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Enhancing the profitability and value of Class 1 New Zealand onions—final report

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EXECUTIVE SUMMARY

Enhancing the profitability and value of Class 1 New Zealand onions—final report

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July 2018

This is a final report for "Enhancing the profitability and value of Class 1 New Zealand onions", a 3-year Sustainable Farming Fund project to understand the causes of variability in onion crops and provide industry with tools to monitor, map and quantify variability in yields and crop development. A Management Action Zone (MAZ) tool was developed and tested. A separate report covers development of this tool. We determined that onion bulb variability is best expressed as a coefficient of variation (CV) and New Zealand crops inherently have a CV of 38% (±3%) for bulb variability. Further, we could determine that the bulk of this variability (61%) is ascribed to growth rate differences between individual plants. The balance is split as 31% of variation because of the spread of emergence of seedlings and 8% because of differences in plant-available space. We found soil compaction, waterlogging and inadequate irrigation are the key management factors causing greater CV% (more variability) in crops. Further, most of this variability is already expressed by the three-leaf stage. Additionally, this measure of variability and the major causes are the same, whether measuring variability between individual bulbs or total yield at field scale.

The MAZ tool is used to identify field-scale zones where plant population is below target or plant growth is below expectation. This provides four broad categories:

1. Yield within potential range and population as expected: No additional management needed
2. Yield within potential, but population below expected: Management practices that will address population establishment need to be considered for subsequent seasons.
3. Yield below potential, but population as expected: Implementing in-season management (e.g. increasing fertiliser) may increase yields and improve outcomes. Alternatively reduced inputs may improve financial returns if yields may not be increased.
4. Yield below potential and population below expected. In-season management needs to be considered, as well as implications for population establishment for subsequent crops.

We used the MAZ tool to guide management practice in a field with good results, thus indicating the potential value for growers.

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1 BACKGROUND

The aim of the Onions New Zealand Inc. Sustainable Farming Fund project “Enhancing the profitability and value of Class 1 New Zealand onions” (Project No. 408098) was to understand the causes of variability in onion crops and provide industry with tools to monitor, map and quantify variability in yields and crop development.

This report summarises work over 3 years in collaboration with LandWISE Inc. to identify and measure variability in onion fields.

We have conducted 3 years’ of work in collaboration with LandWISE Inc. to identify and measure variability, and have developed a tool that can start to be evaluated in growers’ fields. Based on our understanding of variability and growth developed in Year 1 of the project, we have developed the concept of Management Action Zones (MAZ) — areas of the field where growth may be limited and spatial management may improve outcomes. Putting this concept together with image analysis we have developed a tool that can identify these MAZ in the field and indicate if tactical management (in-season) or strategic management is needed to improve outcomes in those areas. This would assist growers in making decisions for their field.

In this report we provide an overview of the results and the development of the MAZ concept, the development of tools to identify the MAZ areas in a field, and implications for management of those areas. We will not report here on details of experiments or methods – these can be found in earlier reports of this project (Bloomer & Searle 2018; Searle et al. 2016, 2017a; Searle et al. 2017b), but we provide an overview of the results, highlight implications of these results and what they mean for onion crop management.

This report summarises the implications of crop variability for growing the crop, and for developing a tool to measure yield and crop variability. A separate, second report discusses the technical aspects of the application of image analysis for spatial mapping that the tool uses, and implementation of the tool by growers.

2 ONION CROP VARIABILITY

2.1 A framework for thinking about crop variability

There are two aspects to variability in an onion crop that affect yield and quality outcomes, and hence the value of the crop. Firstly, plant-to-plant variability results in different bulb weights and sizes, and affects yield and overall quality of bulbs. Onion crops are known for significant variability in weights and sizes between bulbs. Secondly, there is the variability in yield observed within a field that can commonly range from yields less than 40 t/ha in some areas of a field to areas with yields above 90 t/ha. This is a significant range and will affect the overall value of the crop.

We developed a framework to understand and evaluate crop variability and how it develops, and to start to identify the causes. We have called this the “V of variability” (Figure 1, Searle et al 2014). There are a very large range of interacting factors that affect variability and it is not a simple process to identify which ones are affecting a particular crop. Instead of identifying individual factors, or groups of factors causing variability, the framework identifies key stages during growth at which variability can be measured, or key crop factors in which variability has important consequences. The factors can then be narrowed down by identifying those that are key to each crop stage or key factor.

For example, if the variability between plants is very high at emergence, but does not change much after that, then it suggests that factors affecting emergence have primarily affected variability. Knowing this we can identify the key factors driving emergence, and from that the likely causes of variability which allow appropriate management interventions to be developed.

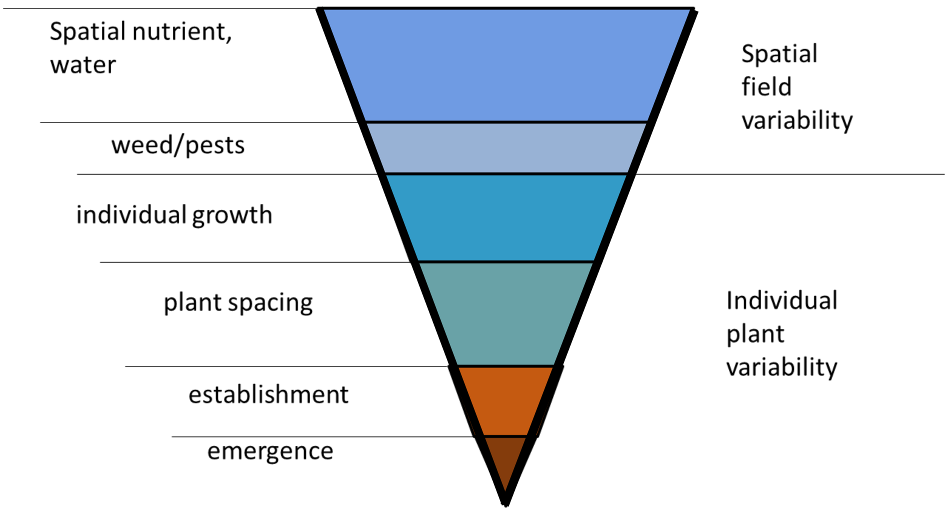

Figure 1. A framework for evaluating variability. Variability starts with the seed and then increases as the crop emerges and establishes. It is increased by variable plant spacing and because individual plants grow at different rates. These result in a variability between individual plants under optimal and uniform field conditions. Spatial variability in nutrient, water or pest pressure will increase variability. The framework, called the ‘V of variability’ highlights that under sub-optimal conditions lower yield is associated with higher variability between plants.

The framework starts with seed variability, which is assumed to be small compared with the final variability (Figure 1). Crop development stages that can lead to greater variability are emergence spread, and at establishment the evenness of plant spacing. The expectation is that a more even spacing will give a more uniform crop. Not all plants grow at the same rate and this difference can on its own be a cause of variability. This growth rate difference can be accentuated by competition between plants – very crowded or late emerging plants will be outcompeted for resources by other plants that have more space or emerged earlier.

Under optimum growing conditions, and if the field is uniform, these would be the things that define variability in a crop and, under these optimum conditions, it would also be the minimum variability possible by the crop.

However, if there are spatial differences within the field in terms of nutrient or water availability, or due to weed or disease pressure, then there will be more variability between plants within the field, as plants in these areas will grow at a slower rate and have lower yields. This means that spatial variability in yield is associated with increased overall plant-to-plant variability.

It would therefore be useful to know what the lowest plant-to-plant variability is that can be achieved between plants. This will happen when the crop grows at potential – it helps understand how much variability growers can control. Also, as yield variation within a field is associated with higher plant-to-plant variability, it provides a way of interpreting those yield differences and start to determine where in the field different management may improve yield outcomes. Our Year 1 experiments where set to help identify this.

2.2 What is the least plant-to-plant variability likely under uniform growing conditions

We conducted experiments with the cultivar ‘Rhinestone’ where we measured several hundred bulbs, and also evaluated bulbs and yields in different fields to obtain an understanding of how much variability would occur under optimum conditions and how what might be causing it.

Under optimum and uniform growing conditions (no observable limitations to growth) we obtained yields of 92 t/ha with an average bulb weight of 153 g. The variation in individual bulb weight was described by a standard bell-shaped curve (see Figure 2), or a normal distribution. A way of describing the variation for data that has a normal distribution is the coefficient of variation (CV) usually reported as a percentage. It is calculated as the standard deviation (or spread of bulb weight) divided by the mean of bulb weight. This allows the variability of different populations where the mean may differ to be compared.

Our results show that the variation of bulb weights at harvest for onions grown under optimum and uniform conditions is a CV of 38% (± 3%). This level of variation can be considered the minimum achievable for onion crops, and is in the range of minimum values recorded from 20 onion crops (where range from 35% to 90%).

The proportion of the crop that is in given weight and diameter ranges is shown in Figure 2. For a crop with a CV of 38% that has grown without any limitations, bulb weight will range between 5 and 350 g, equivalent to 20–95 mm.

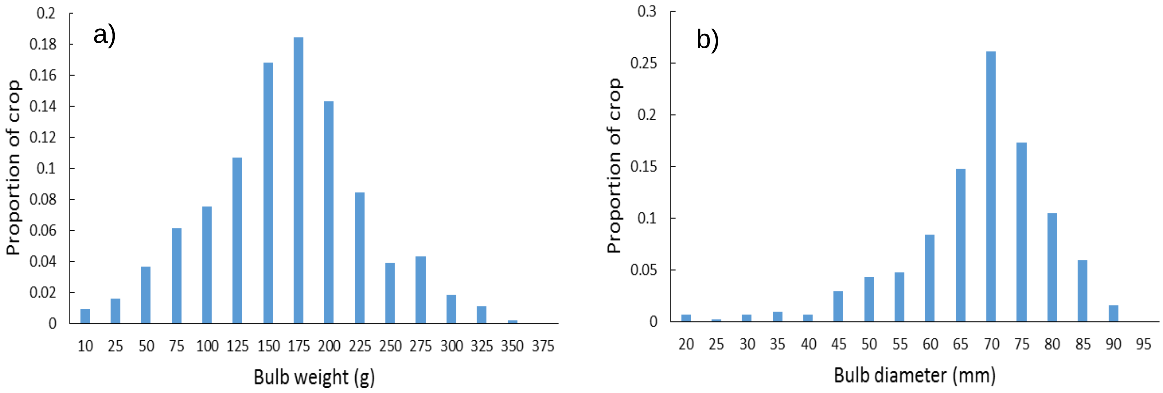

Figure 2. Distribution of a) onion bulb weight and b) diameter for a crop with no limitations to growth. Yields averaged 92 t/ha, with mean bulb weight of 153 g and mean bulb diameter of 67 mm. The coefficient of variation based on bulb weight is 38%. Crop grown at the LandWISE MicroFarm in Hawke's Bay during the 2015–16 season.

With a CV of 38%, approximately one third of the crop will have bulbs lower in weight than 125 g (or 61 mm), the middle third of bulbs will weigh between 125 and 175 g (61–75 mm), and the last third of bulbs will be greater than 175 g and range in weight to up to 350 g (75–95 mm). It should be noted that the upper weight range of 350 g is not a maximum weight – bulbs can reach heavier weights than this (bulbs greater than 450g have been recorded). However, in a crop with a CV of 38%, the highest bulb weight will tend to be around 350 g.

2.3 Causes of plant-to-plant variability

From Figure 1 it can be seen that the causes of plant-to-plant variability arise from variation in emergence, variation in population and spacing, and differences in growth rate between individual plants. Our work in Year 1 of this project attempted to quantify which of these contributed most to final bulb variability, so that key factors that affect variability could be identified and possible management plans identified.

Results of the analysis showed that 31% of total variation came from the spread of emergence, 8% came from variation in plant spacing, and 61% of the total variation was due to differences in individual plant growth rate (Figure 3):

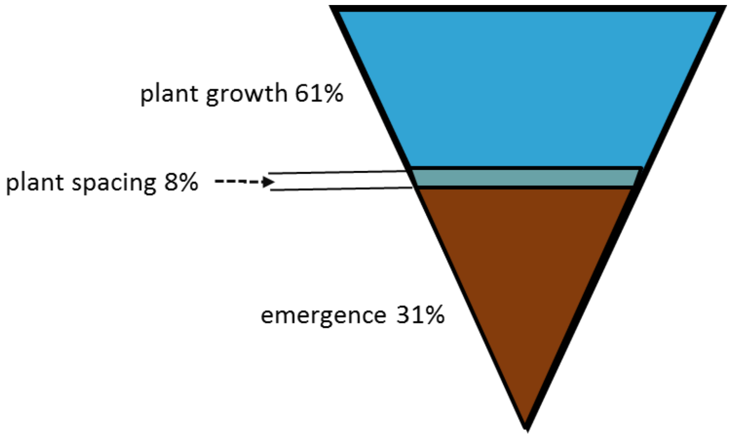

Figure 3. Contributions to plant-to-plant variability of an onion crop grown at potential and minimal limitations to variability at the LandWISE MicroFarm, Hawke's Bay in the 2015–16 season. Total variability expressed in coefficient of variation was 38%, and this can be considered the optimum, or greatest uniformity of variability that can be achieved when the crop is grown optimally. Of this total variation, 31% was caused by spread of emergence, 8% by variability in plant spacing, and the remaining 61% caused by individual plant differences in growth. The size of each part of the "V for variability" figure reflects the percentage contribution of each to the overall variability of onion bulbs.

It is also important to note that by the third leaf stage, the CV was already 31%, indicating that most of the variability was already observable early in the growth of crop. This highlights the fact that management involved in sowing and this early phase of crop growth is key for ensuring the crop is as uniform as possible.

3 DEVELOPMENT OF VARIABILITY

The factors affecting variability development identified in Figure 3 will be considered here in more detail, both in terms of the effect on plant-to-plant variability, and on spatial yield variability in the field. There is a link between plant-to-plant variability in weight and crop yield, as emergence, plant spacing and population are key factors that also define yield, and this highlights the links between uniformity and better yields for onions.

The CV of 38% can be considered an optimum, or the most uniform level of variability that can be obtained when growing an onion crop, and this is obtained when growing with no known limitations – also important to ensuring maximal yields. The only limitations would have been temperature and solar radiation levels experienced during the season. The results for getting a more uniform crop suggest three questions to consider when growing onions to produce a crop with the minimal amount of variability and better yields:

- Has emergence been affected?
- Is the population what is expected?
- Is growth as expected?.

3.1.1 Has emergence been affected?

Emergence of seed was close to optimal in the Year 1 experiment planted at the LandWISE MicroFarm in Hawke’s Bay on 2 August, 2015 (Figure 4); with observed emergence not differing from the estimated potential emergence rate. Soil moisture and temperature are the main drivers of the estimated potential emergence rate. In this experiment, soil moisture was not limiting and so the main factor affecting emergence was temperature. Adverse soil structure did not affect emergence, as observed emergence was so close to modelled potential emergence. The first seeds emerged 20 days after planting.

The bulb weights of plants for each day of observed emergence are shown in Figure 4. Bulb weight at harvest ranged from 10 to almost 350 g for the first emerged plants. This range was similar for plants that emerged over the first 8 days of plant emergence (from 20 to 28 days after planting). Plants that emerged later than 8 days from the first emergence tended to be smaller, and increasingly smaller with a greater delay in emergence. It is plants that emerged more than 10 days after the first emerged plants that contributed most to the bulb weight variation caused by emergence.

There was no significant delay in emergence (Figure 5), and just over 90% of plants emerged by day 8 from the start of emergence, and only 2% of plants emerged more than 12 days after the start of emergence. These few plants that emerged more than 8 days from the first emerged plants that caused 31% of the bulb weight variation at harvest.

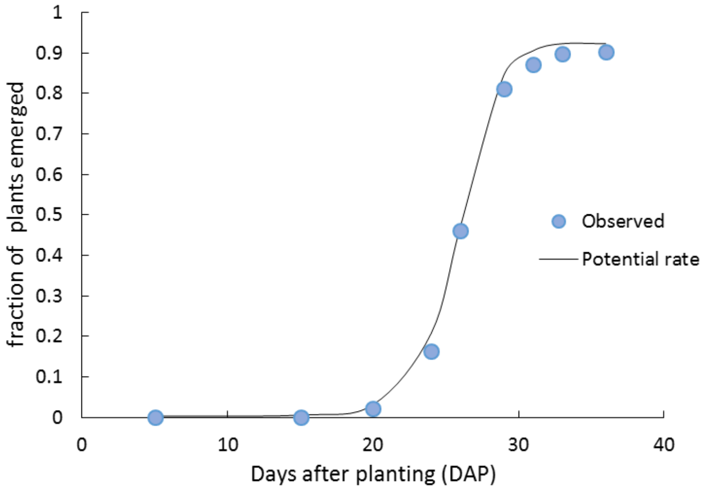

Figure 4. Observed and estimated emergence of ‘Rhinestone’ onion seeds sown on 2 August 2015 at the LandWISE MicroFarm in Hawke’s Bay.

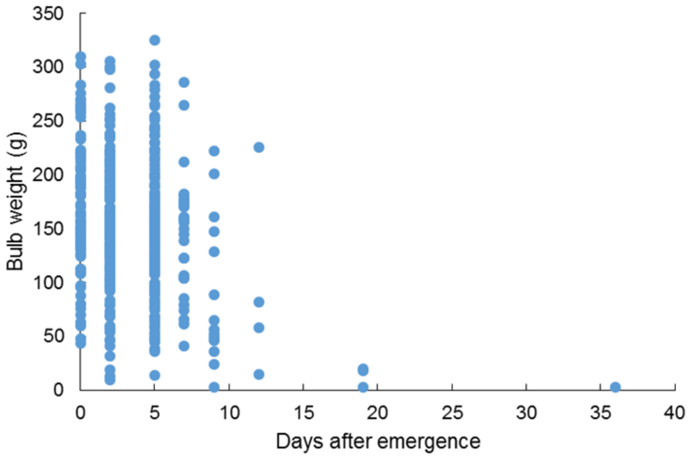

Figure 5. Onion bulb weight on different days of emergence of ‘Rhinestone’ planted on 2 August 2015 at the LandWISE MicroFarm In Hawke’s Bay. The first day of emergence occurred 20 days after planting the seed.

These results mean that to optimise the uniformity of the crop, plants need to emerge as uniformily as possible, and that ideally all plants should have emerged within 8 days from the start of emergence. When evaluated over 20 years, the spread of emergence when planted on 2 August ranged from 10 to 20 days in Canterbury, 10 to 22 days in Hawke’s Bay and 9 to 16 days in Pukekohe. Only 1 in 20 years had conditions that resulted in the spread of emergence being 10 days. This means that there will usually tend to be some spread of emergence increasing bulb weight variability that is determined by temperature conditions during emergence. This is something growers can do little about, though there may be some possibilities by exploring the use of sets or transplants to improve uniformity. This was beyond the scope of this project, but could be worth investigating, especially if uniformity or bulb weights and quality develops an increasing premium. What this implies, though, is that proper seedbed preparation, soil structure and careful sowing is key for improving uniformity and reducing variability.

3.1.2 Is the plant population what is expected?

There are two aspects to consider with regards to plant population. The first is the evenness of plant spacing and affects the plant-to-plant variability. It is generally thought that crowded onion plants will tend to be smaller than plants that have a larger area of space and no very close neighbours. At the LandWise MicroFarm the average distance between plants within the row was 7.1 cm (± 3.1 cm), giving an average space per plant of 142 cm^2 (± 62 cm^2) that ranged from 15 to 280 cm^2. This variation in plant spacing only accounted for an 8% of the variation in bulb weight at harvest.

For any plant spacing less than 200 cm^2, bulb weights ranged from close to 5 to above 300 g (Figure 6), but for plants with an available space greater than 200 cm^2 tended to not have small bulbs, and only larger bulbs. These larger bulbs added to the variability and tended to be associated with the rows sown at the edges of the bed. Some growers already have the practice of reducing the within row planting distance of the outer bed rows to give more uniformity of bulbs. For the planting pattern used at the LandWise MicroFarm, reducing the within row planting distance to 4.8 cm in the outer rows would result in plants having a similar spacing as other rows in the bed, giving a small improvement in uniformity. If overall variability was reduced by 8%, then the CV of bulb weight at final harvest would be 35%.

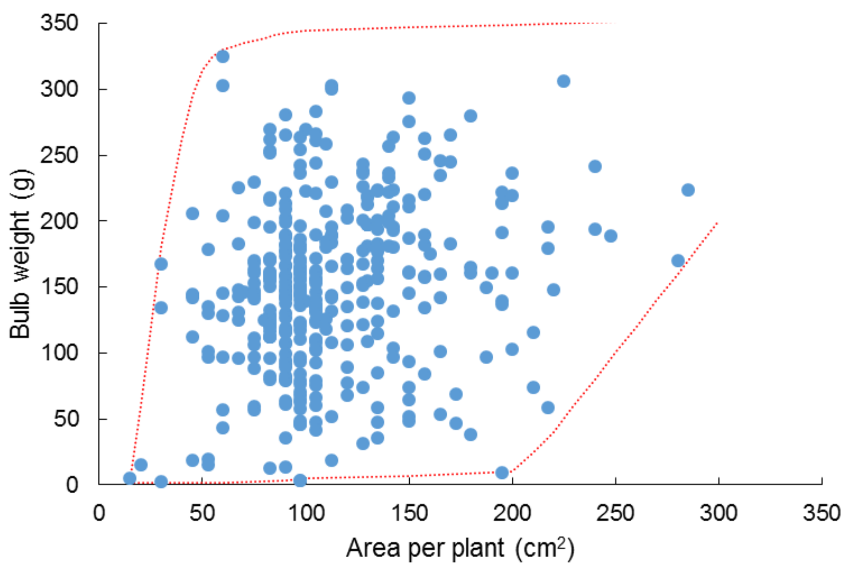

Figure 6. Bulb weight at harvest of plants grown at different plant spacing. The range of plant spacing was observed for a given planting regime of 8 rows on a 1.82 m bed, with an in row spacing of 7.1 cm (± 3.1 cm). Average row spacing was 142 cm^2 per plant. Red lines indicate potential maximum and minimum bulb weights when grown at with a given plant spacing.

Overall, the uniformity of plant spacing is not a significant factor affecting uniformity, but increasing the plant spacing variability by 1% will also increase the growth variability by 0.7% (Searle et al. 2014) because of plant competition. Thus, while the individual effect of plant spacing is not large, ensuring uniformity of plant spacing can result in better bulb uniformity.

The second aspect to consider is the established population. Where this population is below the target level there will be more variability in spacing between plants, leading to greater bulb variability and lower yields. As plant population decreases, yield tends to decrease in any case (see Figure 6), and a general rule of thumb is that for every decrease in population of 10 plants/m^2 below the target population, there will be a yield loss of 13 t/ha. This then affect the spatial variability in yield across a field.

There will be some variability in population occurring naturally in different sampling points of a field, due to the variation in plant spacing that occur. Based on the data obtained from different fields, it can be considered that if the population is 12% lower than the target, that some aspect has compromised the establishment of plants. Data from different onion fields monitored in the project show that many fields had lower populations than a target population (Figure 6).

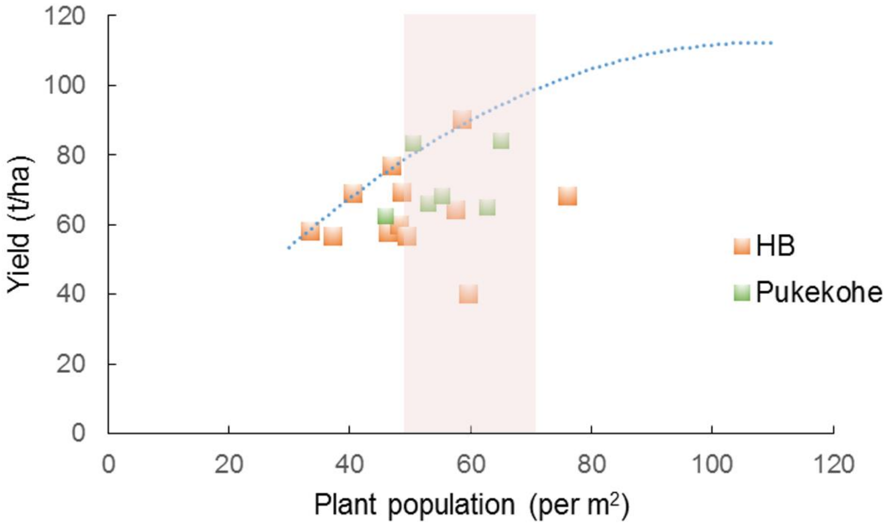

Figure 6. Yield – plant population relationship for onions. Dotted line is the potential yield for given plant populations. Points are for commercial fields used in Year 1 and 2 of the project grown in Pukekohe and Hawke's Bay (HB). Shaded area represents the target population range (target population ± 12%)

Factors that reduce the established population and can be identified by growers are:

- ***Sudden root decline.*** This occurs when the emerged seedling stops growing and dies off. It is associated with poor physiological maturity of seeds (Gracie et al. 2005), but these seeds do not normally form a large part of the seed population selected for sowing.
- ***Nematodes and Onion root fly.*** Nematodes and root fly maggots feed on the roots of seedlings causing seedling death, and can significantly reduce plant population. Often, roots are only stubs and have a 'grazed' appearance as a result of feeding damage. Appropriate insectices should be used to avoid this damage.
- ***Soil flooding.*** Onion seedlings are sensitive to water-logging in the root zone, resulting in significant plant loss and reducing the population. In some seasons, flooding will occur due to heavy rainfalls; appropriate drainage of soils is important for onion production.
- ***Soil water stress.*** If the soil dries out too much it can affect seedlings. A particularly sensitive phase is when seeds have initially imbibed water and the root begins to grow, but then the soil becomes too dry. This occurs approximately after 80 growing degree days after planting and is more likely to occur in later plantings. A light irrigation should be considered to avoid this.

3.1.3 Is growth as expected?

Variation in individual growth of plants caused 61% of the total variation in bulb weight at harvest. This growth rate variability is not something that can be controlled by growers. In general, heavier seeds will result in heavier seedlings (Searle & Tan 2017) but this is not the whole explanation. Causes for this growth variability remain unclear but are likely to be due to small differences in gene activities associated with photosynthesis, leaf expansion, efficiency of radiation use and other aspects of growth physiology.

The effect of this large variation in growth rate between plants can be seen in Figure 7. At any point in time, the weight of plants will range from close to zero to a maximum value depending on the time of growth. By 77 days, the plant fresh weight range is from 0.1 to 2.8 g (inset in Figure 7), and at harvest, bulb weights range from 5 to 350 g.

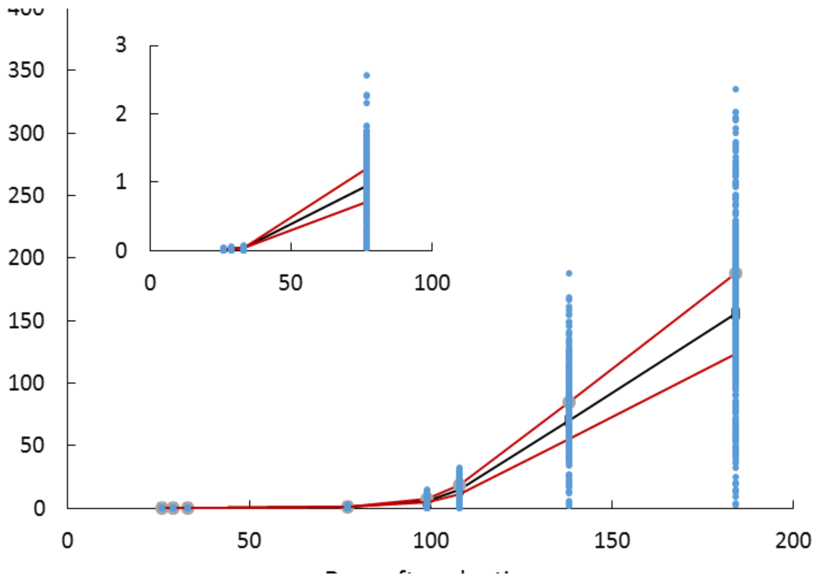

Figure 7. Onion plant fresh mass changes with time from planting for a crop planted at the LandWise MicroFarm site in Hawke's Bay in 2016. Crop grew at potential rate. Blue dots indicate individual plant fresh weights, black line is the average weight, and red lines are one standard deviation from the average. Inset shows plant difference in the first 77 days after planting (third leaf stage).

The crop in Figure 7 grew without limitations to growth, and average bulb weight was 153 g. If growth was limited by some factor we would expect the average weight of the bulbs to be less than 130 – the lowest value within one standard deviation from the average. Over the period of growth if the average is below the lower red line, then growth rate is limited by some factor.

When areas in fields with low yields were sampled (less than 50 t/ha), the weight ranges were similar to that when growth was at potential (i.e. ranged from approximately 10 to 350 g). So, even though growth was limited, the weight range of bulbs remained similar, but there were fewer large bulbs, and many smaller bulbs.

Causes for limitation to growth are many; growers tend to apply sufficient nutrients, maintain pest, weed and disease control so that these are not limiting growth. Causes of growth limitation observed over the course of the project were:

Inadequate irrigation

- Sometimes irrigation resulted in waterlogging in some areas in a field and these areas had lower yields. In large part this is a drainage or compaction issue in the soil that needs addressed.
- Allowing the soil to dry out during seedling establishment. Separate results (Searle) show that allowing the soil to dry to below 80% field capacity before the third leaf stage reduces growth by half. Even if there has been rain or a light irrigation during emergence, there may be value in a light irrigation early establishment.
- If the soil was allowed to dry (below a 50 mm soil moisture deficit) before irrigation was applied, yield tended to be reduced. Timely irrigation is important.

Soil compaction

- There was a 0.04 t/ha yield loss for every Newton increase in soil penetration resistance above 200 Newton. This level of compaction can be a result of previous year's wheel tracks, or from land preparation when the soil is too wet. Avoiding compaction is important for obtaining good onion yields.

Soil-borne pathogens are another factor that may limit yield and is being investigated separately (P Wright, personal communication); these may affect nutrient and water uptake during growth.

4 IMPLICATIONS OF PLANT-TO-PLANT VARIABILITY

4.1 Yield will be spatially variable

Within the current approach to growing onions, and due to the large variation in growth rate between individual plants, even when grown without any limitations there will be some variability in bulb weights of a crop – at least with a coefficient of variation of 38%. Even in a field with uniform soil conditions, this variability in plant weight will result in yield differences within the field, if nothing else due to sampling variation.

Using a CV of 38% we calculated the possible spread of yield within a uniform field when the average yield was 90 t/ha with an average bulb weight of 150 g and plant population at 60 plants /m^2 on 1.82 m beds. Using this mean weight and variability we constructed a population of 10,000 bulbs and selected a sample from it that corresponded to a 1 m^2 area. Over 1000 samples were collected in this manner. The resulting yield within a uniform field with no known growth limitations was from 50 to 135 t/ha (Figure 8). This means that there will be some spatial variability due to plant variability. Within commercial fields measured in this project, it was common to see yields varying from about 40 t/ha to over 130 t/ha, and samples of 140 t/ha were recorded in some fields. This raises the question of what is yield due to plant variability alone and what is the yield due to limitation in growth.

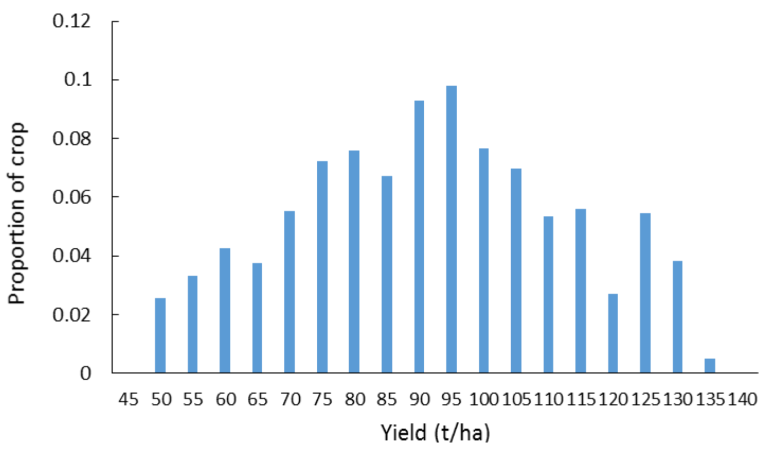

Figure 8. Estimated proportion of crop in different yields for a uniform field and a CV of 38% in onion bulb weight. Crop was set to yield on average 90 t/ha, with an average bulb weight of 150 g and a plant population of 60 plants/m^2.

4.2 Yield can be achieved in different ways

Spatially, yield due to plant variability should be randomly scattered through a uniform field, where as yield due to a limitation should be based in a given area associated with a factor limiting growth. Thus a yield map might give an indication of areas in the field where there are limitations. This can be particularly useful if a yield map can be collected early enough in the growth of the crop to inform management decisions.

However, across a field there will also be differences in plant population and that means that the yield in a given area can be achieved in different ways. An example is shown in Figure 9. Here the black line indicates the plant population and bulb weight needed to achieve a yield of 60 t/ha. There are different combinations of plant population and bulb weight that can achieve this yield, and some cases the yield is from bulbs growing at potential, and in other cases bulbs have not grown at a potential rate. Thus a yield map would indicate areas where the yield is 60 t/ha, but not necessarily indicate if that yield is caused by a limitation to growth.

This led to the development of the Management Action Zone approach to mapping variability in an onion field (Section 5).

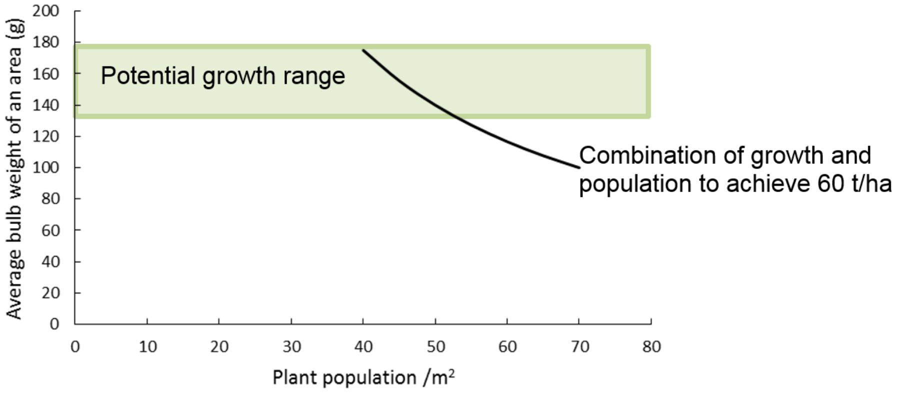

Figure 9. Combination of plant population and average bulb weight needed to achieve a yield of 60 t/ha (black line). The green shaded area indicates the where growth is at potential, indicating that the yield can be achieved by either crop growing at potential or below potential depending on plant population.

4.3 Increased plant variability reduces yield

Our results show that where yield is limited by growth rate, the range of bulb weights tends to be similar to the range when the crop is grown at potential (i.e. 10–350 g), but lower weight bulbs will form a greater proportion of the population. This will increase the variability and the CV value, and because of the greater proportion of lower weight bulbs, the yield will be reduced as well.

To estimate this we mathematically constructed a population of bulbs with a normal distribution where the average weight was 150 g and the variability of bulb weight had a CV of 38%. We set the plant population at 60 plants /m^2. Using this approach gave us a range of bulb weights from 10 to 350 g, and a yield of 90.6 t/ha. This population is an optimum uniformity and yield is at potential. We then assumed growth limitations resulted in lower average bulb weights, while the spread of bulb weight remained close to the range in the potential population (10–350 g), and estimated the CV% and yield for these growth limited populations. Plant population remained constant for all at 60 plants/m^2.

Using this approach we found that our estimated yield decrease was 1.26 t/ha for every 1% increase in CV above 38% (Figure 10; black line). This closely matched some observed data obtained from different commercial fields. Assuming a value of $450 per tonne, this equates to a loss of $568 per hectare for every percent increase in CV.

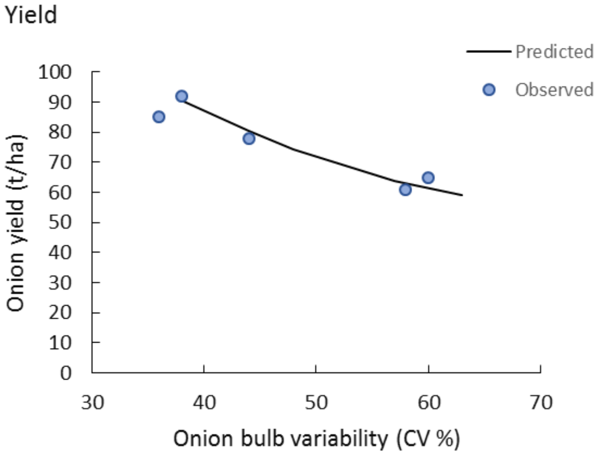

Figure 10. Increase in CV% of onion crops and effects on yield. Estimated response is indicated by the black line, and blue dots are observed values.

5 THE MANAGEMENT ACTION ZONE (MAZ)

5.1 Defining and mapping

The MAZ is an approach to provide a way of identifying and managing spatial yield variability in a field based on population and growth. This approach has a greater potential to better match management to a zone. Results summarised in Figures 8 and 9 indicate that a yield depends on different combinations of growth (easily measured by average bulb weight) and population. Using the results of Figure 9 as a basis, it would be useful to separate out an area of the field that yielded 60 t/ha but where growth was at potential from an area of 60 t/ha but where growth was below potential, and therefore some management may be implemented to improve yields. Our Year 2 experiments focussed on developing the measuring measurement methods to identify and map MAZ areas in fields.

To determine a MAZ knowledge is needed of growth and population of an area. If in that area growth is within the potential range, and the plant population is within the expected target range, then growth in that area is at potential and there is no need to apply management in that area of the field to improve outcomes. However, management can be applied to an area of the field to improve outcomes if either growth or population is less than the potential range for that area (Table 1).

To determine if growth is within the potential we have developed a tool using image analysis (details given by Bloomer and Searle (2018) to estimate the leaf area index (LAI)). The lower potential LAI was determined from individual plant leaf area from 2000 plants, and is one standard deviation less than the average LAI. If LAI measured via image analysis is below this, then growth is considered to be limiting. Population must be within 12% of the target population; if less than this it is limiting yield.

Table 1. Management action zones (MAZ) for different areas of a field based on yield and population being within a potential range. The MAZ defines areas in the field that may respond to management and improve outcomes. It also defines the type of management that may be needed — tactical, within season management or strategic system management.

Management Action Zone	Yield within potential	Yield below potential
Population expected	**MAZ 1** No management needed	**MAZ 3** Revise management (tactical management)
Population below expected	**MAZ 2** Increase population (strategic management)	**MAZ 4** Increase population and growth (review tactical and strategic management)

We have shown (Searle et al. 2017a; Searle et al. 2017b) that a sample at the three-leaf stage can accurately determine what the MAZ of an area is. This allows the field to be mapped and zones identified early in the growth, so that factors limiting growth could be evaluated and management actions decided on. By using the stage of the third leaf (the first three leaf tips, after the flag leaf are visible) to take the measurements to define MAZ, we are using the crop development to define the time scale of measurement. Leaf appearance is strongly dictated by temperature, and the potential leaf growth in these early stages is also strongly dictated by temperature, meaning that in non-limiting conditions the lower potential LAI is an indication of when growth is limited or not. Another approach to determining when the three-leaf stage occurs is to sue thermal time. The third leaf tip appears after 321 growing degree days from emergence. Thermal time should be calculated with a base temperature of 5°C.

5.2 Implementing management based on MAZ

In Year 3 we compared management in a MAZ1 (no growth or population limitations) and a MAZ3 area of a field (growth limitations). The limitation to growth in the MAZ3 area was identified as probably a lack of sufficient water in the early stages of seedling growth resulting in reduced leaf area. While this is a growth limitation, ensuring appropriate irrigation from then on does not greatly improve outcomes, when leaf area is already significantly reduced from water stress.

So, in this case we considered if N fertiliser could be reduced without affecting yield. This would make sense particularly if soil N in both areas was similar indicating that soil N was not a limiting issue. In this case soil N at the three-leaf stage (measured using nitrate test strips) was similar (Table 2) in the different MAZ areas. Standard grower fertiliser practice was used in MAZ1, and in MAZ3 we compared standard practice with a half rate of the standard rate.

The MAZ 3 areas had significantly lower yields than the MAZ1 area (Table 2), but the half rate of fertiliser applied in the MAZ3 area did not result in a lower yield than the standard fertiliser practice. Thus, it is possible to reduce the N rates in a MAZ3 area if soil N is not a limiting factor to growth, without affecting yield. This approach also tends to reduce the residual N in the soil left at harvest, and reduces N removed from the field. Interestingly, the standard fertiliser rate in the MAZ3 area gave higher rots after 3 months storage at ambient conditions, compared with no rots when half the rate of fertiliser was applied.

Table 2. Comparison of fertiliser and rate on onion yield, soil N content, N removal and rots in storage in different Management Action Zones (MAZ) of the same field. Zones were MAZ1 (no limitations to growth) and MAZ3 (growth limited area). Rots were measured 3 months after harvest and storage in ambient conditions. A half rate of standard grower fertiliser practice was used in MAZ3 for comparison.

	N management	Soil N at start (kg/ha)	Soil N at harvest (kg/ha)	N removed (kg/ha)	Yield (t/ha)	Rot (%)
MAZ1	Standard	36.4	43.2	121	54.9	2
MAZ3	Standard	39.2	59.2	107.9	45.6	4
MAZ3	Half	34.1	45.5	52.4	44.7	0
p value		p = 0.404	p = 0.15	p = 0.001	p = 0.006	p = 0.03
LSD		6.73	15.4	19.9	6.63	1.5

These results highlight that using MAZ helps identify appropriate management zones. Implementing appropriate management in these areas can help reduce input costs, and importantly help improve uniformity of bulb quality in storage.

6 SUMMARY

In this 3-year project we have identified how variability between bulbs develop in an onion crop, and how it affects yield variability within a field. We have used the coefficient of variation (CV) as a measure of variability between bulbs in an onion crop.

The most uniform crop that can be grown has a CV of 38% (±3%) for bulb variability. This is achieved for a crop grown in a uniform field with no limitations to growth. Growers have little chance to improve the uniformity, but factors that significantly increase the spread of emergence, plant spacing variability or limit growth will increase plant variability. This will also reduce yield. A key stage of growth to maximise uniformity is in the early stages of crop growth and before the three-leaf stage is passed. Key issues that increased variability and reduced yield in this project were soil compaction, flooding and insufficient irrigation in the seedling stage. We found that a 1% increase in CV% decreased yields by 1.26 t//ha.

To identify areas in a field with lower yields we developed the Management Action Zone concept, MAZ. We showed that using MAZ to decide on nitrogen fertiliser use gave better nitrogen use efficiency, reduced residual soil nitrogen that could be leached, and reduced rots in storage. Thus, use of MAZ can give better outcomes from a crop.

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