 (±1)	7 (±2)	1 (±0)	9(±3)	1(±0)
M116	0.68 (±0.1) *a*	0.82(±0.3)	0.00 (±0.00)	1.47 (±0.4) *ab*	19 (±1)	16 (±2)	0 (±0)	14(±4)	1(±0)
MM106	1.28 (±0.6) *a*	1.56(±0.6)	0.00 (±0.00)	2.76 (1.0) *ab*	8 (±6)	6 (±2)	0 (±0)	35(±9)	1(±0)
P-value for rootstock effect[1]	0.032*	0.43	0.52	0.040*	0.043 (KW)[2]	0.26	0.47	0.075	n.s

[1] *, ** and *** indicate the significance level at 5, 1 and 0.1% respectively, ns indicates no significant effect.
[2] Difference between rootstocks in trait analysed with Kruskal-Wallis test due to non-normal distribution of residuals.

Table 2. Mean and standard error for vigour metrics, production of suckers and yield efficiency for four apple rootstock selections and three standard varieties in 2017. Different letters indicate significant differences at p≤0.05

Rootstock	Vigour			Number of suckers	Yield efficiency	
	TCA[1] (cm^2)	Tree volume (m^3)	Tree weight (kg)		Yield per TCA* (kg/cm^2)	Yield per tree volume (kg/m^3)
M306-6	20.8 (±2.9) *ab*	14.0 (±1.3) *ab*	7.35 (±2.5) *ab*	0.0 (±0.0) c	0.33 (±0.10)	0.50 (±0.1)
M306-20	24.1 (±2.5) *a*	16.0 (±2.3) *a*	8.89 (±3.1) *a*	0.0 (±0.0) c	0.24 (±0.10)	0.36 (±0.2)
M306-79	11.0 (±0.6) *bcd*	6.00 (±0.6) *bc*	3.16 (±0.2) *bcd*	2.5 (±0.5) *ab*	0.18(±0.03)	0.35 (±0.1)
M306-189	3.91 (±0.4) *d*	2.04 (±0.3) *c*	0.80 (±0.2) *d*	3.0 (±1.1) a	0.13 (±0.08)	0.25(±0.1)
M9	9.75 (±1.9) *cd*	4.57 (±1.8) *bc*	2.53 (±0.4) *cd*	1.0 (±0.4) abc	0.11 (±0.03)	0.22(±0.1)
M116	14.3 (±3.2) *abc*	9.14 (±2.9) *abc*	4.38 (±0.4) *bcd*	0.5 (±0.5) *bc*	0.09 (±0.02)	0.21 (±0.1)
MM106	14.6 (±2.1) *abc*	7.82 (±2.8) *abc*	6.05 (±0.9) *abc*	0.3 (±0.25) *bc*	0.16 (±0.06)	0.28 (±0.1)
P-value for rootstock effect	7.5e-05 ***	0.001 **	0.0002 ***	0.0016 **	0.25	0.65

[1]TCA = trunk cross section area.
[2] *, ** and *** indicate the significance level at 5, 1 and 0.1% respectively.

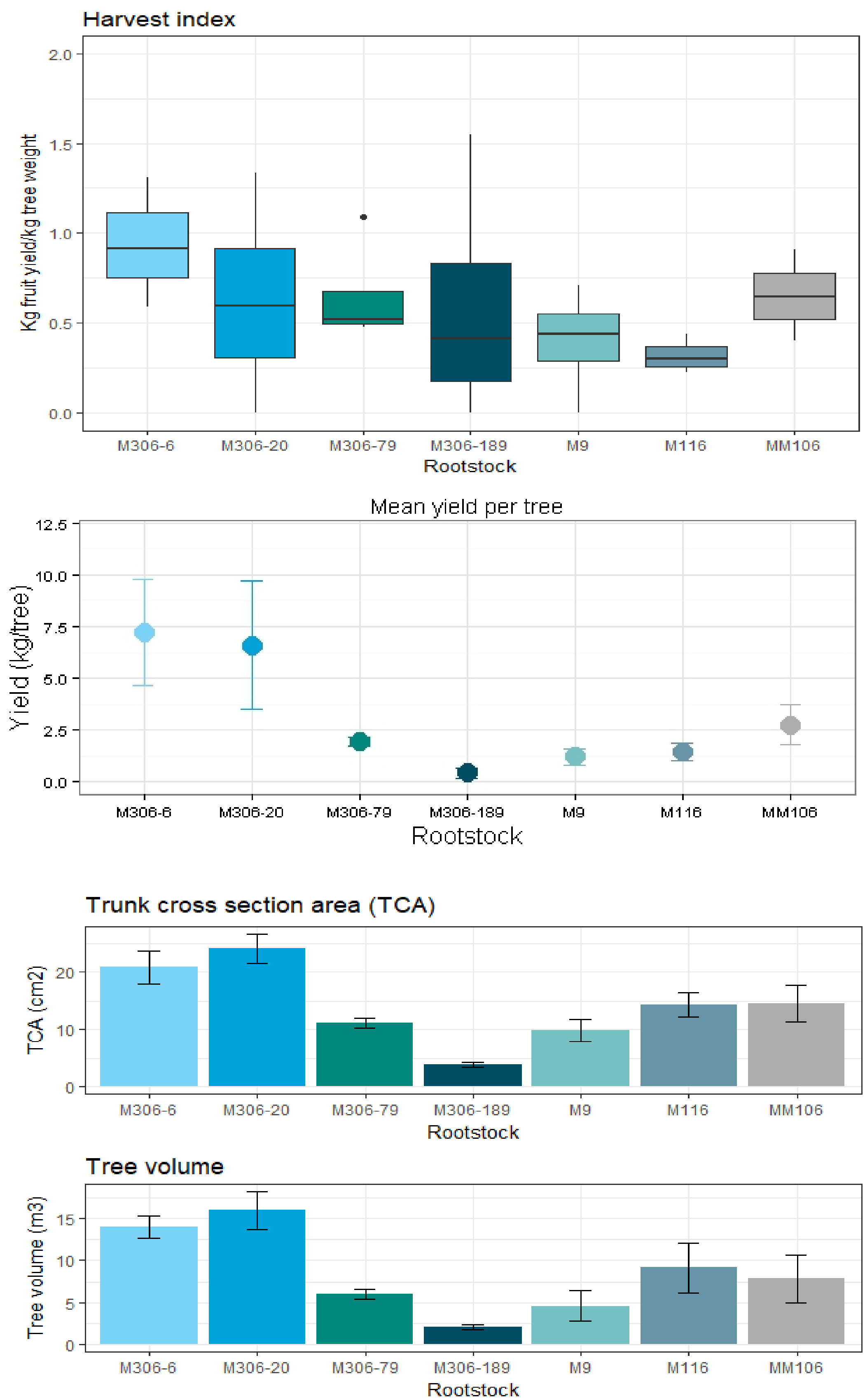


Figure 2. Vigour and yield traits as measured in 2017 for four rootstock selections and three standard varieties (M.9, M.116 and MM.106)

Table 3. Best linear unbiased estimate and likelihood ratio test of yield and yield efficiency as per TCA for the years 2013-2017. The yield and yield efficiency are estimated from the model y ~ Rootstock + (1|Block) + (1|Year) + (1|Rootstock:Year). The same model was used as the alternative model for the likelihood ratio test, from which each of the factors subsequently were removed to produce corresponding null models.

Rootstock	Total yield (kg/tree)	Yield efficiency as per TCA[1] (kg/cm2)
M306-6	8.4	0.9
M306-20	8.4	0.8
M306-79	6.4	1.3
M306-189	2.6	1.3
M9	5.5	1.3
MM106	6.7	0.8
M116	5	0.7
P-value for effect of rootstock[2]	0.0032 **	00.026 *
Chi-square$_{(5,11:6)}$[3]	19.6	14.6
P-value for effect of year	1.4e-11 ***	7.9e-09 ***
Chi-square$_{(10,11:1)}$	45.7	33.3
P-value for rootstock:year	1	0.63
Chi-square$_{(10,11:1)}$	0	0.24

[1] TCA = trunk cross section area
[2] *, ** and *** indicate the significance level at 5, 1 and 0.1% respectively, ns indicates no significant effect.
[3] Numbers within brackets indicate the following degrees of freedom; (null model, alternative model: difference between models)

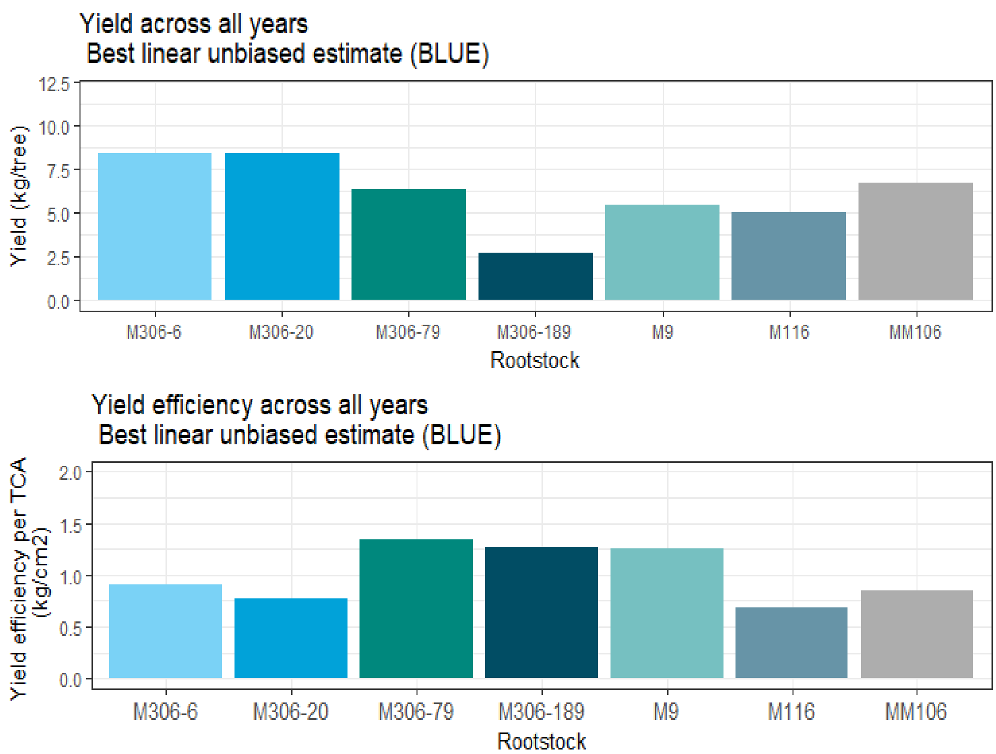


Figure 3. Best linear unbiased estimate of cumulative yield and yield efficiency for trunk cross section area (TCA) for the years 2013 to 2017. The yield and yield efficiency are estimated from the model: y ~ Rootstock + (1|Block) + (1|Year) + (1|Rootstock:Year)

Pear trial, 'Conference' (RF187)

The pear trial in plot RF187 was planted in 2014 and contains 10 selections of pear rootstocks, all planted with 'Conference' as a common scion. 'Quince A' is included as a standard in the trial. The trial flowered and would have cropped in 2017 but fruit set was very badly affected by a frost in late April so no crop could be recorded. Therefore the only data presented is for vigour and tendency to produce suckers (Table 4 and Figure 4). So far all of the rootstocks in the trial appear to be of comparable or less vigorous than 'Quince A' except for PQ37-2 and PQ39-5.

Table 4. Mean and standard error (in brackets) of vigour components and suckering in 10 pear rootstock selections and the standard rootstock 'Quince A'.

Rootstock	TCA	Tree Volume	Suckers
PQ37-2	21.9 (±0.2)	6.68 (±0.7)	0.0(±0.0)
PQ37-3	6.47 (±0.5)	0.53(±0.1)	0.0(±0.0)
PQ37-5	1.78 (±0.3)	0.03 (±0.009)	0.0(±0.0)
PQ37-7	13.2 (±0.4)	1.10 (±0.4)	0.2(±0.3)
PQ37-8	3.76 (±0.50)	0.40 (±0.1)	1.0(±0.7)
PQ38-2	7.43 (±0.6)	1.24 (±0.5)	1.5(±0.5)
PQ39-1	9.21 (±0.4)	1.34 (±0.4)	0.2(±0.3)
PQ39-3	10.6 (±0.23)	3.34 (±0.2)	0.0(±0.0)
PQ39-4	9.25 (±0.1)	4.50 (±0.4)	1.0(±0.7)
PQ39-5	20.8 (±0.7)	5.99 (±0.2)	0.0(±0.0)
Quince A	16.8 (±0.5)	5.23 (±0.7)	0.0(±0.0)
P-value for rootstock effect[1]	2.6e-05 ***	1.2e-06 ***	0.052

[1]*, ** and *** indicates rootstock effect significant at the 5, 1 and 0.1% level respectively.

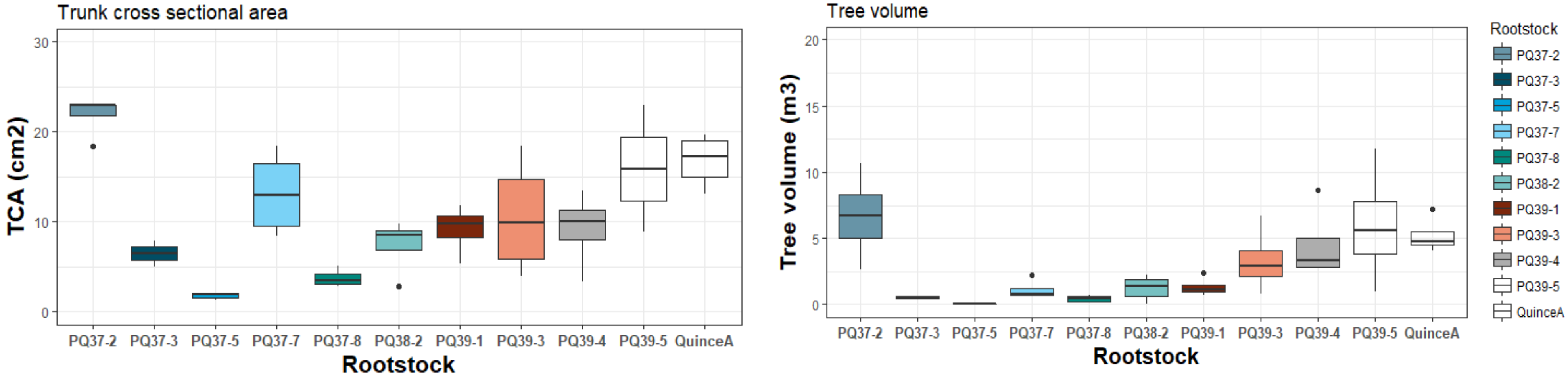


Figure 4. Trunk cross sectional area (TCA) and tree volume for ten pear rootstock selections and the standard variety ‘Quince A’ as measured in 2017

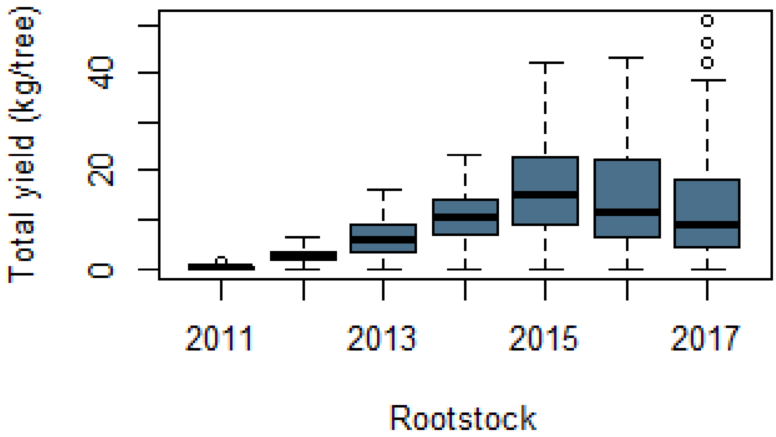
Second stage trials

Conventional apple orchard, ‘Royal Gala’ and ‘Braeburn’ (EE207)

The trial EE 207 contains five rootstock selections which were planted in 2010. The standard varieties included in the trial are ‘M.9’, ‘M.26’ and ‘M.27’. All rootstocks were planted with both ‘Royal Gala’ and ‘Braeburn’ as scions. The fruit was harvested, graded and weighed in September, 2017. The girth and volume of the trees were measured in January 2018 but the final tree weight could not be measured until 29 March due to the very wet conditions of the soil preventing access to the fields with heavy equipment.

The rootstock effect on all measured traits was analysed with ANOVA in R, with scion and block as additional fixed effects. For traits for which there was no significant interaction between rootstock and scion, the aggregated mean across both scions is presented for each rootstock. The best linear unbiased estimate (BLUE) for yield is estimated from yield data between years 2011-2017, whereas for the yield efficiency it is estimated from 2011 and 2014-2017. Figure 5 shows the expected increase of overall yields in the early years of the trial that later stabilised as well as the negative effect of the 2017 spring frost on yield on the last year of the trial.

Figure 5. Boxplot of fruit yield for all rootstocks in the trial EE207 for the years 2011-2017



AR852-3

In this trial, AR852-3 had a similar effect on tree volume to M.9 and M.26 (8.78m^3 compared to 8.83 and 7.91m^3, respectively. The TCA of AR852-3 was higher than for these two standards (22.7cm^2 compared to 16.2 and 20.6 cm^2). However, both the mean yield per tree and yield efficiency of AR852-3 were lower than for M.9 and M.26 in 2017 (Table 5). The estimated mean from all trial years of M9 also outcompeted this selection regarding yield and yield efficiency. AR852-3 had a high proportion (56%) of fruit that were larger than 75mm in diameter.

AR839-9

AR839-9 also had a similar effect on vigour to M.9 and M.26 in this trial. The yield in 2017 and the unbiased estimate of yield were, however, lower than for the standard varieties with similar vigour. The unbiased estimate of yield efficiency for AR839-9 was also lower than for M9. The mean number of suckers produced by AR839-9 was 2.13 per tree in 2017; the highest in the trial.

B24

B24 was by far the most vigorous rootstock in the trial. The tree volume, TCA and tree weight of B24 were significantly higher compared to all three standard varieties (Table 5). However, this high vigour did not result in a significantly larger yield compared to M9 in 2017. The yield efficiency (as per TCA and per tree volume in 2017 and the unbiased estimate) of B24 was also lower than for M.9 and M.27.

R104

R104 was slightly larger than M.9 and M.26 in this trial, but not statistically significantly so (table 4). The fruit yield in 2017 was similar to M.9 (mean yield of 17.9 kg/tree for R104 compared to 18.5 for M.9) as was the unbiased yield estimate. However, the yield efficiency (as per TCA and per tree volume in 2017 and the unbiased estimate) was lower than for M.9.

R59

R59 was the least vigorous selection in this trial with a vigour similar to M.27. It also had a similar yield to M.27 (Table 5 and 7). M.27 yield efficiency was higher in 2017, but across all years the two rootstocks performed very similarly in yield efficiency.

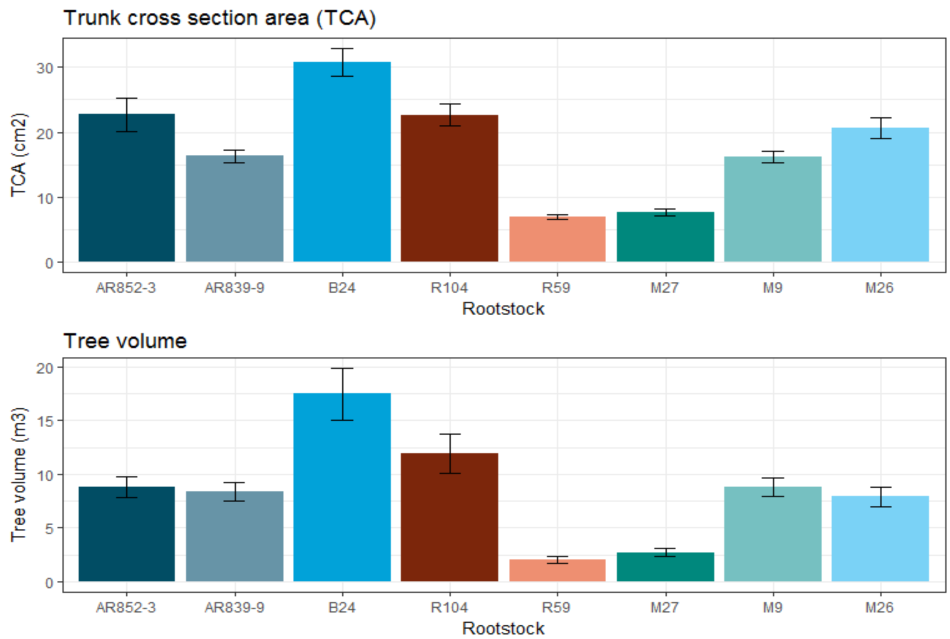


Figure 6. Mean and standard error for trunk cross sectional area (TCA) and tree volume as measured in 2017 for five rootstock selections and three standard varieties

These selections are all still under trial with INN in the continent and many are likely to be used as parents in the near future depending on their pest and disease resistance traits as well as orchard performance.

Table 5 Mean and standard error for traits related to rootstock performance for five selections and three standard varieties. Differing letters indicate significant differences at p≤0.05. The table also shows the p-values for the effect of rootstock, scion, block and rootstock:scion interaction from ANOVA

Rootstock		Tree volume (m^3)	TCA[1] (cm^2)	Tree weight (kg)	Bitter pit (1-5)	Number of Suckers	Fruit yield (kg/tree)	Total number of fruit per tree	Yield efficiency	
									As per TCA (kg/ cm^2)	As per tree volume (kg/ m^3)
AR852-3		8.78 (±1.0) *b*	22.7 (±2.6) *ab*	6.66 (±0.4) *b*	1.31 (±0.2)	0 (±0)	12.4 (±2.9) *abc*	86 (±20) *abc*	0.59 (±0.2)	1.32 (±0.3)
AR839-9		8.35 (±0.9) *b*	16.3 (±1.0) *b*	5.16 (±0.4) *b*	1.81 (±0.2)	2.13 (±0.6)	9.83 (±1.7) *bc*	74 (±15) *abc*	0.59 (±0.08)	1.24 (±0.2)
B24		17.5 (±2.4) *a*	30.8 (±2.1) *a*	11.98 (±1.1) *a*	1.44 (±0.2)	0 (±0)	22.3 (±5.4) *a*	201 (±60) *a*	0.71 (±0.2)	1.30 (±0.3)
R104		11.9 (±1.8) *ab*	22.6 (±1.7) *ab*	7.09 (±0.7) *b*	1.22 (±0.1)	0 (±0)	17.9 (±2.4) *ab*	133 (±20) *a*	0.82 (±0.1)	1.74 (±0.3)
R59		2.02 (±0.3) *c*	6.97 (±0.4) *c*	1.54 (±0.2) *c*	1.75 (±0.4)	0.25 (±0.1)	4.54 (±1.2) *c*	37 (±11) *c*	0.59 (±0.2)	1.99 (±0.5)
M27		2.73 (±0.3) *c*	7.7 (±0.5) *c*	2.02 (±0.38) *c*	1.13 (±0.09)	1.70 (±0.4)	5.44 (±1.0) *c*	42 (±8) *bc*	0.73 (±0.1)	2.32 (±0.5)
M9		8.83 (±0.9) *b*	16.2 (±0.9) *b*	5.19 (±0.4) *b*	1.43 (±0.1)	1.06 (±0.4)	18.5 (±3.29) *ab*	162 (±34) *a*	1.11 (±0.2)	1.93 (±0.3)
M26		7.91 (±0.9) *b*	20.6 (±1.6) *b*	5.33 (±0.54) *b*	1.50 (±0.2)	1.94 (±0.5)	13.4 (±2.5) *abc*	101 (±21) *ab*	0.68 (±0.1)	1.65 (±0.2)
Source of variation[2]	d.f.									
Rootstock	7	< 2e-16 ***	<2e-16 ***	< 2e-16 ***	0.19 (KW)[3]	2.0e-06 (KW)	8.6e-07 ***	3.8e-06 ***	0.14	0.71
Scion	1	0.00068 ***	0.28	0.0054 **			0.0012 **	0.00012 ***	0.014 *	0.62
Block	1	0.64	0.82	0.27			0.021 *	0.11	0.064	0.11
Rootstock:Scion	7	0.86	0.30	0.50			0.11	0.074	0.65	0.80
Residuals	94									

[1] Trunk cross sectional area
[2] *, ** and *** indicate the significance level at 5, 1 and 0.1% respectively.
[3]Difference between rootstocks in trait analysed with Kruskal-Wallis test due to non-normal distribution of residuals

Table 6. Percent fruit yield and total number of fruits by fruit size (≤65, 65-75 and ≥75 mm in diameter). The table also shows the p-values for the effect of rootstock, scion, block and rootstock:scion interaction from ANOVA.

Rootstock	Scion	Fruit yield (kg/tree)			Number of fruit (No./tree)		
		≤65 mm	65-75 mm	≥75 mm	≤65 mm	65-75 mm	≥75 mm
AR852-3	Braeburn	11	34	56	33	37	30
AR839-9	Braeburn	14	39	47	38	34	28
B24	Braeburn	18	39	43	30	40	30
R104	Braeburn	31	41	29	44	38	18
R59	Braeburn	17	40	43	45	32	24
M27	Braeburn	30	40	30	50	35	15
M9	Braeburn	17	36	47	30	38	32
M26	Braeburn	20	37	43	35	36	28
AR852-3	Royal Gala	32	57	11	42	50	7
AR839-9	Royal Gala	31	60	9	41	53	6
B24	Royal Gala	68	31	1	75	25	0
R104	Royal Gala	35	59	7	45	51	4
R59	Royal Gala	47	51	2	57	42	1
M27	Royal Gala	27	66	7	36	60	4
M9	Royal Gala	70	29	1	76	24	0
M26	Royal Gala	41	56	3	50	48	2
Source of variation	D.f						
Rootstock	7	5.7e-06 ***	0.00017 ***	0.00019 ***	1.8e-05 ***	8.6e-05 ***	9.8e-05 ***
Scion	1	3.6e-06 ***	5.4e-05 ***	3.0e-14 ***	2.7e-05 ***	4.6e-06 ***	7.8e-13 ***
Block	1	0.43	0.13	0.020 *	0.32	0.13	0.019 *
Rootstock:Scion	7	0.029 *	0.88	0.10	0.0010 **	0.80	0.11
Residuals	94						

[1] *, ** and *** indicate the significance level at 5, 1 and 0.1% respectively

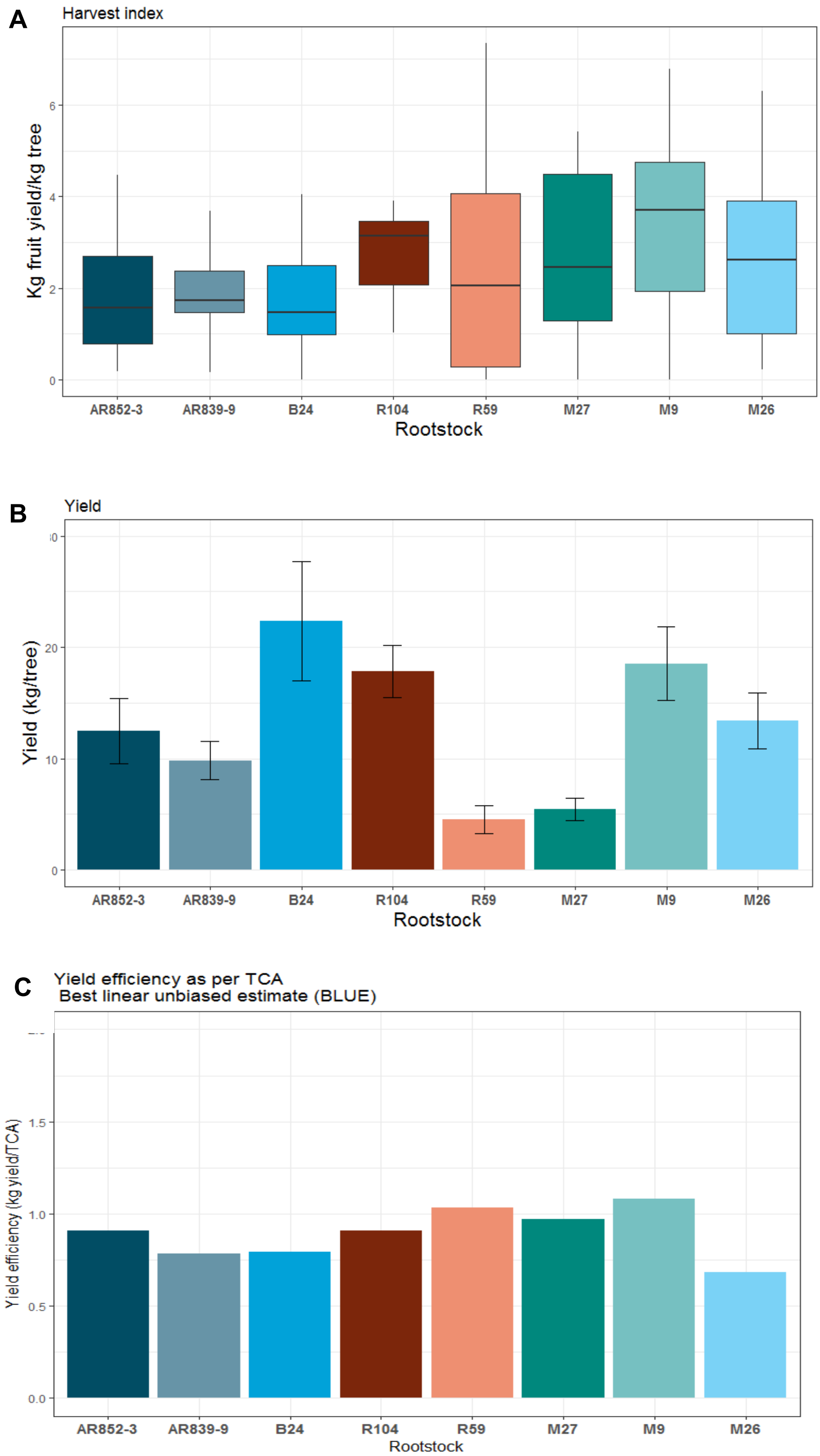


Figure 7. **A** Harvest index for 2017, **B** Mean and SE of yield in 2017, **C** Best linear unbiased estimate of yield efficiency as per TCA based on data from 2011 and 2014-2017

Table 7. Best linear unbiased prediction of yield and yield efficiency for five rootstock selections and three standard varieties.. The yield and yield efficiency are estimated from the model y ~ Rootstock + Scion + (1|Block) + (1|Year) + (1|Rootstock:Year). The same model was used as the alternative model for the likelihood ratio test, from which each of the factors subsequently were removed to produce corresponding null models.

Rootstock	BLUE	
	Total yield (kg/tree)	Yield efficiency as per TCA (kg/cm²)
AR852-3	10.0	0.90
AR839-9	6.83	0.78
B24	11.2	0.79
R104	10.6	0.91
R59	3.33	1.03
M27	3.35	0.97
M9	10.1	1.08
M26	7.68	0.68
P-value for effect of rootstock[2]	3.3e-05 ***	0.017 *
Chi-square$_{(6,13:7)}$[3]	32.5	17.1
P-value for effect of year	< 2.2e-16 ***	< 2.2e-16 ***
Chi-square$_{(12,13:1)}$	442.1	285.9
P-value for rootstock:year	0.38	1
Chi-square$_{(12,13:1)}$	0.8	0

[1] Trunk cross sectional area
[2] *, ** and *** indicate the significance level at 5, 1 and 0.1% respectively.
[3] Numbers within brackets indicate the following degrees of freedom; (null model, alternative model: difference between models)

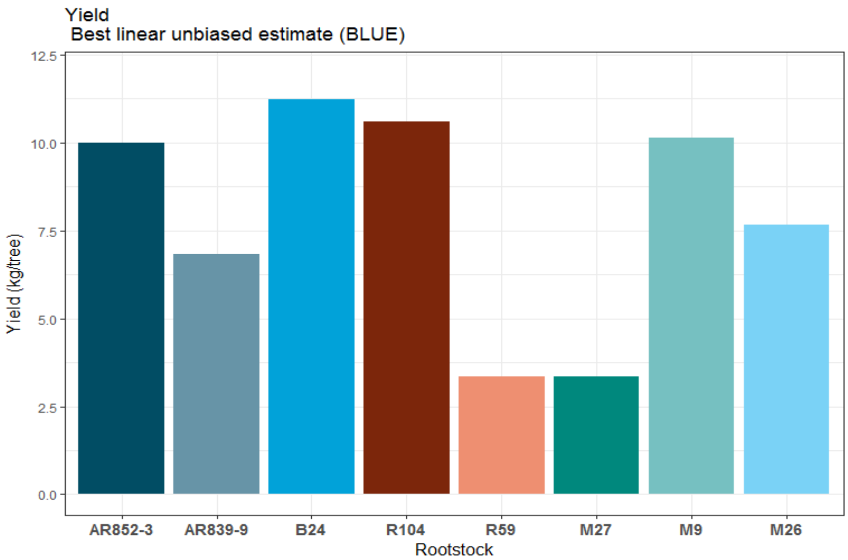


Figure 8. Best linear unbiased estimate of yield based on data from 2011-2017 in one trial.

Organic orchard, 'Red Falstaff' (VF224)

Five rootstock selections were trialled with M116 and MM106 as standards in this organically managed orchard, planted in 2010. The fruit was harvested, graded and weighed in September 2017. The girth and volume of the trees were measured in January 2018 but the final tree weight could not be measured until the 29th March due to the very wet conditions of the soil preventing access to the fields with heavy equipment. As in the case of EE207, yield in 2017 was affected by spring frost leading to a decrease in production compared to 2016 (Figure 9).

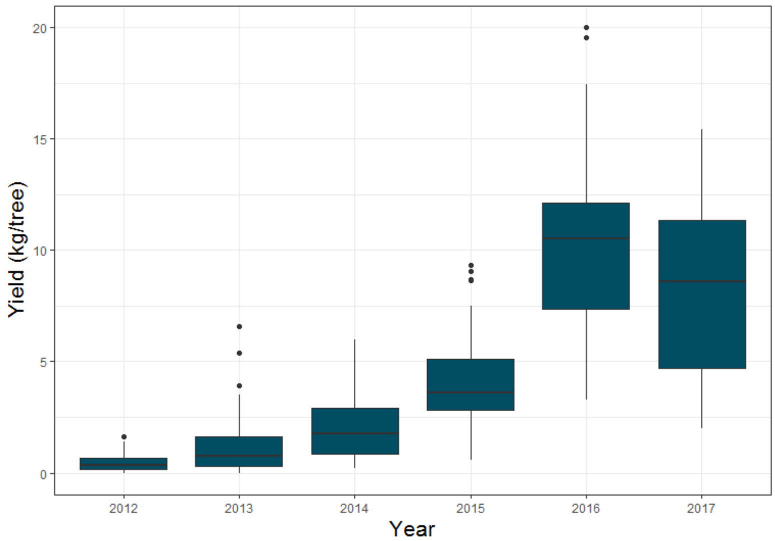


Figure 9. Boxplot for yield per tree for all rootstocks in the trial 'VF224'

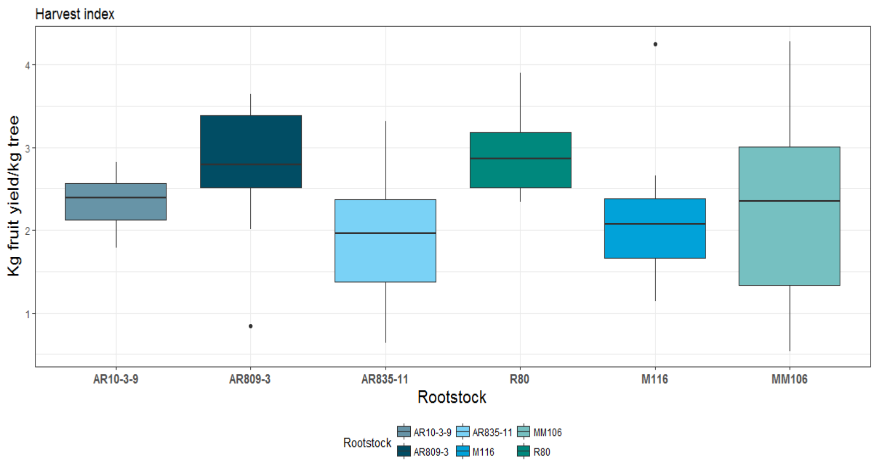


Figure 10. Boxplot of harvest index (kg fruit yield/kg of tree weight) for the four rootstock selections and two standard varieties trialled in VF224.

AR10-3-9

AR10-3-9 had similar tree vigour, measured as tree volume and TCA to the two standard varieties M.116 and MM.106 (Table 8). The yield and yield were also comparable to the standards for this selection that has also shown encouraging results in the continent. Unfortunately, it does not offer any additional pest or disease resistance compared to M.116 so it is unlikely to be released as a commercial rootstock.

AR809-3

AR809-3 had the lowest vigour of all rootstocks in this trial and would be better assessed alongside more dwarfing stocks. The tree volume and TCA for AR809-3 was significantly differing from that of M.116 (Table 8 and Figure 10) but the mean and best estimate yield of this selection were also lower than for both standard varieties (Table 8 and 9). The yield efficiency of AR809-3, as a measure of tree volume, was slightly higher than the two rootstock standards in 2017.

AR835-11

AR835-11 was the most vigorous rootstock in terms of tree volume (Table 8). However in 2017, the mean yield and yield efficiency was lower than for M.116 and MM.106. The BLUE for yield and yield efficiency were comparable to that of the two standard varieties. This selection is performing fairly well in INN trials but it is probably too vigorous for commercial release.

R80

R80 was the best performing rootstock within the VF224 trial in terms of yield and yield efficiency. The mean yield in 2017 for R80 was 10.7 kg/tree, whereas for M116 and MM106 it was 9.23 and 7.2kg/tree, respectively. It also had the highest mean and unbiased estimate of yield efficiency as per TCA of the whole trial (Table 8 and 9) although the less vigorous AR809-3 was more efficient when yield efficiency was calculated based on tree volume. This rootstock is also promising in INN trials and will continue to be assessed.

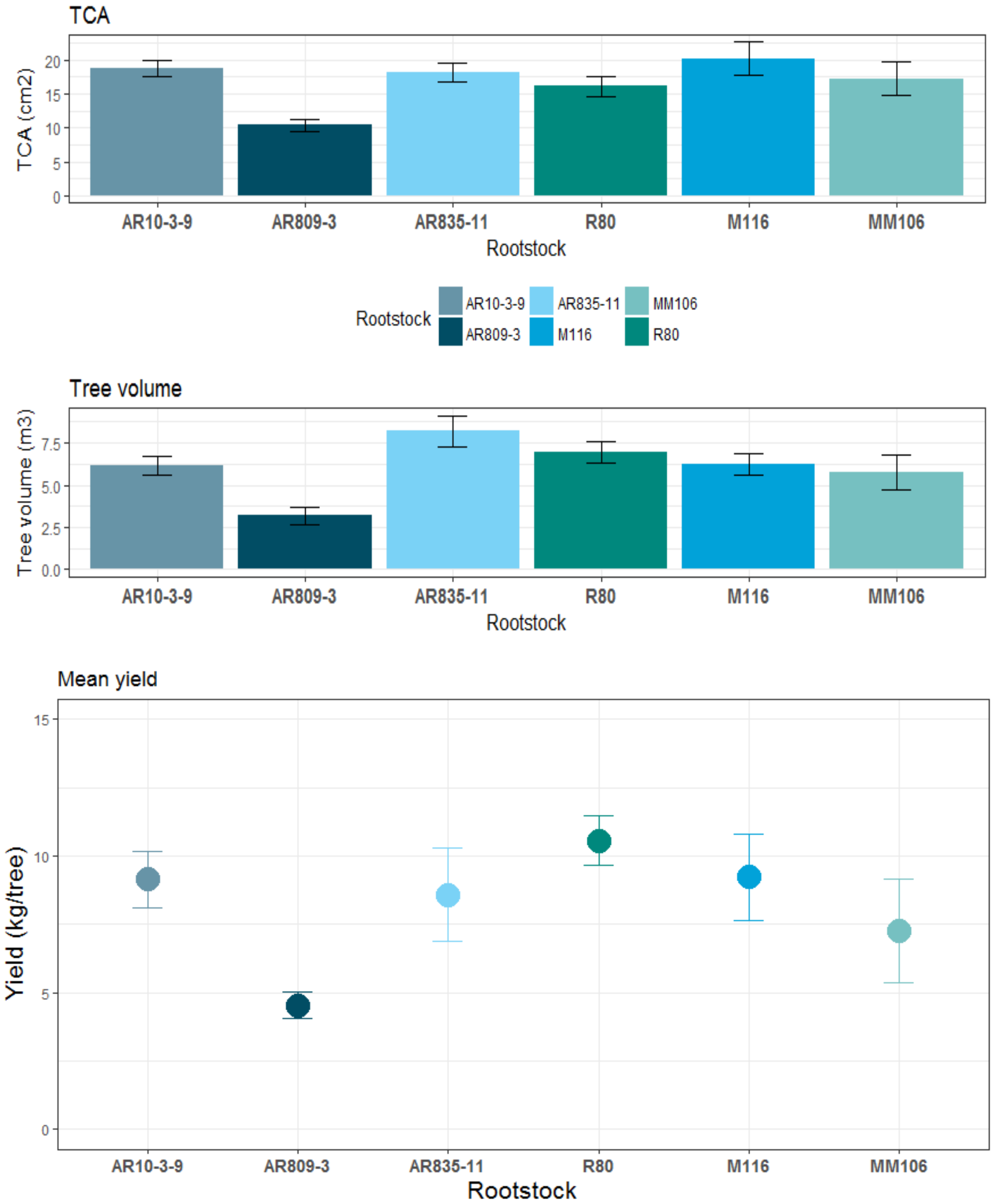


Figure 11. Mean and standard error of TCA, tree volume and yield for four rootstock selections and two standard varieties trialled in an organically managed orchard

Table 8 Mean and standard error for traits related to rootstock vigour, incidence of bitter pit in fruit and suckers in the orchard as well as yield efficiency for four apple rootstock selection selections and the two standard varieties M116 and MM106. Differing letters indicate significant differences at p≤0.05. The table also shows the p-values for the effect of rootstock from ANOVA

Rootstock	Tree volume (m^3)	TCA[1] (cm^2)	Tree weight (Kg)	Bitter pit (1-5)	Number of suckers	Yield efficiency: As per TCA (kg/cm^2)	Yield efficiency: As per tree volume (kg/m^3)
AR10-3-9	6.15 (±0.5) *a*	18.9 (±1.2) *a*	3.86 (±0.3) *a*	2.13 (±0.1)	0 (±0)	0.48 (±0.04)	1.50 (±0.1)
AR809-3	3.19 (±0.50) *b*	10.4 (±1.0) *b*	1.80 (±0.2) *b*	2.25 (±0.2)	0 (±0)	0.45 (±0.05)	1.64 (±0.3)
AR835-11	8.20 (±0.9) *a*	18.1 (±1.3) *a*	4.51 (±0.4) *a*	2.00 (±0.3)	0 (±0)	0.47 (±0.08)	1.08 (±0.2)
R80	6.92 (±0.6) *a*	16.1 (±1.5) *ab*	3.75 (±0.4) *a*	2.88 (±0.2)	0.13 (±0.1)	0.67 (±0.04)	1.56 (±0.1)
M116	6.22 (±0.61) *a*	20.2 (±2.5) *a*	4.21 (±0.5) *a*	2.42 (±0.3)	0 (±0)	0.47 (±0.09)	1.43 (±0.17)
MM106	5.75 (±1.0) *ab*	17.3 (±2.5) *ab*	3.41 (±0.5) *a*	2 (±0.2)	0 (±0)	0.44 (±0.1)	1.31 (±0.3)
P-value for rootstock effect[2]	0.00055 ***	0.0028 **	1.3e-05 ***	0.063	0.46	0.19	0.40

[1] Trunk cross sectional area

[2] *, ** and *** indicate the significance level at 5, 1 and 0.1% respectively.

Table 9 Mean and standard error for productivity traits for four selections and the two standard varieties M116 and MM106. Differing letters indicate significant differences at p≤0.05. The table also shows the p-values for the effect of rootstock from ANOVA

Rootstock	Fruit yield (kg/tree)				Number of fruit (No./tree)			
	<65mm	**65-75mm**	**>75mm**	**Total yield**	**<65mm**	**65-75mm**	**>75mm**	**Total number of fruit**
AR10-3-9	6.90 (±0.8) *ab*	2.24 (±0.4)	0 (±0.0)	9.15 (±1.0) *ab*	107 (±15) *ab*	22 (±4)	0 (±0)	129 (±15) *ab*
AR809-3	3.38 (±0.2) *b*	1.15 (±0.3)	0 (±0.0)	4.53 (±0.5) *b*	58 (±7) *b*	10 (±2)	0 (±0)	67 (±8) *b*
AR835-11	4.56 (±1.2) *ab*	3.80 (±0.7)	0.22 (±0.2)	8.58 (±1.7) *ab*	74 (±19) *ab*	28 (±6)	1 (±1)	104 (±22) *ab*
R80	7.69 (±0.9) *a*	2.86 (±0.4)	0.016 (±0.0)	10.7 (±0.9) *a*	145 (±25) *a*	22 (±3)	0 (±0)	167 (±23) *a*
M116	6.32 (±1.1) *ab*	2.91 (±0.9)	0 (±0.0)	9.23 (±1.6) *ab*	115 (±19) *ab*	22 (±7)	0 (±0)	138 (±21) *ab*
MM106	4.99 (±1.3) *ab*	2.25 (±0.7)	0 (±0.0)	7.2 (±1.9) *ab*	95 (±27) *ab*	14 (±5)	0 (±0)	109 (±28) *ab*
P-value for rootstock effect[1]	0.026 *	0.055	0.16	0.036 *	0.020 *	0.063	0.15	0.014 *

[1] *, ** and *** indicate the significance level at 5, 1 and 0.1% respectively.

Table 10. Best linear unbiased estimate and likelihood ratio test of yield and yield efficiency as per TCA for the years 2012-2017 (yield) and 2014-2017. The yield and yield efficiency are estimated from the model y ~ Rootstock + (1|Block) + (1|Year) + (1|Rootstock:Year). The same model was used as the alternative model for the likelihood ratio test, from which each of the factors subsequently were removed to produce corresponding null models

Rootstock	BLUE	
	Yield (kg/tree)	Yield efficiency per TCA[1] (kg/cm²)
AR10-3-9	4.6	0.42
AR809-3	2.6	0.50
AR835-11	4.7	0.47
R80	5.9	0.63
M116	4.7	0.40
MM106	4.1	0.41
P-value for effect of rootstock[2]	0.00045 ***	0.00016 ***
Chi-square$_{(5,10:5)}$[3]	22.4	24.6
P-value for effect of year	< 2.2e-16 ***	3.2e-09 ***
Chi-square$_{(9,10:1)}$	69.3	35.0
P-value for rootstock:year	0.078	1
Chi-square$_{(9,10:1)}$	3.1	0

[1] Trunk cross sectional area
[2] *, ** and *** indicate the significance level at 5, 1 and 0.1% respectively.
[3] Numbers within brackets indicate the following degrees of freedom; (null model, alternative model: difference between models)

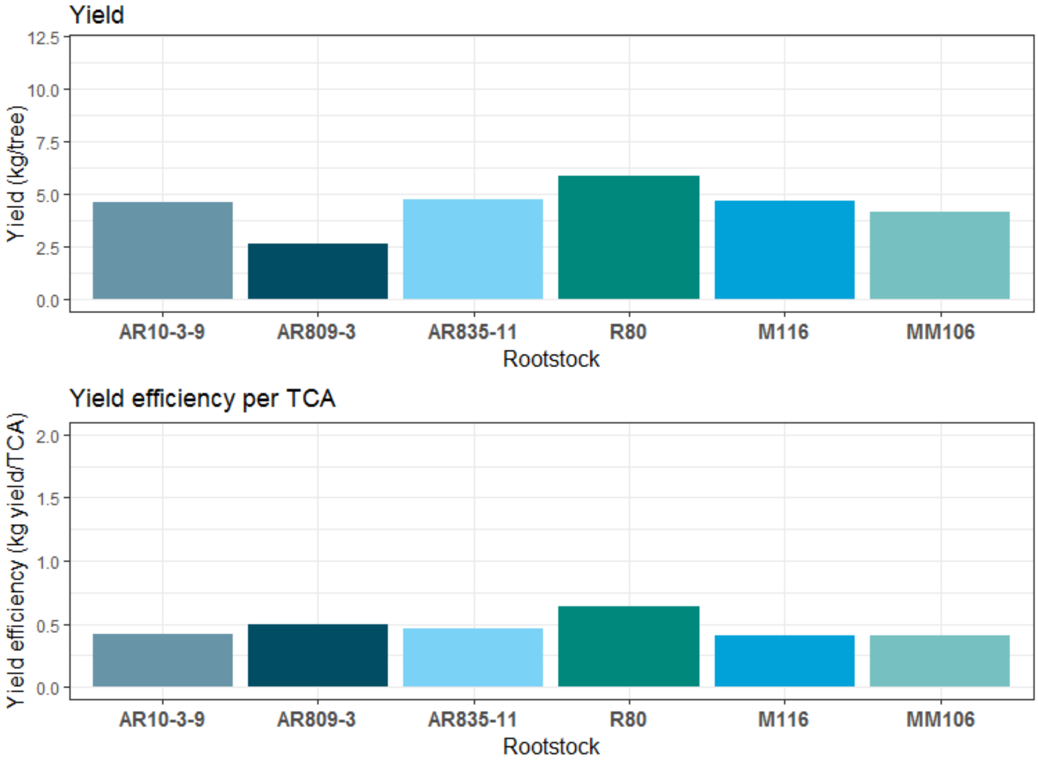


Figure 11. Best linear unbiased estimate of yield and yield efficiency per TCA for four rootstock selections and the two standard varieties 'M116' and 'MM106'

Canadian rootstock selections (SP250)

The trial SP250 was planted in 2014 and contains six Canadian rootstock genotypes and the four standard varieties ‘M27’, ‘M9’, ‘M26’ and ‘MM106’. The trial is under conventional management with ‘Gala’ and ‘Braeburn’ as scions. Due to errors during propagation, the different rootstocks are planted in uneven sample sizes. The trial is therefore analysed with a mixed effect linear model instead of ANOVA.

The fruit was harvested, graded and weighed in September 2017. The girth and volume of the trees were measured in January 2018 and pruning weights were recorded in April. 2018.

SJM127

SJM127 was only grown with ‘Braeburn’ as a scion, and all estimates are therefore based on the performance with this scion. This rootstock had a similar tree volume and TCA to M9 (Table 12). It had a higher estimate yield than M9 (Table 12) and as visualised in Figure 12, the median yield of SJM127 was higher than for M9 with ‘Braeburn’. The estimate yield efficiency of SJM127 was comparable to M9 when calculated as a function of tree volume.

SJM15

SJM15 was only grown with ‘Gala’ as a scion, therefore all estimate means are based on the rootstock’s performance with this particular scion. SJM15 was the least vigorous of the trialled selections. Its estimate tree volume was 0.4m^3 larger than of M27 with 79% higher yield than resulting in a higher yield efficiency both measured as a function of TCA (1.4kg/cm^2) and of tree volume (2.4 kg/m^3) (Table 11). As seen in figure 12, the variation in yield efficiency was much smaller for SJM15 than for M27. On the negative side, a high proportion (42%) of the fruit produced on SJM15 was smaller than 65mm (Table 12).

SJM167

Trees on SJM167 showed a vigour between M9/M26 and MM106 (Table 12) and the trees required the most labour to maintain as it had the highest estimate pruning weight of all rootstocks. Please note that pruning was conducted after the measurement of tree volume for the season. The estimate total yield was higher than for all standard rootstocks, although due to the vigour of the rootstock, this did not translate into higher yield efficiency per tree volume compared to the standards M9, M26 and M27.

SJM188

With a tree volume of 6 m^3 and a TCA of 9.6cm^2, this rootstock was slightly less vigorous than M9 and M26 in this trial with a similar yield efficiency.

SJP84-5162

SJP84-5162 was also slightly less vigorous to M9 and M26 (Table 12). This selection had a good performance regarding yield and yield efficiency; it had a 0.3 kg higher estimate mean yield per tree than M9 and the estimate yield efficiency as per tree volume of SJP84-5162 was similar to M27 (higher than M9 and lower than M26). The yield efficiency as per TCA was higher for SJP84-5162 than all standard genotypes.

SJP84-5174

The vigour of SJP84-5174 was similar to M.26 (which in this trial was less vigorous than M.9; Table 11) but it did not exceed the yield and yield efficiency performance of the rootstocks with similar vigour (M.9 and M.26). It also had a high incidence of fruit with bitter pit (estimate mean score of 2.1, compared to scores of 1.8 for M.9 and M.26).

SJP84-5217

SJP84-5217 was a selection of similar vigour to M.9. It had a slightly higher estimate mean yield and yield efficiency (as per TCA and tree volume) compared to M.9.

Table 11. Estimated means of fruit yield and number of fruit per tree by fruit size class. The means are estimated from the linear mixed model and averaged over the level of scion

Rootstock	Fruit yield by size (kg/tree)			Number of fruit by size (No./tree)		
	<65mm	65-75mm	>75mm	<65mm	65-75mm	>75mm
SJM127	2.1	8.0	3.5	20.5	55.2	18.0
SJM15	3.6	3.3	1.7	37.8	26.4	8.1
SJM167	2.4	7.0	2.5	23.9	49.0	11.5
SJM188	1.0	3.7	1.7	11.2	25.2	8.0
SJP84-51	1.7	4.6	3.2	17.3	31.5	15.2
SJP84-51	1.5	5.2	2.3	16.4	35.4	11.3
SJP84-52	1.6	6.5	2.5	15.1	45.0	12.2
M27	0.8	3.1	1.0	8.8	19.2	4.6
M9	1.4	5.7	1.9	13.7	37.9	9.6
M26	2.5	5.4	2.1	23.9	38.2	9.8
MM106	4.0	6.5	0.6	39.6	44.5	3.0

Table 12. Estimated means for six Canadian rootstock selections as well as four standard rootstock varieties. The table also shows the p-values for the effect of rootstock, scion and rootstock:scion from a linear mixed effect model

Rootstock	Yield (kg/tree)	Number of fruit per tree	Bitter pit (1-5)	Number of suckers per tree	Tree volume (m^3)	TCA[1] (cm^2)	Pruning weight (g)	Yield efficiency	
								As per TCA (kg/cm^2)	As per tree volume (kg/m^3)
SJM127	13.4	91.7	1.4	0.0	9.3	12.3	1.2	1.2	1.7
SJM15	8.6	72.1	1.7	0.2	4.3	7.8	0.8	1.4	2.4
SJM167	11.9	85.2	1.3	0.0	9.0	12.1	1.6	1.0	1.3
SJM188	6.4	44.3	1.1	0.0	6.0	9.6	0.8	0.7	1.3
SJP84-5162	9.3	62.8	1.3	0.1	6.9	8.4	0.9	1.1	1.5
SJP84-5174	9.0	63.3	2.1	0.0	7.5	11.1	1.5	0.9	1.4
SJP84-5217	10.7	73.0	1.7	0.0	8.8	11.5	1.2	1.0	1.4
M27	4.8	31.8	2.5	0.4	3.9	5.8	0.5	0.8	1.5
M9	9.0	61.8	1.8	0.1	8.7	11.3	1.3	0.8	1.3
M26	10.0	71.9	1.8	0.4	7.2	10.9	1.2	1.0	1.7
MM106	10.9	85.7	1.5	0.1	11.4	15.3	2.2	0.7	1.0
P-value for effect of rootstock[2]	0.009**	0.02 *	0.002 **	0.058	0.0009 ***	1.4e-06 ***	1.8e-05 ***	0.065	0.10
Chi-square$_{(6,16:10)}$[3]	23.3	21.5	28.4	17.8	28.8	46.0	39.8	17.4	15.9
P-value for effect of scion	0.0009 ***	3.9e-06 ***	0.049 *	0.47	0.07	0.0002 ***	1.0e-06 ***	1.2e-08 ***	1.7e-08 ***
Chi-square$_{(15,16:1)}$	11.0	21.3	3.9	0.52	3.32	14.0	23.9	32.4	31.8
P-value for effect of scion:rootstock	1	1	1	1	1	1	1	1	1
Chi-square$_{(14,15:1)}$	0	0	0	0	0	0	0	0	0

[1] Trunk cross sectional area

[2] *, ** and *** indicate the significance level at 5, 1 and 0.1% respectively.

[3] Numbers within brackets indicate the following degrees of freedom; (null model, alternative model: difference between models)

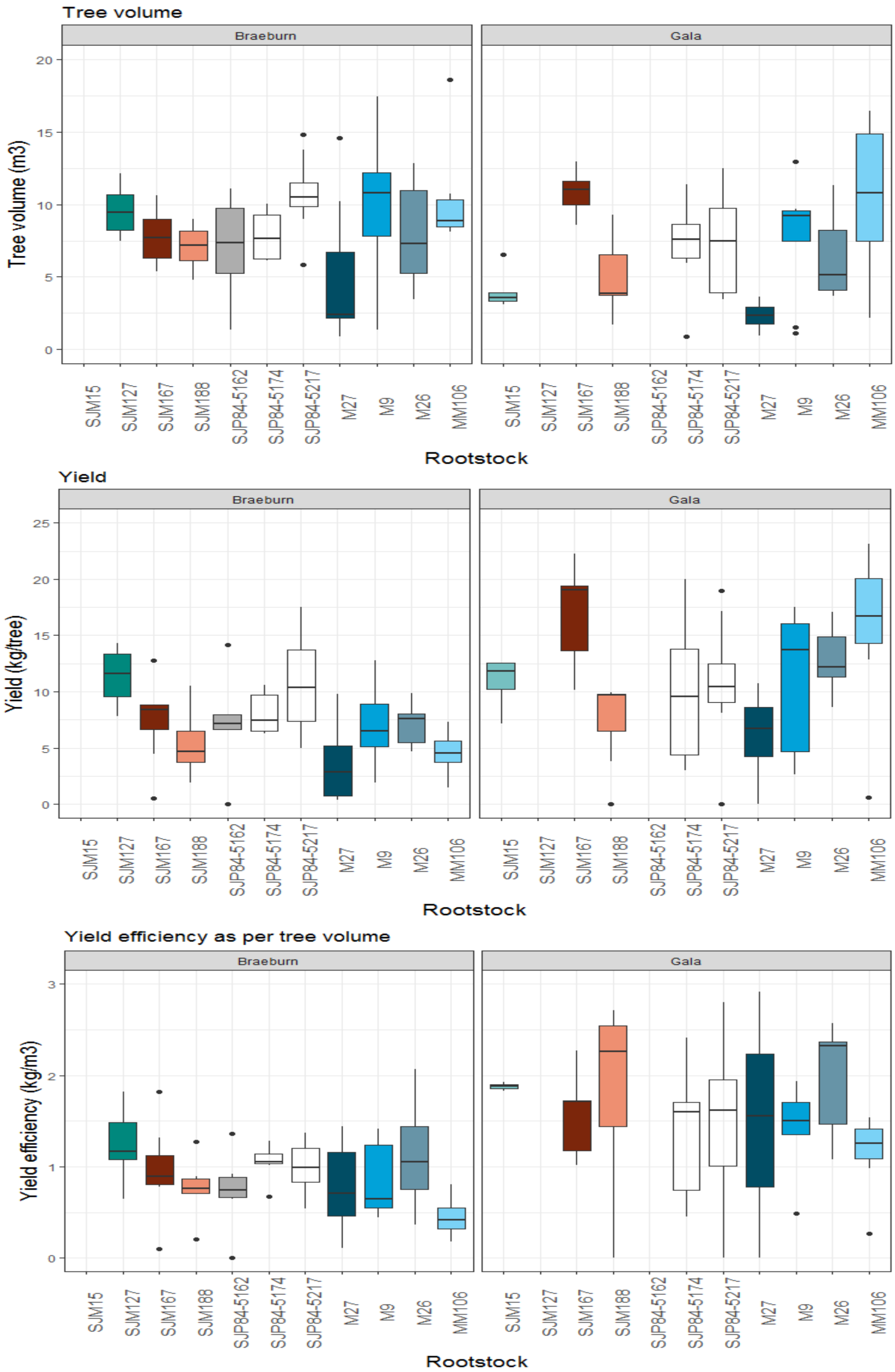


Figure 12. Boxplots of tree volume, yield and yield efficiency as per tree volume. The rootstock SJM127 is only planted with 'Braeburn' and SJM15 only with 'Gala'

EUFRIN multisite apple rootstock trial

In 2017, NIAB EMR became one of the sites for the new international rootstock trial coordinated by the European Fruit Research Institutes Network (EUFRIN) which will evaluate rootstocks in 19 sites from Norway to Spain. Six of the 18 apple rootstocks planted in these trials in 2017 are from the EMRC. Trees were propagated courtesy of IFO in France and distributed to all partners in March 2017.

The trial was designed to compare genotypes with sufficient number of trees also under apple replant conditions. To this aim, the whole trial was planted in the plot of a recently grubbed apple orchard. Most blocks were treated with granular Basamid® (soil sterilant containing 97% dazomet) at a rate of 70 g/ m² as per common practise in many areas of continental Europe; for the application to be successful, soil needs to be moist but not too wet and at least 12-15 °C at the time of application and for two weeks afterwards. Due to weather conditions at NIAB EMR in spring 2017, soil preparation and application could not be completed out until June. To avoid delaying the trees too much, they were taken out of the cold store and temporarily potted up until they could be planted without risk of phytotoxicity on 3 August. Trees were well watered and, over all have established well; we will report on their growth in 2018-19.

The trial is divided on two sub-trials: one for genotypes of a comparable vigour to M.9 or smaller (plot CW152) and another for genotypes more vigorous than M.26 (plot CW153)

Table 13. Number of trees of each genotype planted in the EUFRIN trial at NIAB EMR in 2017 in each of the two field plots (CW152 and CW153) according to expected vigour

Genotype	CW152 (< M.9 size)		CW153 (> M.26 size)	
	Treated	ARD[1]	Treated	ARD[1]
AR 10 3 9			12	
AR 295-6	12	12		
AR 486-1	12			
AR 680 2	12			
AR 835-11	12			
B10/MITCH N°62396	12	12		
G11	12	12	12	
G202			12	
G41	12	12		
G935			12	12
N°3038	12			
P67	12	12		
Pajam2	12	12		

[1] ARD = Apple Replant Disease (not treated with Basimid®)

A trial for pear and quince rootstocks for pear is planned for 2019 and we expect two NIAB EMR quince selections to be included.

Breeding activities

New seedling populations

Nearly 4,200 seeds from nine crosses were sown in winter 2016-17 to raise 2,561 new apple seedlings from eight families; all seeds from M604 failed to germinate and only one of 200 from M.603 succeeded likely due to the age of the seed batches (Table 14).

Similarly, 728 new pear seedlings from six families were raised and in 2017 (Table 15); as for the apples, old seed (PRP57 and PRP58) showed worse germination than fresher ones but still produced a reasonable number of seedlings in the case of PRP57. The use of stored seed was unavoidable due to poor seed production in 2015 and 2016.

All healthy seedlings from all families except M.606 were planted in August 2017 through mypex in double rows. They will be budded late August or early September 2018 with a common scion for field evaluation. Control rootstock varieties for these two plots will be grafted in February 2019 to be planted out the same autumn. Only 34 seedlings from family M606 were planted un-screened with its contemporaries in 2017 (Table 14). The rest were introduced to the woolly apple aphid (WAA) screening (see later). Resistant seedlings will be screened with DNA markers linked to fire blight (FB) resistance in 2018; seedlings resistant to both WAA and FB will be bench grafted and planted alongside the controls cultivars for this population in 2019. Additionally, genotypes carrying WAA resistance as well as pyramided FB from both the Evereste (FB_E) and C.G. parent (FB_R5) could be preserved as parental material.

Table 14. Apple rootstock seedlings planted in 2017

Family	Cross		Number Sown	Number potted	Germination Rate	Planted Aug 2017
	Parents	Year				
M603	AR86-1-20 x C.G.11	2010	200	1	> 1%	1
M604	M.9 x M.116	2013	61	-	0%	-
M605	Novole x M.116	2014	98	14	14%	14
M606	Evereste x C.G. 202	2015	542	324	60%	34*
M607	Evereste x C.G. 11	2016	293	185	63%	172
M608	Evereste x AR295-6	2015	976	585	60%	504
M609	M.13 x AR295-6	2015-16	505	400	79%	349
M610	Bud 9 x Evereste	2016	736	648	88%	610
M611	AR295-6 x C.G.30	2015-16	779	405	52%	364
Total			**4,190**	**2,561**	**61%**	**2,048**

Table 15. Pear rootstock seedlings planted in 2017

Family	Cross		Number Sown	Number potted	Germination Rate	Planted Aug 2017
	Parents	Year				
PRP57	BP1 x P. betulifolia	2010	1150	320	28%	315
PRP58	OHF333 x Junsko Zlato	2010	821	9	1%	9
PRP59	OHF51 x Pyronia (x2)	2015	236	56	24%	56
PRP60	Old Home x BP3	2015	227	200	88%	183
PRP61	OHF69 x BP2	2015	69	55	80%	46
PRP62	OHF333 x Farmingdale	2016	171	119	70%	119
Total			2674	759	28%	728

Crossing and germination

The crossing programme was carried out between 3 and 19 April 2017. A number of planned crosses involving EM selections (particularly in pear) could not be carried out due to insufficient flowers on those young trees. Nonetheless, 3,800 flowers were hand-pollinated and the initial fruit set was fairly good in both apple and pear crosses but a frost in late April decimated fruit/seed survival reducing the number of viable seeds harvested, which was one of the lowest ever in the programme. In fact, no seeds could be collected from four apple and two pear crosses, and 965 apple and 335 pear viable seeds were harvested from the rest (Table 16).

Table 16. Apple and pear rootstock crosses made in 2017. Numbers of flowers pollinated and viable seeds collected

Crop	Cross			No. Flowers pollinated	No. Seed extracted
	Female	x	Male		
Apple	Geneva 11	x	AR295-6	391	16
Apple	M.116	x	AR295-6	119	143
Apple	Geneva 30	x	AR440-1	114	45
Apple	Novole	x	M.9	262	325
Apple	*Malus koreana*	x	M.9	358	409
Apple	*Malus brevipes*	x	M.9	633	-
Apple	AR86-1-20	x	AR295-6	334	5
Apple	C.G. 202	x	Everest	327	22
Apple	AR295-6	x	C.G. 30	239	-
Apple	AR295-6	x	C.G.41	55	-
Apple	M.116	x	C.G.41	45	-
Pear	OHxF69	x	BP2	246	-
Pear	Old Home	x	BP3	248	270
Pear	OHxF51	x	Pyronia (2n)	195	65
Pear	OHxF69	x	Farmigdale	235	-

No pear seeds were due to be grown in 2018 so all were stored as were the seed from the two families shaded green in Table 15. The rest of the seed lots produced in 2017 were supplemented with seed stored in previous years. Over 2,800 apple seeds from six families (Table 17) were stratified at 2°C for 14 weeks from 22nd of December and are currently germinating in a heated glasshouse (Day Tm > 18 °C, Night Tm >15°C) with supplementary lighting, as needed for 16h day light to be planted out in the summer of 2018.

Table 17. Apple seeds sown in 2017 by family; parentage and the year(s) the seed was produced is indicated

Family	Parentage	Years of crossing	Seeds sown
M612	C.G.11 x AR295-6	2015-17	53
M613	M.116 x AR295-6	2016-17	198
M614	C.G.30 x AR440-1	2016-17	134
M615	Evereste x C.G.30	2014	1690
M616	Novole x M.9	2017	325
M617	M. koreana x M.9	2017	409
Total			2,809

Evaluation of existing seedling populations

Apple

Thirty five apple families were assessed by breeders in September 2017 (Table 18) Records on vigour, crop load, suckering and fruit size were taken as appropriate and, in certain genotypes, other traits such as poor anchorage or the incidence of bitter-pit or burr-knots were also recorded. Woolly apple aphid colonization was also noted and susceptible seedlings from segregating families deselected.

Table 18. Apple rootstock seedlings evaluated in September 2017; year of planting, plot and parentage are indicated as well as number of selections made where appropriate.

Year planted	Plot	Family	Parentage	Number of seedlings	Number of selection
2011	SC199	**M557**	M.116 x M.9	93	3
2011	SC199	**M558**	C.G.30 x M.116	114	1
2011	SC199	**M559**	Bud 9 x M.9	110	1
2011	SC199	**M560**	AR86-1-20 x C.G.11	242	6
2011	SC199	**M562**	M.M.106 x C.G.202	228	4
2011	SC199	**M563**	M.M.106 x Bud 9	127	6
2012	SP241	**M555a**	C.G.30 o.p.	123	None yet
2012	SP241	**M556a**	Ottawa 3 o.p.	85	None yet
2012	SP241	**M559a**	Bud 9 x M.9	56	None yet
2012	SP241	**M560a**	AR86-1-20 x C.G.11	184	None yet
2012	SP241	**M561**	M.27 x C.G. 30	6	None yet
2012	SP241	**M562a**	M.M.106 x C.G.202	212	None yet
2012	SP241	**M563a**	M.M.106 x Bud 9	83	None yet
2012	SP241	**M564**	C.G.202 x AR295-6	10	None yet
2012	SP241	**M565**	Bud 9 x M.116	8	None yet
2013	SP246	**M566**	Bud 9 x Evereste	20	None yet
2013	SP246	**M567**	M.27 x C.G.11	11	None yet
2013	SP246	**M568**	Torstein x M.27	4	None yet
2013	SP246	**M569**	Torstein x M.9	11	None yet
2013	SP246	**M570**	C.G.202 op	86	None yet
2013	SP246	**M571**	C.G.11 op	76	None yet
2014	SC204	**M573**	Bud 9 x Evereste	6	None yet
2014	SC204	**M574**	Evereste x M.9	303	None yet
2014	SC204	**M575**	M.9a x Evereste	5	None yet
2014	SC204	**M576**	A469-4 x MH.10.1	26	None yet
2014	SC204	**M577**	Evereste x C.G. 30	5	None yet
2014	SC204	**M578**	C.G. 11 x AR295-6	52	None yet
2014	SC204	**M579**	C.G. 30 x M.27	15	None yet
2014	SC204	**M580**	C.G. 30 x AR295-6	148	None yet
2014	SC204	**M581**	M.27 x C.G. 11	41	None yet
2014	SC204	**M582**	M.M.106 x C.G. 30	35	None yet
2014	SC204	**M583**	Torstein x M.27	210	None yet
2014	SC204	**M584**	Torstein x M.9	124	None yet
2014	SC204	**M585**	M.9EMLA x Sally	9	None yet
2014	SC204	**M586**	M.26 x AR633-1	16	None yet

For families planted in 2011 (SC199; Table 18), only promising individual were recorded and 21 of those were selected for propagation (Table 19). All selected seedlings were cut down below graft union in winter 2017-18 to be earthed up In June-July 2018 to initiate propagation. Full records were taken for the rest of the families in Table 18 which will continue to be assessed.

For the 1,345 seedling in the nine families (M.586 – M.594) planted in 2015 (budded 2016) the only records taken were of survival, bud take and suckering.

Table 19. Apple seedlings selected in 2017, based on four year data for vigour, crop load, and suckers as well as fruit size in 2017. Vigour was scored as very weak (vw), weak (w), medium weak (mw), medium (m), medium vigorous (mv), vigorous (v) and very vigorous (v v). Crop load was graded as none (0), very low (vl), low (l), medium low (ml), medium (m), medium high (mh), high (h), very high (vh). Fruit size was scored as very small (vs), small (s), medium (m), larger (l), very large (vl). Suckers were assessed as none (0), few (+), plenty (++), many (+++)

Selection	2014			2015			2016			2017			
	Vigour	Crop	Suckers	Vigour	Crop	Suckers	Vigour	Crop	Suckers	Vigour	Crop	Fruit Size	Suckers
M557-6	v	0	+	mw	m	+	m	h	+	m	m	l	++
M557-7	v	0	+	m	ml	++	mv	mh	+	mv	m	ml	+
M557-64	mv	0	+	m	m	++	mw	m	+	mw	+	l	+
M558-17	v	0	+	v	0	+	mv	h	-	mv	m	l/vl	-
M559-54	w	0	++	w	m	++	w	h	+	vw	mh	l	+
M560-3	m	0	+	m	mh	-	w	h	-	vw	h	vs	-
M560-87	mv	0	+	mv	m	++	m	h	-	m	mh	m	+
M560-94	m	0	-	mv	ml	-	mv	m	+	m	h	m	++
M560-135	mv	l	++	m	h	++	m	mh	-	mv	m	l	+
M560-167	m	0	+	m	mh	++	mw	mh	+++	mw	h	l	++
M560-214	w	0	++	vw	h	++	vw	m	+++	vw	m	ms	++
M562-49	m	0	+++	mw	0	+++	m	h	++	m	mh	ml	-
M562-93	mw	0	+++	w	0	+++	vw	h	+++	w	vh	ml	++
M562-108	mw	0	++	w	m	+++	w	h	++	w	mh	ms	+++
M562-139	mh	0	++	w	h	+++	m	h	+	m	l	l	+
M563-45	v	0	++	v	l	++	mv	mh	++	mv	mh	m	++
M563-54	v	0	+	v	0	+	v	h	+	mv	h	m	++
M563-65	mw	0	++	w	0	+++	w	h	++	w	mh	m	+
M563-83	m	0	++	m	0	++	mw	m	+	m	m	m	+
M563-90	m	0	-	m	vl	+	m	m	-	m	mh	m	-
M563-109	mw	0	++	w	0	+++	m	h	+++	mv	m	m	++

<u>Pear</u>

Ten pear families were evaluated in 2017 (Table 20); records were taken on vigour; suckering and crop load and, if present, fruit size. From five of the six families planted in 2011, 21 individual were selected for propagation (Table 21). All selected seedlings were cut down below graft union in winter 2017-18 to be earthed up In June-July 2018 to initiate propagation. Additionally, for the 405 seedlings of the five families planted in SC205 in 2015 the only records taken were of survival, bud take and suckering.

Table 20. Pear rootstock seedlings evaluated in September 2017; year of planting, plot and parentage are indicated as well as number of selections made where appropriate

Year planted	Plot	Family	Parentage	Number of seedlings	Number of selections
2011	SC200	**PRP45**	PB11030 x OHxF87	66	1
2011	SC200	**PRP46**	BP2 op	74	0
2011	SC200	**PRP47**	BP1 x P. betulifolia	235	3
2011	SC200	**PRP48**	OHxF333 x Junsko Zlato	236	6
2011	SC200	**PRP49**	PB11030 x OHxF333	114	3
2011	SC200	**PRP50**	OHxF87 x BP1	201	8
2013	SP247	**PRP49a**	PB11-30 x OHxF333	69	None yet
2013	SP248	**PRP50a**	OHxF87 x BP1	132	None yet
2013	SP249	**PRP51**	OHFx87 x P525-3	4	None yet
2013	SP250	**PRP52**	BP1 x P525-3	351	None yet

Table 21. Pear seedlings selected in 2017, based on three year data for vigour, crop load, suckers fruit size in 2017. Vigour was scored as very weak (vw), weak (w), medium weak (mw), medium (m), medium vigorous (mv), vigorous (v) and very vigorous (v v). Crop load was graded as none (0), very low (vl), low (l), medium low (ml), medium (m), medium high (mh), high (h), very high (vh). Fruit size was scored as very small (vs), small (s), medium (m), larger (l), very large (vl). Suckers were assessed as none (0), few (+), plenty (++), many (+++).

Selection	2015			2016				2017			
	Vigour	Crop	Suckers	Vigour	Crop	Fruit Size	Suckers	Vigour	Crop	Fruit Size	Suckers
PRP45-15	mv	0	+	mv	0		-	mv	h	m	+
PRP47-5	mv	0	++	v	0		+	m	mh	s	+
PRP47-22	v	0	++	mv	mh		++	mv	m	s	++
PRP47-221	v	0	+	v	m	m-l	+	v	m	s	++
PRP48-51	w	0	+	mw	l	m	++	m	vl	l	+
PRP48-79	v	0	+	mv	m	m	+	mv	h	m	+++
PRP48-89	m	0	+++	m	m	ml	+++	mv	m	l	++
PRP48-170	v	0	+	v	0		+	v	h	ml	++
PRP48-205	mv	0	++	m	l	l	+++	m	l	l	++
PRP48-215	m	0	-	m	0		-	mw	mh	l	-
PRP49-47	w	0	+++	w	m	m	++	w	m	m	+++
PRP49-69	v	0	+	mv	h	s	-	m	vl	l	+
PRP49-87	mv	0	++	mv	0		++				
PRP50-24	m	0	++	m	vl	m	-	mv	m	ml	+
PRP50-121	mv	0	-	m	m	m	-	mv	l	m	-
PRP50-141	w	0	+++	mw	ml	l	++	mw	mh	s	+
PRP50-148	v	0	++	v	h	l	+	mv	m	ml	-
PRP50-151	mv	0	+	m	ml	l	+	m	h	l	+
PRP50-154	m	0	+	m	vl	s	-	m	m	l	-
PRP50-174	m	0	++	m	m	vl	++	m	l	l	++
PRP50-188	w	0	+++	w	0		+++	m	m	vl	+

Propagation

Grafting for new trials:

Between eight and 15 liners of 16 apple selection and four controls were grafted with Gala in April 2017 (Table 22).

Similarly, between the 7th and 9th of March of 2017, variable numbers of liners of 15 pear selections and tree commercial rootstocks were grafted with 'Conference' (Table 23)

Success rates were generally good and following genotyping to confirm trueness-to-type of all the replicates in 2018, these trees will be planted as a new preliminary trials. Those genotypes with insufficient number of replicates for a full entry in the trial might be used as guards for observation.

Table 22. Apple rootstock selections and controls grafted in 2017

Rootstock	Grafted	Successful
M432-203	10	8
M432-217	10	9
M480-3	10	10
M482-11	10	4
M482-13	15	8
M482-158	15	11
M508-1	15	13
M508-49	7	7
M509-22	7	5
M545-83	10	9
M546-110	10	6
M546-22	8	2
M547-1	15	7
M547-41	15	9
M547-72	15	13
M547-8	10	6
M27	10	9
M9	10	10
AR295-6	10	6
M116	10	10

Table 23. Pear rootstock selections and controls grafted in 2017.

Rootstock	Grafted	Successful
PQ34-3	8	7
PQ35-2	9	8
PQ35-3	4	3
PQ37-1	13	12
PQ39-1	29	28
PQ39-2	15	13
PQ39-6	5	5
PQ39-7	9	8
PQ39-8	4	0
PQ41-9	16	15
PQ42-33	8	8
PQ42-47	5	5
PQ43-34	5	5
PQ44-11	15	14
PQ44-26	19	18
QA	6	6
QC	6	6
Q ELINE	6	6

Winter propagation through hard wood cutting (HWC)

It is worth noting that in 2016-17, when propagation on most genotypes was negatively affected by excessive heat in the rooting bin, a few genotypes did comparatively quite well, including M.116 which is usually quite hard to root (data from a different experiment, not shown), M.550-40, PQ37-3 and PQ37-8 (Tables 23 and 24).

In winter 2017-18, cuttings of 64 apple and 31 pear genotypes (Tables 25 and 26) were taken with the intention to produce young plants for pest and disease screening as well as to establish mother plants in the glasshouse. Unlike in 2016-17, results so far are encouraging.

Table 23. Apple rootstock selections taken for propagation in winter 2016-17

Selection	Number of field rooted[1]	Number of HWC taken for rooting bin[2]	Total available summer 2017
M345-18	0	2	0
M345-32	0	7	0
M360-191	0	1	0
M430-203	0	6	1
M430-249	0	2	0
M432-203	0	7	7
M432-217	0	16	8
M432-247	6	3	8
M432-250	2	0	2
M480-3	5	6	10
M481-10	2	0	2
M482-11	0	12	0
M482-42	0	14	8
M482-44	10	3	11
M482-49	9	7	15
M482-54	1	5	5
M482-65	0	3	0
M482-76	2	0	2
M482-84	5	3	8
M482-87	0	2	1
M482-110	0	2	0
M482-133	0	3	1
M482-153	0	2	0
M482-175	0	2	1
M508-1	0	12	7
M508-49	0	10	6
M509-22	0	9	0
M510-4	0	5	4
M545-57	0	1	0
M545-145	0	9	4
M546-9	1	2	2
M546-22	0	5	0
M546-110	0	10	6
M546-125	0	3	3
M547-8	0	2	0
M547-41	0	10	5
M548-2	1	4	1
M549-59	0	5	1
M549-83	0	5	1
M549-94	0	6	4
M549-122	0	2	1
M549-146	0	1	0
M550-12	4	0	4
M550-25	0	3	2
M550-30	3	0	3
M550-32	6	0	6
M550-40	11	7	18
M550-41	1	0	1
M550-67	4	2	4
M551-8	0	1	1
M551-50	8	5	11
M552-55	0	5	0
M552-89	1	11	7
M552-92	0	7	7
M552-108	1	6	4
M552-111	2	2	2

[1] Shoots rooted on the field were potted up straight on into P11 pots and placed in the glasshouse
[2] Hard wood cuttings collected from field and glasshouse placed in the heated bin for rooting and potted up in the root trainers if root initiation was successful

Table 24. Pear rootstock selections taken for propagation in winter 2016-17.

Selection	Number of HWC taken for rooting bin[2]	Total available summer 2017
PQ34-1	20	3
PQ34-3	3	3
PQ34-6	22	1
PQ35-2	20	4
PQ35-3	6	5
PQ37-1	6	5
PQ37-2	19	6
PQ37-3	13	13
PQ37-5	11	5
PQ37-7	2	1
PQ37-8	26	21
PQ38-2	12	0
PQ39-2	2	0
PQ39-4	3	0
PQ39-5	2	0
PQ39-6	1	0
PQ39-7	7	0
PQ39-8	4	0
PQ41-26	3	1
PQ41-60	1	0
PQ41-61	8	0
PQ41-9	8	4
PQ42-11	5	0
PQ42-23	3	0
PQ42-33	12	7
PQ42-47	4	1
PQ43-42	3	0
PQ43-50	10	2
PQ44-11	4	2
PQ44-26	5	0
PQ5-13	11	0
PQ5-6	14	0
PQ5-8	25	4
Quince C	50	50

[1] Shoots rooted on the field were potted up straight on into P11 pots and placed in the glasshouse
[2] Hard wood cuttings collected from field and glasshouse placed in the heated bin for rooting and potted up in the root trainers if root initiation was successful

Table 25. Apple rootstock selections taken for propagation in winter 2017-18

Selection	Number of field rooted[1]	Number of HWC taken for rooting bin for the field[2]	Number of HWC taken for rooting bin for the glasshouse[2]	Total available summer 2017
M306-6	-	6	5	0
M306-20	-	42	0	0
M345-18	-	-	4	0
M430-249	-	-	2	0
M432-203	-	-	46	33
M432-217	-	-	33	24
M432-250	-	-	10	10
M480-3	-	-	30	3
M482-13	-	-	11	0
M482-158	-	-	27	21
M508-1	-	-	41	25
M509-22	-	-	3	3
M510-4	-	-	23	10
M546-22	-	20	0	2
M546-110	-	7	5	3
M547-1	-	18	0	0
M547-41	-	20	0	0
M547-72	-	23	0	1
M550-12	-	32	13	3
M550-32	-	12	0	1
M550-40	-	42	5	20
M550-55	-	5	14	7
M551-50	-	3	2	5
M552-43	-	6	29	23
M552-55	-	7	23	24
M552-89	-	2	0	2
M552-92	-	8	15	7
M552-108	-	1	0	0
M552-111	-	11	0	10
M553-2	3	4	20	22
M553-28	2	11	7	20
M553-32	7	6	0	8
M553-64	8	12	19	29
M553-77	1	-	31	9
M553-83	7	11	20	24
M553-85	4	14	6	22
M553-112	-	9	0	3
M553-117	-	4	0	3
M553-124	-	21	0	1
M553-127	-	3	0	0
M554-17	-	1	10	3
M554-40	2	3	-	5
M554-72	8	14	-	11
M554-92	4	5	-	6
M554-95	2	12	-	4
M554-135	7	7	13	18
M554-209	3	3	26	31
M554-214	1	17	19	16
M554-264	1	3	-	2
M554-343	6	3	-	7
M555-30	6	15	-	15

Selection	Number of field rooted[1]	Number of HWC taken for rooting bin for the field[2]	Number of HWC taken for rooting bin for the glasshouse[2]	Total available summer 2017
M555-85	5	5	-	8
M555-122	4	6	-	6
M555-136	3	3	-	3
M555-185	3	5	-	3
M555-189	6	5	-	6
M555-252	3	3	-	3
M555-282	1	8	-	3
M556-7	9	4	-	9
M556-36	10	11	-	14
M556-46	6	4	-	7
M556-52	7	6	-	10
M556-165	1	3	-	2
M556-191	9	5	-	12

[1] Shoots rooted on the field were potted up straight on into P11 pots and placed in the glasshouse

[2] Hard wood cuttings collected from field and glasshouse placed in the heated bin for rooting and potted up in the root trainers if root initiation was successful

Table 26. Pear and quince rootstock selections and advanced selections taken for propagation in winter 2017-18

Selection	Number of HWC taken for rooting bin for the field[2]	Number of HWC taken for rooting bin for the glasshouse[2]	Total available summer 2017
PQ34-1	38	33	37
PQ34-3	12	37	30
PQ34-6	9	21	9
PQ35-2	26	20	28
PQ35-3	23	5	14
PQ37-1		42	2
PQ37-2	22	3	15
PQ37-3	16	21	20
PQ37-5		6	0
PQ37-7	31	5	19
PQ37-8	23	4	3
PQ38-2	29	19	17
PQ39-2		39	28
PQ39-3	20	7	7
PQ39-4	21	20	12
PQ39-5		16	13
PQ39-6		23	15
PQ39-7		40	19
PQ39-8		13	11
PQ41-9	9	32	34
PQ41-26		6	5
PQ41-60	7	37	29
PQ41-61		12	10
PQ42-33	10	3	4
PQ42-47	6	7	8
PQ43-34	6	15	11
PQ43-50	3	28	11
PQ44-11	7	10	13
PQ44-26	10	29	33
PQ5-8	15	0	4
PQ5-13	25	0	4

[1] Shoots rooted on the field were potted up straight on into P11 pots and placed in the glasshouse
[2] Hard wood cuttings collected from field and glasshouse placed in the heated bin for rooting and potted up in the root trainers if root initiation was successful

Pest and disease resistance screening

Fire blight (FB)

Six NIAB EMR advanced selections (Table 27) were tested at Agroscope (CH) in 2017 of which three have been previously tested with intermediate or low responses that needed verification. Graft-wood from these genotypes was sent to Wädenswil in January for inoculation and monitoring by Markus Kellerhals's team.

Results for this test were received in August 2017 and Figure 13 shows the evolution of the infection for the six selections as well as the two control genotypes following inoculation and Figure 14 the final lesion levels in order of ascending susceptibility relative to the performance of the susceptible control.

Table 27. Apple genotypes tested for FB resistance in 2017 by Agroscope

Genotype	Parentage	Previous data on response to FB	Shoots tested
AR486-1	Ottawa 3 x M.7	Medium susceptibility (Agroscope 2016)	10
AR628-2	Ottawa 3 x M.M.106	Not tested	8
AR682-6	M.26 x MI.793	Not tested	6
AR801-11	M.26 x M.9	Not tested	7
AR835-11	MI.793 x M.9	Medium susceptibility (Germany 2012&13); Low susceptibility (Agroscope 2015)	8
AR839-9	M.7 x M.27	Medium susceptibility (Germany 2012&13); Low susceptibility (Agroscope 2015)	8

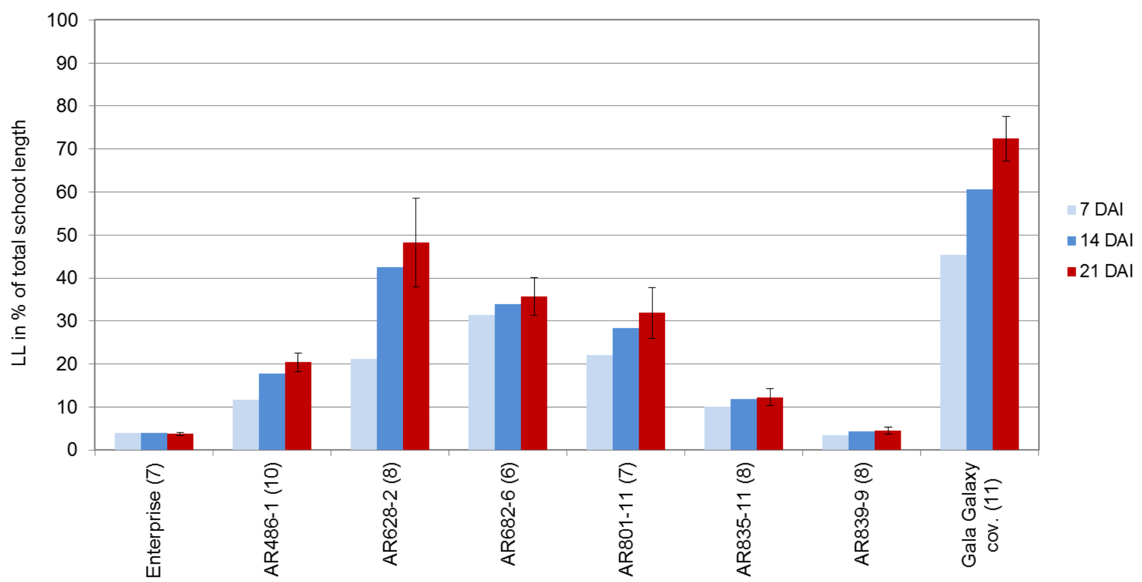


Figure 13. Evolution of fire blight infection in 2017 test; Lesion length as a percentage of total shoot length of eight apple genotypes (for six NIAB EMR apple rootstock selections as well as the susceptible ('Gala Galaxy') and resistant ('Enterprise') controls) measured 7, 14 and 21 days after inoculation with *Erwinia amylovora* (strain FAW610Rif at 109 cfu/ml^{01}). The numerals in brackets after the genotype name indicate number of replicates assessed for each

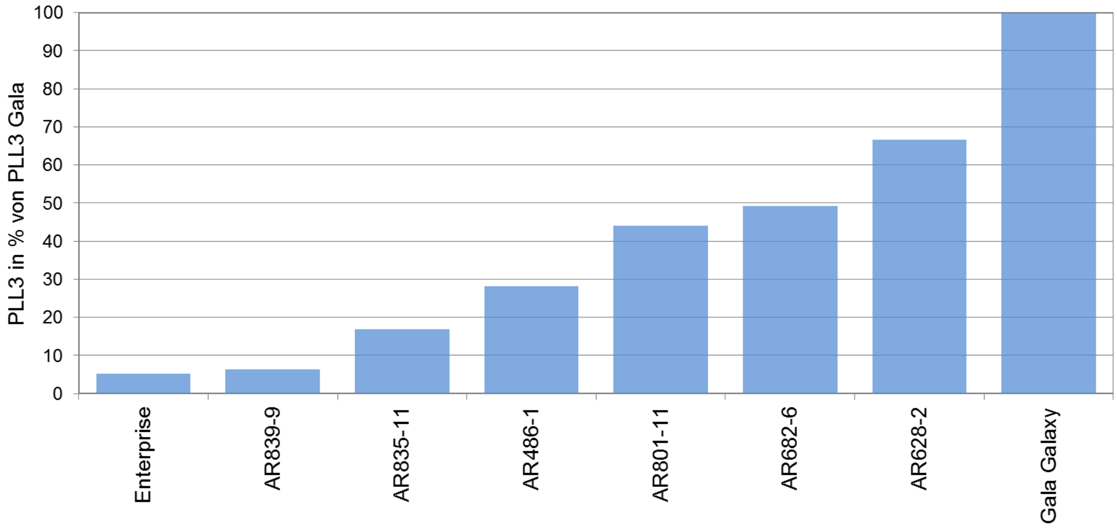


Figure 14. Percentage of lesion length 21 days after inoculation days after inoculation with *Erwinia amylovora* (PLL3) as a percentage of PLL3 in the susceptible control ('Gala Galaxy')

According to the protocol described in the methods section, material tested could be classified (Figure 15) with regards to its response to fire blight by measuring the percentage of lesion developed in shoots in comparison with the response of the susceptible control ('Gala Galaxy') as shown.

resistant	lesion length (%LL3)	< 5%	compared to %LL3 from 'Gala Galaxy'
very low	lesion length (%LL3)	5 - 25%	compared to %LL3 from 'Gala Galaxy'
low	lesion length (%LL3)	25 - 40%	compared to %LL3 from 'Gala Galaxy'
medium	lesion length (%LL3)	40 - 60%	compared to %LL3 from 'Gala Galaxy'
high	lesion length (%LL3)	60 - 100%	compared to %LL3 from 'Gala Galaxy'
very high	lesion length (%LL3)	> 100 %	compared to %LL3 from 'Gala Galaxy'

Figure 15. Classification of fire blight susceptibility in percentage compared to susceptible control 'Gala Galaxy' following inoculation at Agroscope (CH)

In this test, AR486-1 was found to show low susceptibility (28.2% compared to Gala) compared to the medium susceptibility (45% of Gala) shown in 2016. Similarly, results for AR835-11 and AR839-9 were also lower in 2017 (17 and 6.2% of Gala respectively; classed as very low) than they have been in the past (27 and 29% of Gala respectively in 2015; classed as low) suggesting that the test was perhaps less effective than usual in 2017. Bearing that in mind, AR801-11 (44% of Gala) and AR682-6 (49.3% of Gala) both classed as of medium susceptibility in 2017 might need to be retested for confirmation whereas AR628-2 (66.6% of Gala; high susceptibility) is very likely to remain in the same class.

Table 28 provides a summary of all phenotyping for fire blight susceptibility in apple carried out during the life of this project. Ideally, in 2018 we would have been able to complete the validation of results for all the advanced selection by re-testing AR682-6, AR801-11, AR837-19, B24 and R80 for which previous results are intermediate and not corroborated for more than one year of testing (Table 28) however this will not be possible due to changes within Agroscope. Genotyping (DNA testing) with exiting linked markers has been shown to be very useful to identify full resistance but not intermediate responses so new avenues for phenotyping will need to be explored.

Table 28. Summary of fire blight (FB) resistance screening for EMR rootstock genotypes following repeated inoculation with *Erwinia amylovora* isolates ‘Ea782’, ‘Ea797’ and ‘Ea914’ in 2012 and ‘Ea797’, ‘Ea839’ and ‘Ea951’ in 2013 (both in Germany) and after single inoculation with ‘Ea FAW610 Rif’ in 2015, 2016 and 2017 (Agroscope, CH). Numbers of repetitions tested in each experiment are given in brackets

Genotype	% of necrosis (absolute disease)				PLL3 / PLL3 in Gala Galaxy (%)			Susceptibility score
	2012		2013					
	Range	Mean (reps)	Range	Mean (reps)	2015 (R)*	2016 (R)*	2017 (R)*	
AR10-2-5			55-100	87 (9)				High
AR10-3-9	47-100	78 (7)	60-86	66 (6)		76 (9)		High
AR120-242						130 (7)		Very high
AR295-6			3-25	10 (7)	15 (10)			Very low
AR440-1					70 (10)			High
AR486-1						45 (11)	28 (10)	Medium-Low
AR628-2							67 (8)	High
AR680-2			65-100	82 (6)				High
AR682-6							49 (6)	Medium/High?
AR801-11							44 (11)	Medium/High?
AR809-3	17-100	74 (8)						High
AR835-11	4-95	53 (5)	21-84	42 (7)	27 (9)		17 (8)	Low
AR837-19			18-74	44 (10)				Low?
AR839-9	2-100	41 (8)	N/A	29 (1)	29 (9)		6(8)	Low
AR852-3	47-100	80 (5)						High
B24	21-100	73 (4)						Medium/High?
R104	53-100	77 (4)						High
R59	58-100	84 (8)						High
R80	19-100	68 (6)						Medium/High?
CG-935					2 (7)			Resistant
M.9 T337	19-100	69 (7)	16-100	48 (6)	102 (9)			Very high
M.116						99 (11)		High

* Number of reps in brackets

Phytophthora cactorum

Propagation of hardwood cuttings (HWC) was very poor in 2017 due a malfunction in the temperature regulation of the heated bin. Safeguards are now in place with a new temperature monitoring device connected to a remote alarm, however, the shortage of HWC for a range of genotypes made it impossible to carry out a *P. cactorum* screening.

Woolly apple aphid (WAA)

Due to poor propagation, only six of the selections (Table 29) under preliminary evaluation could be entered into the aphid screening in 2017 in sufficient replication for classification Table 27 summarises the ongoing screening of selections form the programme and indicates does that need to be retested for confirmation. Additionally, 32 preliminary selections from families M.533 to M.556 will also be included in the 2018 screening (subject to propagation success).

Although not many selections could be tested, aphid populations grew well and were in sufficient numbers to allow for the screening of 280 individuals of the M.606 (Evereste x C.G. 202) family as single seedlings of those only 42 were found to be resistant instead of the 50% that could have been expected for the single mayor resistance gene previously reported from *Malus robusta* 5 that C.G.202 was expected to carry. These results are similar to those we found in 2016 in another progeny derived from the same C.G. rootstocks. These findings will require further investigation.

Table 29. Summary of the results for woolly apple aphid screening at NIAB EMR between 2014 and 2017. Many genotypes were not tested (NT) in certain years

Genotype	Tested				To test	Consensus
	2014	2015	2016	2017	2018	Score
M345-18	NT	NT	NT	NT	Y	NT
M430-249	NT	NT	Resistant	NT	Y	Resistant
M432-203	NT	NT	Fairly resistant	NT	Y	Fairly resistant?
M432-217	Unclear	Pos. resistant	Susceptible	NT	Y	Susceptible?
M432-250	Susceptible	NT	Susceptible	NT	-	Susceptible
M480-3	NT	NT	Fairly resistant	Susceptible	Y	Inconclusive
M482-13	Unclear	Susceptible	Susceptible	NT	-	Susceptible
M482-158	Susceptible?	Unclear	Susceptible	NT	-	Susceptible
M508-1	NT	NT	Fairly resistant	Fairly resistant	?	Fairly resistant
M509-22	NT	NT	Unclear	NT	Y	Inconclusive
M510-4	NT	NT	NT	NT	Y	NT
M546-22	Resistant	NT	Fairly resistant	NT	?	Resistant
M546-110	Resistant?	NT	Fairly resistant	Fairly resistant	-	Fairly resistant
M547-1	Susceptible	NT	Susceptible	NT	-	Susceptible
M547-41	NT	NT	Resistant	NT	Y	Resistant
M547-72	NT	NT	Susceptible	NT	Y	Susceptible
M550-12	NT	NT	Fairly resistant	Mod susceptible	Y	Inconclusive
M550-22	NT	NT	NT	NT	Y	NT
M550-32	NT	NT	NT	NT	Y	NT
M550-40	NT	NT	Susceptible?	Mod susceptible	?	Susceptible
M550-55	NT	NT	NT	NT	Y	NT
M551-50	NT	NT	Susceptible	NT	Y	Susceptible
M552-55	NT	NT	NT	NT	Y	NT
M552-89	NT	NT	Susceptible	NT	Y	Susceptible
M552-92	NT	NT	Susceptible	NT	Y	Susceptible
M552-108	NT	NT	Susceptible	NT	Y	Susceptible
M552-111	NT	NT	NT	Susceptible	Y	Susceptible?

Knowledge and Technology Transfer

Rootstocks United (Tree Fruit Magazine, AHDB) spring 2017

EMRC management committee meeting – East Malling, September 2017

EMRC management committee meeting – East Malling, January 2018

Presentation on progress at the AHDB-EMLA Tree Fruit day, February 2018

Presentations on progress and future plans at INN meeting – Cape Town, March 2018