Final Report

Improving performance in the fresh potato supply chain

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1.1. Executive Summary

The aim of this project was to maximise the amount of fresh potato crops in desired retail specification from field to pack-house by using a range of tools with growers and the supply chain. These tools included technical training and the use of a crop yield model developed by NIAB to provide forecasts of total and graded yield ahead of harvest (the NIAB Potato Yield Model). The project worked with 14 growers in the East of England supplying fresh potatoes for retail in ASDA stores, through their integrated supply chain partner, IPL. The project team collected data to determine the impact of the initiative on reducing losses of marketable yield from field to pack house.

In this project, growers and the supply chain responded well to the presentation of objective data and metrics in order to facilitate a conversation about continuous improvement. The application of training and modelling tools provided a framework for sharing ideas and benchmarking performance. The project found a large variability in potato yields and performance between fields, most notably between the crop with the highest total yield and the lowest. For the varieties Belana, Nectar and Maris Piper the difference between highest and lowest yields was 2.5, 1.3 and 1.5 times respectively. The average amount of crop packed in the desired size grade (and thus meeting specification) was 77%, 82% and 86% for Belana, Nectar and Maris Piper respectively. The difference in crops meeting specification, between the poorest performing crops and best performing crops was 22% for Belana, 19% for Nectar and 6% for Maris Piper. For Belana, the best performing crop generated nearly £10,000 per hectare higher revenue than the lowest performing crop. Even for Nectar where the differences were not so pronounced, this difference was £2,000 per hectare. This variability is only between 14 growers in a similar geographic area, therefore it is possible that differences between growers across the whole of the UK are likely to be larger. There is huge opportunity to improve yields and the amount of crop meeting specifications in order to maximise financial returns for the whole supply chain.

This project has gone some way to collecting the objective data that is required in order to assess variability and ultimately help improve the performance of crops in future years. The NIAB potato yield model has an almost 1:1 relationship with the grower reported yield giving confidence that the model reliably predicted the harvested yield. However, it was impossible to collect consistent and reliable data once the crop had been lifted because growers measure their yield in different ways and at different points during crop handling (making it unclear how much crop has been 'wasted' and where). As a result, the difference between the grower reported yield and what was reported as delivered to IPL was highly variable. Our key recommendation is that ensuring common data standards that operate across the whole industry is vital to effective performance monitoring and improvements.

2. Background and aims of project

2.1. Background

Potato is a major food crop grown in over 100 countries across the world and production has increased steadily from 267 million tonnes in 1990 to 385 million tonnes in 2016[1]. The UK ranks 11th globally for production of potatoes and in 2016, 1,925 registered growers produced 5.22 million tonnes of potatoes on approximately 116,000ha, with 14% of the registered growers planting 53% of the potato area[2]. In 2016 the largest market sector for potatoes grown in the UK is for packing into bags for convenience (the 'pre-pack' market) and 37% of the planted area used for potato production was intended for use in the pre-pack sector[3].

This project was focussed on reducing waste in fresh potato supply chains, from field to pack house. According to WRAP, potato accounts for the fresh produce category most often wasted in the home, at over 700,000 tonnes per year. This figure far outstrips any other vegetable, with onion at just over 100,000 tonnes wasted being the next largest category (see WRAP, 2018)[4]. Waste in the supply chain, from field to pack house is comparatively smaller than that wasted in the home, but food waste pre-farm gate is not well understood for any sector and, given the volume of potato waste any efforts to reduce the number can have a significant impact. Within the fresh potato supply chain, the objective is to grow as much crop within the desired retail specification. This is governed by the size of the potato and its quality. Very little crop is actually thrown away, or 'wasted', but in most cases a proportion of the crop is diverted from its intended end-use to lower value uses, such as other markets or stock feed, due to falling outside of the retail specification. This represents significant lost revenue for the farmer and supply chain. In this project, our focus was to work with the supply chain to maximise the 'percentage of potential', i.e. the amount of crop meeting the desired retail specification, otherwise known as the 'marketable yield' of fresh potatoes.

2.2. Aims and deliverables

The aim of this project was to maximise the percentage of potential of fresh potato crops used for their intended end usage from field to pack-house using a range of tools with growers and the supply chain. Specific objectives were to:

- Deliver best practice advice to growers on growing the potato crop to maximise quality and yield (the marketable yield), thereby reducing waste in field, storage and pack house.

- Collect data to provide robust estimates of potato yields ahead of harvest, and actual yields at harvest in order to facilitate better supply and demand planning by growers and the commercial teams in IPL/ASDA and drive continuous improvement in future years.
- Determine the effect of the initiative on reducing waste by measuring losses from field to supply chain, and provide tangible actions the supply chain can take to reduce waste in future years.
- Cascade the project results to the wider Courtauld 2025 signatory base and industry to increase the uptake of best practice and the contribution towards the Courtauld 2025 ambition.

2.3. **Maximising the potential of the potato crop**

In order to understand the relevance of the tools and techniques applied in this project, it is important to understand how the potato supply chain operates and how salad and fresh potatoes are grown to meet market requirements.

The interception of radiation by leaves and the partitioning of dry matter to the harvested tubers drive potato growth. Each crop has a biological potential that is rarely achieved in practice due to a range of factors such as soil conditions, nutrition, disease, pests, management practices etc.

A farmer usually grows potatoes to a contract with an end user. All contracts are specific to each grower and confidential, but usually include the variety to be grown, volume expected, price per tonne and the desired specification. In the case of salad and pre-pack potatoes, this specification will include quality requirements (such as permitted levels of disease) and the size of the potato. The total yield (tonnes/hectare) and the number of tubers (tubers/hectare) determine the size of potatoes at harvest. To achieve a grade out at harvest that meets targeted size specifications it is essential that the number of tubers in the crop are appropriate for the harvested yield. For example, 1,000,000 tubers/ha may be required to achieve optimum grade out in a 30t/ha Belana crop for salad potatoes, whereas 400,000 tubers/ha may be required for a 70t/ha Nectar crop for baking potato sales. The crop (which refers to the entire amount of potato tubers within the field), is planted in the spring and grown until harvest in June to October. The farmer can still deliver crops to the pack house that do not meet the requirements of the contracted specification, but the price paid is usually less, and in most cases significantly less, so this is an undesirable outcome for farmer and supply chain. Thus, during the season, the objective of the farmer is to maximise both the total yield of the crop, but also the amount of crop that falls into the desired size grade and quality requirements. To achieve this, one of the things a farmer will do is capture data through the season to inform their management practices. This includes measuring the rate at which the crop canopy is growing using a grid to measure leaf cover and taking a number of samples to gauge the size of the tubers in the field, which helps the grower decide when to destroy the crop canopy to stop the tubers growing, before harvest. During the season, the pack house may change the desired size specification according to market demand, or as a response to field conditions. For example, in a poor year with low yields the size specification may be widened to accommodate more crops in the desired specification. .

At harvest, tubers are lifted off the field. There will be some crop loss in the field which is dependent on crop size, field conditions and harvesting system. Most farmers will grade the crop on the farm at the time of harvest and load the potatoes into 1 tonne boxes. At this point the farmer will likely discard any unusable crop which has significant defects (such as heavily rotted tubers). Depending on the facilities available, and the contract, the farmer will either deliver the harvested crop directly to the pack-house or store the crop for anything up to 8 months before delivery. During storage, there may be a loss of moisture from the tubers and food waste due to quality defects (e.g. rotting). In some cases, farmers may combine crops from different fields to go to the pack house in order to fulfil the contract, or even decide not to send the crop to the pack house at all and sell it to someone else. Once at the pack-house, the packer will measure the total tonnage and amount of crop falling into the desired specification and pay the farmer accordingly.

Due to the variables described above, crop yields are not measured to a consistent standard from field to pack house. Most growers will take some form of data during the season and measure a final yield of the crop, but to varying degrees of accuracy. This can be a barrier to continuous improvement year on year, due to a lack of objective data to evaluate the reasons for underperformance of the crop. During this project we attempted to measure performance, and losses of the crop at every stage from field to pack house.

3. Project approach and activities

3.1. Supply chain

This project worked with 14 growers in the ASDA supply chain, through Integrated Procurement & Logistics (IPL), ASDA's wholly owned supplier of fresh produce. The growers selected were growing salad potatoes and fresh potatoes to be bagged and sold in ASDA stores. The varieties used by the growers were:

- **Belana** - proprietary first early, salad potato grown for ASDA with premium pre-packing quality. Desired size grade of the tubers is less than 45mm.

- **Nectar** - an early maincrop variety used as a general purpose white potato, particularly where a firm consistency is required. Desired size grade is between 45mm and 85mm for pre-packing.
- **Maris Piper** - a popular general potato in the UK used for fresh and processing uses. It is high yielding but often can have high losses of potential due to quality defects. Desired size grading is between 45mm and 80mm.

The majority of the 14 growers monitored two different crops in the project, and activities took place in the cropping year 2016/17 for crops that would be sold on ASDA shelves anytime from Summer 2017 to Summer 2018.

3.2. **Tools applied through the growing season**

This project applied a number of tools through the season to help growers maximise the percentage of the crop falling into the desired specification, facilitate better supply and demand planning by the supply chain and encourage continuous improvement.

Potato Agronomy Experts from NIAB's Potato Agronomy Research Group (NIAB CUF) hosted an introductory meeting, three training sessions from NIAB's ARTIS Training Platform (www.artistraining.com) and a final review workshop with growers and the supply chain. The training sessions were held in January and February 2017 before crops were planted, and equipped growers with the best practices needed to maximise the performance of the crop. The training was as follows:

- *Improving potato yields and profitability by measuring and monitoring performance.*
- *Understanding and optimising potato nutrition.*
- *Scheduling irrigation to optimise yield and quality in potatoes.*
- *Understanding potato crop growth stages.*

Once the crops were planted, the growers were asked to measure performance using NIAB CUF's Potato Yield Model (PYM). This model utilises data collected in commercial potato crops to provide the following outputs:

- A forecast of total and graded yield up to 10 weeks before harvest, which can be used to make early decisions around supply and demand by both farmer and supply chain.
- A decision making tool to help growers decide when to kill the crop canopy to stop the tubers growing before harvest, in order to maximise the amount of crop within the desired size grade.

- Crop metrics at the end of the season to provide an objective evaluation of performance, including key metrics such as stem counts, tuber population and how the crop canopy performed against the benchmark for that variety.

The objective of the project was to test whether provision of this information could help growers and the supply chain work more objectively towards maximising crop performance and reducing losses. The outputs were provided to growers and the supply chain through the season using the 'NIAB Network' digital interface made available by KisanHub (www.kisanhub.com). Meetings were held with buyers from IPL to present results, and a final workshop with growers evaluated crop performance. Growers inputted data to the digital interface, including a weekly image of the crop canopy which is used to measure the rate of development of the canopy against the benchmark for that variety (figure 1) and a 'test dig' in the field 40-50 days after emergence to measure yield and size of tubers. NIAB's PYM combines this data with long term averages for each variety, field level weather data and other key metrics to produce the outputs listed above.

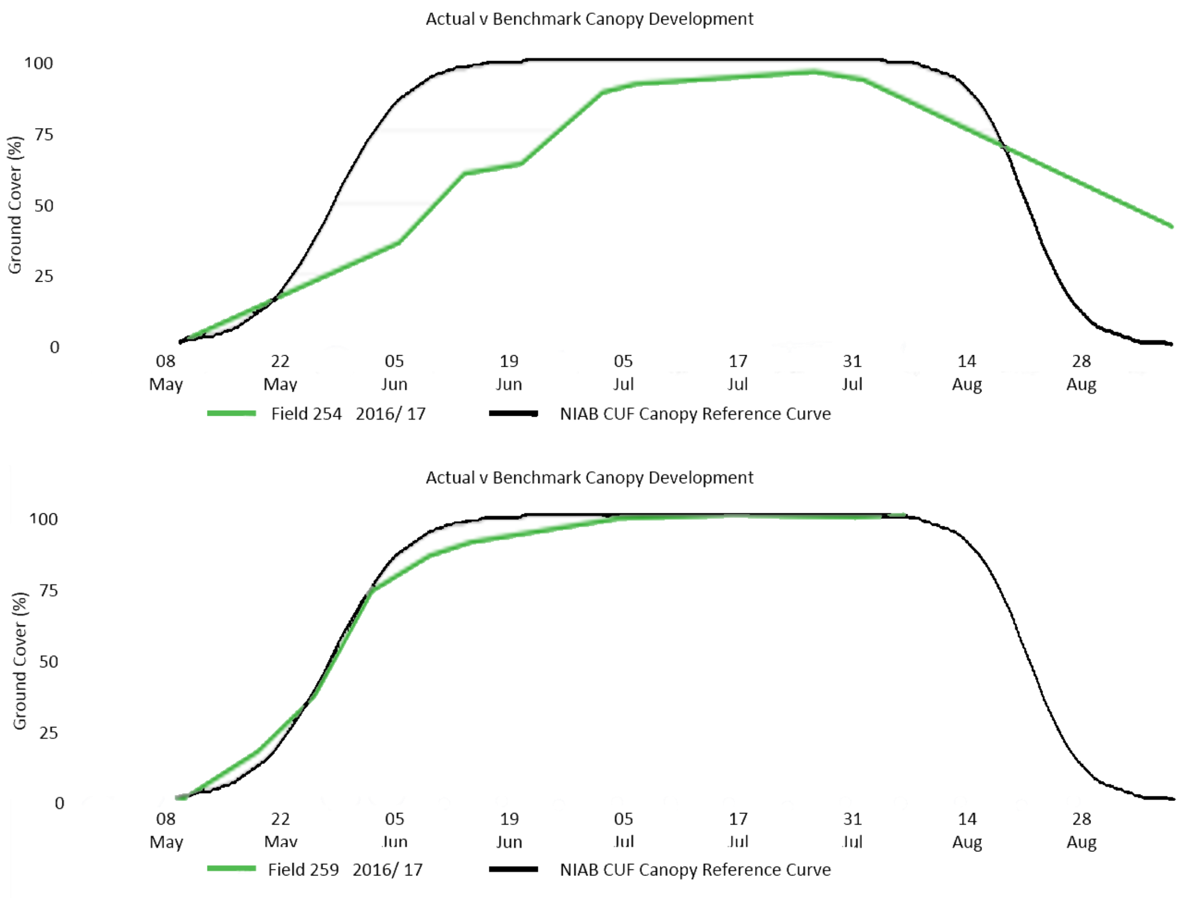

Figure 1: Comparison of the canopy development between the benchmark reference curve (black line) and actual performance of the canopy (green line), calculated by NIAB's PYM from canopy images entered by a grower with two crops of Maris Piper.

3.3. Assessing the impact of the project on improving the marketable yield

To assess the effect of the tools in helping the supply chain to maximise potential of the crop the project team aimed to gather data on how well each crop had performed and the losses observed from harvest to pack house. The data for the crops in the project was available at three points:

- A predicted total and graded yield for each crop during the season, derived from NIAB's PYM and based on sample data from each grower.
- A final grower reported yield of total tonnage from each crop.
- A final yield as delivered to the pack house, measuring total yield and the amount of crop falling into the desired size grade.

Growers in the project were encouraged to take further pre-harvest 'test digs' in the field just after the crop canopy had been destroyed which would measure the final total and graded yield of the entire crop in the field. Due to the pressures of the season, we only received this information from 12 growers.

Data on final yields delivered to the pack house were compared to other growers supplying IPL to assess performance against an average.

4. Results

4.1. Headline findings

Table 1 shows the overall performance of each crop in the project. Data is reported through the season, from the forecast provided by NIAB before harvest, to the individual grower report of final yields and the final measure given by IPL when the crop was delivered to the factory. For the amount of crop packed in the desired specification, the forecast provided by NIAB is based on the amount of crop falling into the desired size grade alone. Growers only reported a total yield so the values here are derived by taking this figure and manually calculating the tonnes in each size grade based on the estimates provided by the NIAB PYM forecast. The IPL reported pack-out rate is how much of the crop from each field made the specification (got packed in the bag) and is based on the amount of crop in the desired size plus removal of any potatoes due to quality defects. We do not have packing data for all crops grown in this project. Data gaps have arisen either because crops that were originally destined for IPL were then subsequently sold to other buyers, or because of crop failure. Each crop is identified by a randomly assigned number for confidentiality. The headline results show a large range in performance between growers, which is elaborated on in later sections. All data reported by growers and IPL have been reported ‘as is’ in this table.

Table 1: Total yields and amount of crop falling into the desired specification for each crop in the project. Data gathered at three points through the season.

		Yield (t/ha)			Amount of crop packed in desired specification (t/ha)			
Variety/ crop number	Tubers (000/ha)	Forecast from NIAB	Grower reported	IPL reported	Forecast from NIAB (based on size alone)	Grower reported *	IPL reported pack-out rate	IPL pack out rate (%)
Belana								
Average		**34.5**	**33.2**	**37.0**	**24.5**	**23.9**	**29.4**	**77.2**
Standard deviation		**8.3**	**9.0**	**13.4**	**9.7**	**10.2**	**11.6**	**7.9**
252	825.7	35.2	31.3	31.4	26.4	23.5	26.7	85
314	(411.9)	21.3	17.6	-	11.5	9.5	-	
667	(504.9)	30.2	27.1	-	12.4	11.1	-	
211	1281.7	48	48.5	63.8**	40.8	41.2	51.0	80
212	1260	47.5	48.5	-	38.5	39.3	-	
310	(780.1)	33.2	32.6	20.6	22.2	21.8	13.0***	63
311	(804.7)	36.3	32.6	-	22.1	19.9	-	
234	(492.1)	25.9	30.1	30.4	12.2	14.1	22.5	74
235	(908.8)	31.4	23.8	34.5	24.2	18.3	29.4	85
300	916.5	41.1	39.8	37.7	32.5	31.4	29.1***	77

		Yield (t/ha)			Amount of crop packed in desired specification (t/ha)			
Variety/ crop number	**Tubers (000/ha)**	**Forecast from NIAB**	**Grower reported**	**IPL reported**	**Forecast from NIAB (based on size alone)**	**Grower reported ***	**IPL reported pack-out rate**	**IPL pack out rate (%)**
213	(932.5)	36	34.6	-	29.5	28.4	-	
214	(1022.5)	26.1	32.4	40.7	22.2	27.5	34.1	84
Nectar								
Average		**68.0**	**65.9**	**65.8**	**63.2**	**61.4**	**54.5**	**82.2**
Standard deviation		**5.1**	**7.5**	**10.3**	**5.1**	**8.3**	**12.3**	**7.6**
505	346.3	58.7	62.0	48.71	55.8	58.9	36.5	75
504	407.1	69	68.0	62.2	64.2	63.2	49.8	80
503	458.1	75.5	78.0	77.8	72.5	74.9	65.4	84
249	430.2	69.3	57.3	63.0	63.1	52.1	46.0	73
250	505.5	67	57.3	-	59.6	51.0	**-**	
312	(354.8)	66.1	69.4	73.0	62.8	65.9	67.1	92
313	(403.4)	70.2	69.4	69.9	64.6	63.8	62.2	89
Maris Piper								
Average		**53.1**	**43.7**	**47.1**	**43.5**	**38.2**	**40.7**	**86**
Standard deviation		**10.7**	**13.3**	**16.1**	**13.2**	**14.3**	**14.5**	**3**

		Yield (t/ha)			Amount of crop packed in desired specification (t/ha)			
Variety/ crop number	Tubers (000/ha)	Forecast from NIAB	Grower reported	IPL reported	Forecast from NIAB (based on size alone)	Grower reported *	IPL reported pack-out rate	IPL pack out rate (%)
258	(345.1)	42.7	44.2	-	38.4	39.8	-	
254	380.3	48.8	23.1	50.1**	37.1	17.6	44.6	89
638	255.2	45.36	40.7	29.8	35.4	31.7	24.8	83
251	581.8	67.3	57.7	61.5	63.3	54.2	52.9	86

*Growers did not provide graded yields at harvest. These figures have been obtained by taking the total grower reported yield, and manually calculating the tonnes in each size grade based on the estimates provided by the NIAB PYM forecast.

** The confidence in the accuracy of these data points is low because; for crop 211 we would not expect a crop of salad potatoes to yield this high, and for crop 254 IPL have stated they are not confident that this yield pertains to this specific field.

*** These crops of Belana were subsequently graded in a different size band of 45-75mm and 75-90mm and used for a different end use than salad potatoes (pre-pack).

4.1.1. Gathering consistent data through the supply chain is challenging

The intention of this project was to gather data from field to pack house to assess performance of the crop. One of the headline findings of this project is that gathering consistent, robust and reliable data through the supply chain has been hugely challenging, and that action should be taken by the industry to address this in order to provide objective metrics that can aid continuous improvement. There are data gaps in Table 1, which are due to IPL not having data on specific crops because at harvest the growers decided to sell the crop to different customers, or because the crop failed. Where we had data, the expectation of the project team was that (a) forecast total and graded yields would be close to the actual harvested yields achieved by growers, and that (b) the reported yields by IPL once crops had been delivered to the factory would be similar, or slightly lower than the grower reported yield at harvest to account for losses between the farm gate and the factory (e.g. losses in storage). In reality the data in Table 1 shows that:

For total yields

- The forecast total yields provided by NIAB were close to the actual total yields reported by growers (see section 4.2.1).
- In some cases, the actual total harvested yields reported by growers were considerably different to the actual total delivered yields reported by IPL both in terms of gains and losses (e.g. crop 505 lost 13.29 tonnes and crop 254 gained 27 tonnes in-between harvest and pack house). This indicates that either one of the two data points are inaccurate, or that something happened to the crop between harvest and delivery at the factory that the project team is not aware of and has not been recorded by the supply chain.

For graded yields

There is a considerable difference between the estimated tonnage in the desired size grade of the crop when forecasted by NIAB, and the total tonnage pack-out rate provided by IPL, both in terms of gains and losses.

There are a number of possible reasons for the variances in data:

For total yields

Grower reported total yields were provided to NIAB with little context on how they had been calculated and when the measure had been taken, and thus we can only talk about potential reasons for the variance. Based on NIAB's experience of the industry it is likely that this has been done with varying degrees of accuracy. The only true method of assessing the performance of a crop is to measure the yield whilst the tubers are still in the ground, as this accounts for the whole crop, including any small tubers or those with significant quality defects that are discarded at harvest. However, the obvious limitation to this strategy is that the tubers are still in the ground and can only be measured through the taking of a number of sample 'test digs' which are representative of the crop. We encouraged growers to take these test digs, to then calculate final yields using the NIAB PYM which utilises long term data to model the outcome, however this is labour intensive and due to time pressures at harvest only a few growers managed to do this. As such, the most common method to measure yield is after the crop has been harvested. The accuracy of this measurement is usually based on how much equipment a grower has available, and thus whilst it is preferable to pass all crops over a weighbridge, they may for example be packed into one tonne boxes and the total yield estimated.

To provide further variability, growers may sometimes combine crops from multiple fields to make up the final crop delivered to the pack house in order to meet contractual requirements. We are also uncertain what happened to crops at the pack house, and how data was calculated. For example, the gross yield reported for crop 211 of Belana was 63.8t/ha, which is significantly higher than other values and likely to be incorrect given this is a salad variety with a yield expectation much lower than this. These factors could account for any increases in volume of the crop between field and pack house.

For graded yields

The forecast of the percentage of crop falling into different size grades by the NIAB PYM is generated by taking data from a grower's 'test dig' and using a model, developed using long term data on performance of each variety, to generate a final number. The accuracy of the forecast for size grading will be determined by the quality of the data being submitted to the model and may be the consequence of the sampling not being representative of the crop in the field because of variation across the field. The NIAB PYM grades the crop into 3 different size bands, however IPL only grade the crop into one size band (in specification and out of specification), and thus obtaining a true validation of how well the forecast has performed against actual is challenging. We can only accept the data from the pack house *as is* and cannot account for any inaccuracies, which may account for variance.

4.2. **Performance between growers in the project**

The data in Table 1 shows that there are huge differences between the best performing crops and the poorest performing within the same variety, demonstrating that there is significant room to optimise the efficiency of the supply chain.

4.2.1. Total yield

Total yield is a measure of the total tonnage of a specific crop. For the crops produced by the growers within the project there was a good correlation (R^2=0.92) between the total yield forecasts produced and the actual yields reported by the growers at the end of the season. The model has an almost 1:1 relationship with the grower reported yield giving confidence that the model reliably predicted the harvested yield (Figure 2).

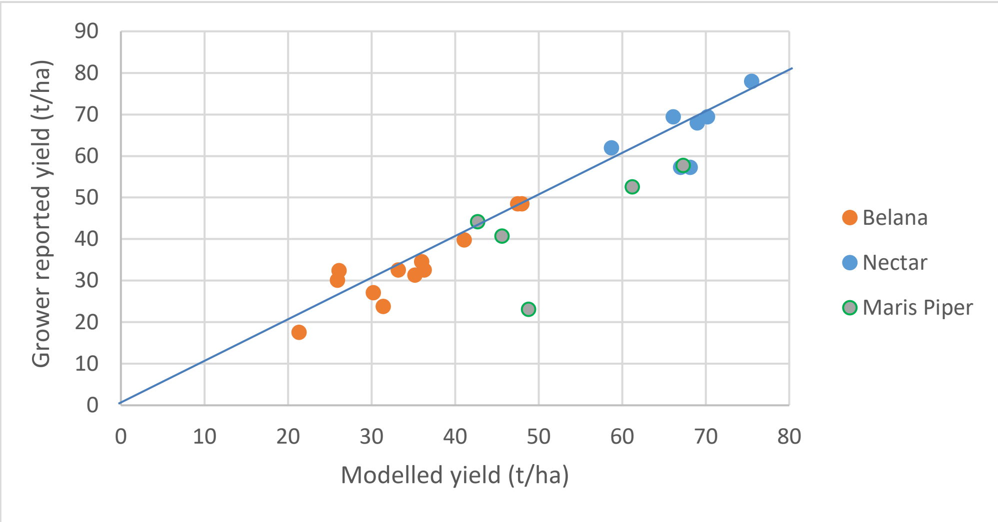

Figure 2: Correlation between total yield forecasts and actual yields reported by growers.

The total yields recorded on farm (Table 1) highlighted the enormous variation between crops for the same variety. This was particularly true for Belana where the highest total yield was more than 2.5 times higher than the lowest total yield (Table 2). For Belana, these differences in yield were likely to be influenced by the three-fold variation in the number of tubers between crops, as the canopies of crops containing fewer tubers were destroyed earlier so that the tubers would not grow too large for the specification (Table 1). Had the crops with relatively low numbers of tubers contained more tubers, then they could have produced higher total yields. This indicates that in future years the farmer could consider a higher planting density/sowing rate. The difference between the highest and lowest yields for Nectar and Maris Piper was between 1.3 and 1.5 times the lowest yield. There was less variation in the number of tubers in the crops of Nectar and Maris Piper compared to Belana, and for these varieties yield is less likely to be limited by the number of tubers due to the larger size specification (Table 1). For these varieties however, excessive numbers of tubers can cause reduced marketable yield as tubers do not reach their optimum size. All growers in the project were farming in a similar geographical area. Despite this huge variation in yields (or tuber numbers), the exact causes are unknown. There may be very specific issues at a field level that cause lower yields, but in general on an industry level the main causes of variation between crops is less known. There is a general need for further investigation into the major causes of variation, and importantly the need to understand the key 'levers' to pull to improve the situation. However, in order to do this effectively, growers and the supply chain must have an objective method to gather comparable, objective and robust data, which this project has proved is currently not being achieved.

Table 2: Summary of total yields reported from the growers in the project using the PYM.

	Belana	Nectar	Maris Piper
Number of crops	12	7	4
Average yield (t/ha)	33.2	65.9	48.8
Standard Deviation (+/-)	9.0	7.5	13.3
Lowest yield (t/ha)	17.6	57.3	40.7
Highest yield (t/ha)	48.5	78	57.7

4.2.2. Graded yield

The grade of a tuber is a major factor in whether a potato makes it into the desired specification and is ultimately packed into the pre-pack bag ('pack-out rate') (for more detail see Section 2.3). The NIAB PYM reports the total and graded yield of the crop against a number of pre-defined size bands. The size bands used by the NIAB PYM were agreed with IPL during the season, before crop forecasts were produced. The criteria for specification in terms of size band was subsequently changed by IPL as the crops were purchased in order to maximise crop utilisation. This is a typical for fresh potato supply chains to respond to growing conditions and availability of the crop. For the analysis below we have therefore used a desired size band consistent with the final size band applied by IPL and applied this throughout the analysis, benchmarked against standard industry values.

The pack house purchases the whole crop and it is sorted by size in terms of crop falling into specification and crop not in specification, which is based on size of tubers and their quality. The tubers out of specification are redistributed to lower value markets (for example, value pack products, ready meals), or sent for animal feed. Prices are generally agreed on contract between buyers and growers and are confidential, however most contracts are based on the tuber size, quality and conditions of delivery. This section uses average industry values for different size grades in order to illustrate the financial impact of achieving the desired specification (Table 3).

Table 3: Average industry returns for the different size grades used in the NIAB PYM tool to produce the forecasts. Source: IPL.

	Size (mm)	Average industry value (£/t)
Belana	< 25 25-35 35-45 > 45	5 300 300 30
Nectar	< 45 45-65 65-85 > 85	5 85 85 30
Maris Piper	< 45 45-70 70-85 > 85	30 180 85 30

To illustrate this, Table 4 shows the estimated financial value of crops in the project, based on the estimated amount of crop falling into the desired size grade (derived from the PYM), and the reported gross yield of the crop by the grower. The table illustrates the large impact on revenue to a grower of getting more crop in the desired size grade. For the Belana crops, the best performing crop generated revenue worth more than three times the worst performing crop. Even for Nectar, where the differences were not so pronounced, the best performing crop still generated a revenue worth over £2,000/ha more than the worst performing crop. For an average field size of 10 ha, this is worth £20,300. There are likely to be site-specific reasons why the poorest crop may never be as good as the best crop, such as soil type or localised weather conditions, however this example serves to illustrate the difference and why graded yield is so important.

Table 4: The estimated value of lowest, highest and average crops in the project, based on estimate of crops falling into the desired size grade, the reported gross yield by the grower and the average industry prices in Table 3. The desired size grade for Maris Piper from IPL was 45-80mm, which is less granular than the industry standard size grades in Table 3. For this analysis we have assumed the price paid is £180 per tonne

	Average industry value (£/t)	Estimated % of crop falling into desired size grade - lowest yield crop (£/ha)	Estimated % of crop falling into desired size grade – average across all crops (£/ha)	Estimated % of crop falling into desired size grade – highest yield crop (£/ha)	Difference between highest and lowest revenue crops (£/ha)
Belana	£300 (<45mm)	2 851 (54% in desired grade)	7 154	12 367 (85% in desired grade)	**9 516**
Nectar	£85 (45 – 85mm)	4 335 (89%)	5 211	6 365 (96%)	**2 030**
Maris Piper	£180 (45 – 80mm)	3 160 (76%)	6 883	9 763 (94%)	**6 603**

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Table 5 shows the graded yields as reported by the pack house.

Table 5: The value of the lowest, highest and average crops in the project as provided by IPL from the crops in the project as they reach the pack house

	Average industry value	Actual % of crop falling into desired size grade - lowest yield crop (£/ha)	Actual % of crop falling into desired size grade – average across all crops (£/ha)	Actual % of crop falling into desired size grade - highest yield crop (£/ha)	Difference between highest and lowest revenue crops (£/ha)
Belana	£300 (<45mm)	6 756	8 819	15 310	**8 554**

		(74% in desired grade)		(80% in desired grade)	
Nectar	£85 (45 – 85mm)	3 105 (75%)	4 632	5 705 (92%)	**2 600**
Maris Piper	£180 (45 – 80mm)	4 454 (83%)	7 334	9 522 (86%)	**5 068**

4.2.3. Proportion of crop meeting desired specification

Based on final data provided by the pack house the average pack out rate was 77%, 82% and 86% for Belana, Nectar and Maris Piper respectively (Table 1). The % difference between the lowest yielding crops and highest yielding crops was 22% for Belana, 19% for Nectar and 6% for Maris Piper, so there is room to make the entire supply chain more profitable by closing the gap.

Table 6 shows the proportion of each crop being diverted to lower value uses at the pack house due to grade of the tubers and quality issues. The grower delivers the total crop to the factory (minus any crop that has already been diverted at the farm). The pack house then sorts the crop into the desired size grade, any crop not making the desired size grade is diverted to lower value uses such as 'value packs' or processing into products such as ready meals or chips. The pack house then sifts out any crop not meeting the desired quality specification, e.g. high levels of scab, and a further proportion of the crop is diverted to lower value uses.

Table 6 shows that the amount of crop diverted from their intended use to lower value uses ranges from 13.9% to 36.6% of the total crop across all varieties. The table shows that crop out of the size spec causes more diversions to lower value uses than quality defects.

Table 6: The proportion of each crop being diverted to lower value uses at the pack house due to grade of the tubers and quality issues.

Variety	Field	Area grown (ha)	Total gross crop delivered to IPL (t/ha)	Total in desired size grade (t/ha)	Total in desired size grade and desired quality (t/ha)	Total diverted to lower value uses (t/ha)	Total diverted to lower value uses (%)
Belana	252	13.7	31.4	29.2	26.6	4.8	15.3
	211	7.8	63.8	54.8	51.3	12.4	19.5
	310	11.3	20.6	15.0	13.1	7.5	36.6
	234	11.8	30.4	24.8	22.5	7.9	26.0
	235	5.3	34.5	32.0	29.3	5.3	15.2
	300	5.1	37.8	31.1	29.2	8.6	22.7
	214	10.2	40.7	36.7	34.0	6.7	16.4
Nectar	505	8.8	48.7	45.5	36.4	12.3	25.2
	504	11.8	62.2	59.5	50.0	12.2	19.6
	503	10.0	77.8	75.3	65.5	12.3	15.8
	249	4.5	63.0	51.8	45.9	17.1	27.1
	312	4.1	73.0	71.8	66.9	6.1	8.4
	313	3.9	69.9	68.0	62.3	7.6	10.8
Maris	254	10.7	50.1	45.3	44.7	5.4	10.8
Piper	638	5.9	29.8	26.3	24.6	5.2	17.5
	251	6.1	61.5	61.5	52.9	8.5	13.9

4.3. **Performance between growers in the project and other IPL growers**

Only a limited amount of data was available for crops delivered to IPL by other growers outside of this project. These data were used to compare the yields of crops grown by growers in this project and crops grown outside the project. This did not include statistical analysis due to the limited dataset. The Belana and Maris Piper crops in this project had a higher yield than growers from outside the project (Figure 3). For Nectar, the yields of crops in the project were lower than those outside, but the amount of crop not in specification was higher than crops within the project (by 4%), so marketable yields were similar. For Maris Piper, the data on crops outside the project is less reliable because we were not given data on how much crop was diverted to lower value uses because of size out grades. Overall, the Figure below shows growers inside the project have on average more crop packed in the desired specification than growers outside of the project.

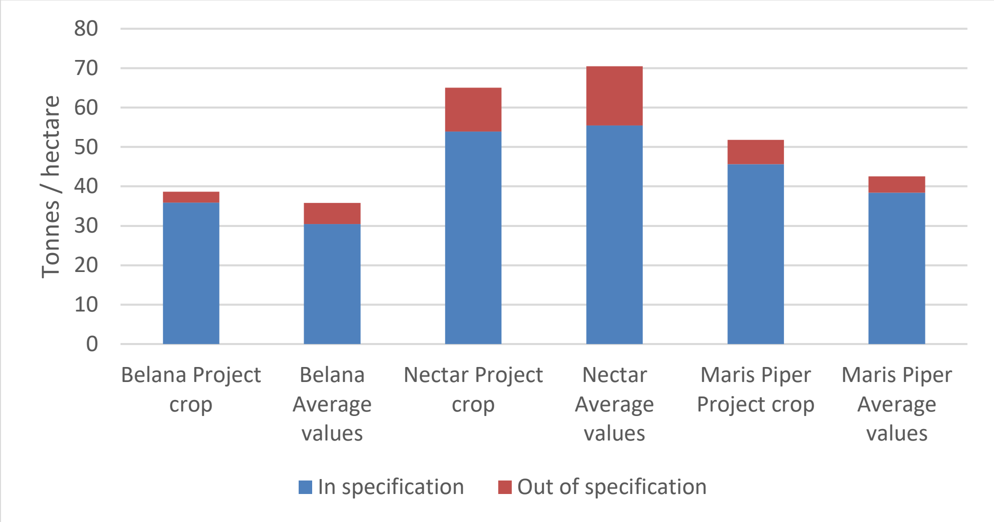

Figure 3: Comparison of the gross average yields (t/ha) from batches processed by IPL from growers both inside and outside the WRAP project

4.4. Using the Potato Yield Model to choose the optimum time to stop crop growth

One of the main outputs for a grower of the PYM is that the model generates an optimum date to destroy the crop canopy. Once the crop canopy is destroyed (either manually by cutting, or with a desiccant), the potato tubers stop growing. If a grower destroys the canopy too early, they may lose out on tonnes of marketable yield, destroy too late and the tubers will get too big and go out of specification.

As an example, the crop of Belana shown in Table 7 was defoliated on 11th July when the model predicted 75% (26.6 t/ ha) of the crop would be in the premium prepack grade of <45mm (with 54% between 35 and 45mm), and would have maximum returns for the grower of around £8 000 per hectare. By destroying the canopy too soon, the tubers will not have reached their optimum size so whilst the tubers will still fall within the <45mm premium prepack grade the average size will be less (the PYM predicts 50% of the tubers will be between 25 and 35mm) and this will have an obvious impact upon yield and financial returns to the grower.

Table 7 Effect of the timing of defoliation of the potato crop on yield and value of the crop

Belana (crop 252)	Defoliated 1st July		Defoliated 11th July	
	<45mm	>45mm	<45mm	>45mm
Graded yield (t/ha)	20.0	1.0	26.6	8.2

Industry average values (£/t)	£300	£30	£300	£30
Maximum return (£/ha)	6 000	30	7 980	246

4.5. **The effect of the tools on improving performance**

4.5.1. Training

At the end of training sessions feedback was taken to generate metrics on impact. This showed that on average there was a 33% improvement in understanding in each subject area covered and 85% of the attendees said they would either make or consider making changes to the way they operate. Areas of particular interest for further consideration were the timing of fertiliser applications, seed rates and increasing efficiency in irrigation, particularly irrigation scheduling.

4.5.2. Potato Yield Modelling

Throughout this project we held several meetings with growers and the supply chain to use the results of the PYM to stimulate a conversation about how crop performance could be improved. The following sections describe the project team's qualitative observations gathered at meetings and through one on one conversations.

Growers

The aim of this project was to provide technical training and digital tools to help growers improve their marketable yield, and thus reduce waste. The growers taking part in the project were amenable to sharing data with one another and taking part in a group conversation about how to improve performance. The PYM proved to be a valuable method to facilitate this discussion because it takes key data and produces objective, irrefutable metrics of performance for each crop. This means that the conversation becomes more productive, because metrics cannot be dismissed due to perceived inaccuracy or 'special circumstances'. At a final workshop in December 2017, the project team collated tables of the forecast yield and actual grower reported yield. Whilst differences in performance between crops are anecdotally understood by growers and the supply chain, it was not until this point that irrefutable and accurate quantifiable data was presented. The atmosphere in the room when these data were presented was notably different. Growers and the supply chain were animated by seeing the data and started informed conversations and questioning why the variation occurred. The key insight is that objective, consistent data collection is vital to help the supply chain improve. One caveat is that multiple growers stated that they were not sure how comfortable they would be to share all their data with the supply chain on an ongoing basis for fear that this would be detrimental to achieving a preferential contract price. In order to facilitate effective conversations between the supply chain, either the level of trust must increase, or independent facilitators must be used to conduct sessions with strict rules around the sharing of data.

For many of the growers, use of the PYM was their first experience of using digital decision support tools and most of the growers said they had a positive experience and would use the PYM in the future. For the 2018 season, three of the growers in the project have continued to use the PYM, paying for it as a commercial service. Most of the growers said that they did not feel confident enough in the first year to rely on the model outputs (burn down date) to make their decisions, but took the time to compare the predicted outputs against actual and were impressed how accurate the predictions were, and thus would consider using the outputs more in subsequent seasons. This demonstrates the need to ground truth digital models with clear evidence, and the need for continued use to build up trust in their recommendations. One of the growers said that the PYM was an excellent tool to provide quantitative data to help prove the impact of different decisions. They cited one example of an agronomic decision that they had wanted to make, but had subsequently been overruled by senior managers. The metrics from the PYM at the end of the season had subsequently shown that had this grower taken the decision it would have increased the marketable yield. This unbiased quantitative data means that this farm can now make an informed decision about how to progress in future years.

The supply chain

For IPL, the aim of this project was to provide objective yield forecast data from the PYM that could be used to facilitate more effective supply planning to reduce waste, and provide key metrics to help have an informed conversation with growers about how to improve. A meeting was held in July 2017 with IPL agronomists, buyers and quality managers to present the yield forecasts generated by the PYM. The hypothesis was that yield forecasts would provide IPL with a quantifiable picture of the total and graded yield of crops ahead of harvest, thus assisting with supply chain planning. In reality, whilst the forecasts did provide these data, the 2017 crop was not substantially different to average production for the forecasts to trigger IPL making any decisions off the back of the information. The comment was made that the data can be used to have an informed conversation with the grower in order to facilitate contract negotiations in future years.

5. Conclusions

This project has shown that there is a huge variability in potato yields and performance between fields, with the highest total yield for Belana, Nectar and Maris Piper being 2.5, 1.3 and 1.5 times the lowest respectively. The average amount of crop packed in the desired size grade (and thus meeting specification) was 77%, 82% and 86% for Belana, Nectar and Maris Piper respectively. The difference in crops meeting specification, between the poorest performing crops and best performing crops was 22% for Belana, 19% for Nectar and 6% for Maris Piper. This huge difference is between a relatively small sample size of growers who are operating in the same geographical area. It is possible that differences could be larger when extrapolated across the national crop. Relatively little is known about the causes of this variability, however despite this the industry is not gathering the consistent, comparable and reliable data that is needed to be able to close the gap and ultimately reduce 'waste' (or maximise the percent of potential). This project has gone some way to collecting the objective data that is required to address the opportunity to improve performance. However we have found that it was impossible to collect consistent and reliable data once the crop had left the field due to the inconsistency of the way yield was measured and the lack of knowledge over what happened to the crop before it was measured (e.g. was it combined with crop from another field, had defects already been removed). The way the supply chain operates compounds this problem because the desired size grade (the goal to aim for) may be changed at the last minute to account for crop availability. This should not be discouraged as it can help the grower in difficult seasons. In addition growers may combine crops from different fields to fulfil a contract, or discard potatoes without quantifying the impact. Ensuring common data standards that operate across the whole industry is vital to ensure crop performance can be monitored and ultimately improved. The commonly used saying; 'if you can't measure it, you can't manage it' is pertinent. One of the growers in the project commented that he had grown potatoes for 40 years, some years the yield was good, some bad, some disastrous, however he had no reliable data to show him exactly why this was the case and what he should do differently next time.

In this project, growers and the supply chain responded well to the presentation of objective data and metrics in order to facilitate a conversation about continuous improvement. The application of training and modelling tools provided a framework for sharing ideas and benchmarking performance.

6. Recommendations

The key recommendation from this project is that work should be done to provide common data standards and metrics for measuring the performance of commercial potato crops in the field so that the industry can objectively identify the causes of variation and continuously improve. Supply chains should look to use common data standards and metrics to ensure that growers can improve performance across the board. To maximise impact this standard should operate across the industry and not be specific to individual supply chains. There is also no reason why such a standard should not operate across different potato categories (fresh and processed), or perhaps even other fresh produce crops. Data standards would include protocols for collecting data during the season (e.g. canopy cover and test digs) and at the end of the season. At the end of the season, specific guidance should detail how to measure the yield of the crop, at what point(s) it should be measured and what to include the calculation. Data gathered should also include key metrics needed to evaluate crop performance such as planting date, date of 50% emergence, plant, stem and tuber counts as well as quality information. This is vital to help understand the correct 'levers' to pull in order to close the gap in actual marketable yield and biological potential, and to reduce the current wide variation in commercial crop performance. WRAP and its 'Fresh Produce Working Group', working with an appropriate technical partner such as NIAB would be well placed to co-ordinate such an effort.

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8. Acknowledgements

We would like to acknowledge IPL and all the growers who took part in this project and provided their time in-kind to collect data in the field. This project was carried out with funding from WRAP.

9. Appendix

9.1. Key learning outcomes of training courses

22 February 2017 Understanding and optimising potato nutrition

- The legislative and commercial framework to potato crop nutrition
- Where to find relevant sources of information
- The supply of nutrients from soils and how these are measured
- How to maximise the benefits of organic amendments
- How potato crop physiology affects fertiliser requirement
- The practicalities of making fertiliser recommendations
- Nutrient management in the context of sustainability and rotations

23 February 2017 Scheduling irrigation to optimise yield and quality in potatoes

- Know how and why plants use water (calculation of evapotranspiration, crop coefficients)
- Be able to select fields for different end uses based on soil water supply
- Be able to choose varieties for tolerance/resistance to drought
- Be able to schedule irrigation (legislation, methods, data collection)
- Understand the effect of irrigation on crop quality
- Be able to weigh up the benefits and disadvantages of soil moisture measurement tools (accuracy, precision, practicality)
- Be able to select application technology (equipment selection, operation and uniformity)
- Understand how scheduling works in practice

24 February 2017 Understanding potato crop growth stages

- Key aspects of potato growth and development
- How to use knowledge of crop growth to guide agronomic decisions including seed rates and fertiliser requirements
- Factors limiting crop productivity and quality