YIELD MAPPING

For potato growers, predicting yield, and determining paddock variations or disease occurrence, can be a guessing game. New technology that combines gaming algorithms with agricultural science might (literally) be a game-changer, writes Dr Jenny Ekman.

WHY MAP YIELD?

Every morning, when a hydroponic grower enters their greenhouse, they confidently scan a flat ocean of uniformly green, uniformly sized, and uniformly productive plants. Counting the size and weight of cucumbers in one section should, in theory, provide a good estimate of the yield from an entire half hectare glasshouse (assuming it is well managed).

Growing in soil however is a lot less uniform. Added to this is the challenge of a crop developing unseen, below-ground.

An apple orchardist can inspect size, quality, and quantity of fruits on trees. They can visually inspect and identify which areas of the orchard are less productive, have disease issues, or physical damage due to wind or hail.

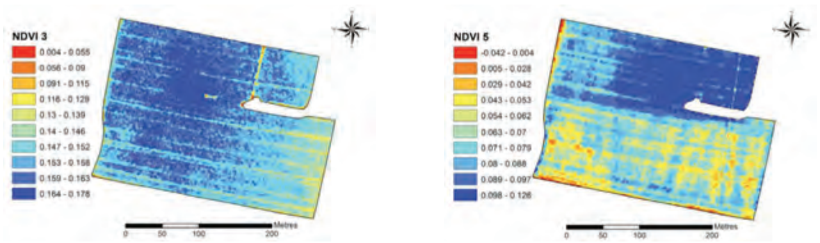
For the root crop grower, yield and quality are often first known at harvest. While every grower will have dug out a few plants here and there to look how the tubers are developing, extrapolating a few plants to a whole pivot is unreliable.

Associate Professor Brett Whelan, University of Sydney, is an expert in precision agriculture. In 2016 he completed a study (Project PT13000 Understanding spatial variability in potato cropping to improve yield and production efficiency) taking some of the lessons from grain and applying them to Tasmanian potatoes[1].

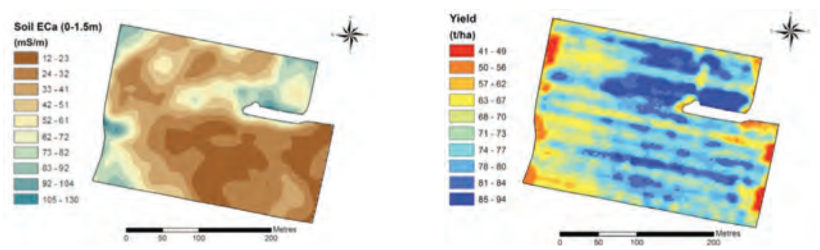
“We found that yield ranged from 28t/ha to 96t/ha, averaging around 64t/ha.”

“Such three-fold variations in yield within a paddock aren’t that unusual. We sometimes see similar results in grain crops."

"However, growing potatoes is expensive. At the time of our study the break-even point for potato production in Tasmania was around 42t/ha, so margins are extremely tight. Avoiding cropping unproductive areas could really help lift profitability of the whole crop.”



NDVI maps of a Tasmanian potato field taken 14 (left) and 19 (right) weeks after planting. Source: Whelan and Mulcahy, 2015



Apparent soil EC (left) and yield map (right) of a Tasmanian potato field. Source: Whelan and Mulcahy, 2015

Yield maps can help identify these unproductive areas, either for remediation or removal from production. The maps can also be used to examine changes over time, and the effects of different agronomic treatments where these have been broadly applied.

YIELD MAPPING FROM ABOVE

Canopy measurements can provide clues as to what is going on underneath. For example, the NDVI (Normalised Difference Vegetation Index) produces a measure of crop greenness.

Several researchers have used multispectral and hyperspectral satellite images to generate NDVI values. Machine learning models combine this with weather and irrigation data, plus previous local yield information to predict total yield.

The method has been applied to estimate potato yield in diverse environments, including Mexico[3], Spain, Bangladesh and even Saudi Arabia (Figure 1). These models can also be used to detect water or nutrient stress, estimate nitrogen use, and alert growers to areas of disease.

Many of these studies have also concluded that images taken during tuber initiation and bulking are more predictive that images taken later during crop development[2].

In Dr Whelans' study, they found that NDVI measurements corresponded well with yield when taken at weeks 14 and 16. The images were less predictive early in crop growth as well as close to harvest (week 19).

The researchers also examined the influence of elevation, soil texture and apparent electrical conductivity (ECa). ECa varied most in the top part of the soil and tended to be higher in low parts of the paddock. ECa was negatively related to NDVI, meaning the crop was often greenest at high points in the field, where ECa values were low.

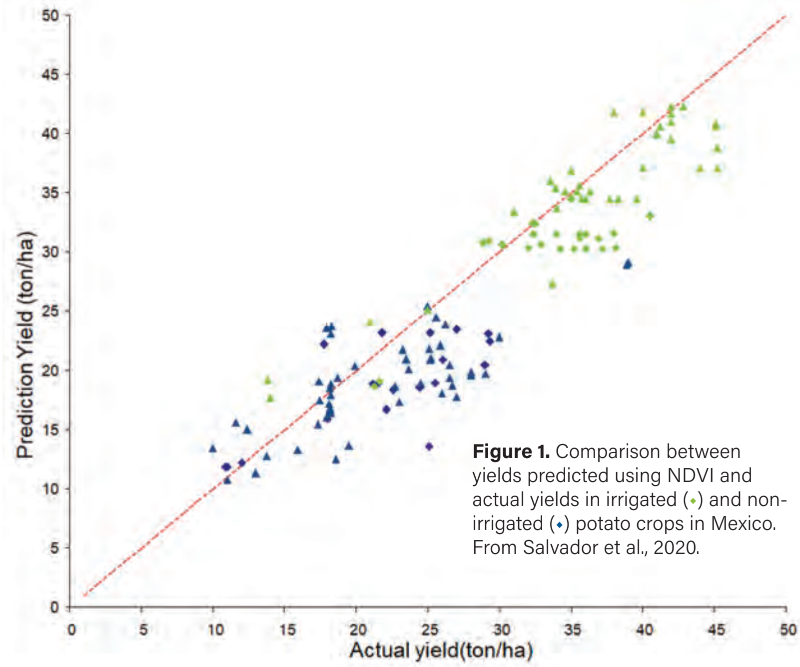
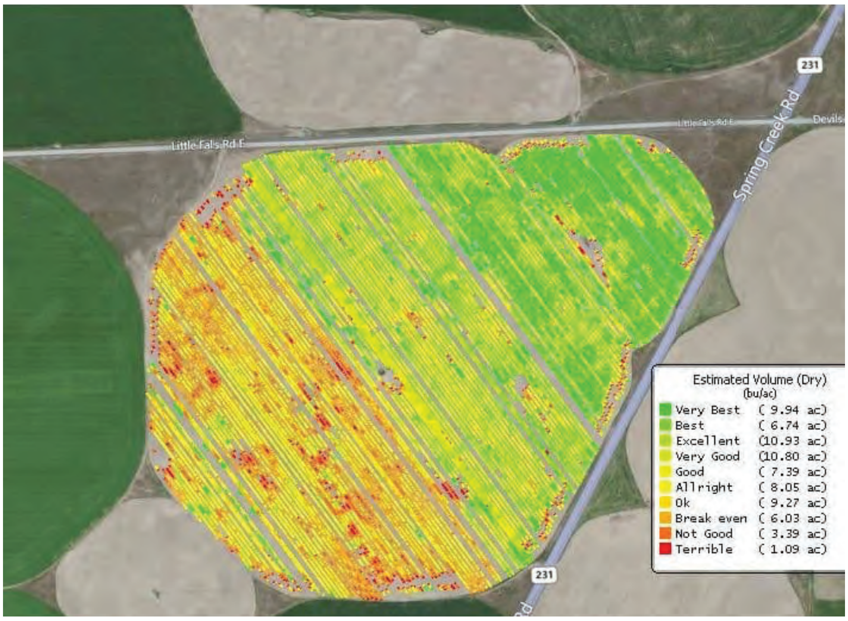


Figure 1. Comparison between yields predicted using NDVI and actual yields in irrigated (•) and non-irrigated (•) potato crops in Mexico. From Salvador et al., 2020.

Potato weight is usually recorded using a load cell on the harvesting belt. This is combined with GPS tracking data and conveyor speed to calculate total yield and generate a yield map.



Example of a harvest yield map created using a load cell system. Image by RiteYield (greentronics.com/products/riteyield/).

Despite this, only 36% of the crops studied had a statistically significant relationship between elevation and yield, with both positive and negative outcomes. In other words, none of these factors individually was a good predictor of yield.

YIELD MAPPING AT HARVEST

Pre-harvest estimates can be useful, but in the end there is no substitute for measuring potatoes dug out of the ground.

The most common method of measuring and mapping actual yield is using a load cell on the harvester machine. Data is combined with GPS tracking and conveyor speed, generating a yield map. Results may be viewed on a screen in the cab in real time and/or sent to the cloud for later analysis. Examples include

- The Casma Yield Monitor by HarvestMaster
- RiteYield by Greentronics
- YieldTrak by Topcon
- Advanced Technology Viticulture

Yield mapping using such systems is common for grain crops, and it has also been adapted to other mechanically harvested products, including tomatoes, grapes, almonds, and carrots.

Calibration of the yield monitor is one of the most important steps in ensuring data collection is accurate. It is not uncommon for the load cells to record weights significantly different to the actual weights recorded in bins. This can increase during harvest, as dirt builds up on the harvest belt.

For example, O'Halloran and van Sprang (2020)[4] tested the accuracy of yield monitoring of carrots. In this study, yield was consistently 20% lower than indicated by the load cell.

Calibration data for yield monitor. From O'Halloran and van Sprang, 2018.

Actual yield	Yield monitoring output (kg)	Accuracy
4043	5110	79
4161	5280	79
4074	5490	74
4202	5270	80

Project PT13000 also mapped yield using a load cell on the harvesting machine. Actual yield/paddock was compared with monitored yield. In 45% of fields the difference between the two was 3t/ha or less. However, in others it was 10 or even 15t/ha. In one paddock, total yield was underestimated by over 100T, a substantial difference.

According to Dr Whelan, load cells work well for grain crops. However, with potato crops there can be rocks and rejects, plus the tubers bounce around on the belt, making them harder to measure. He also noted that occasionally the harvester had to stop or backtrack, or even quit harvesting part way through a block due to weather or loading. All these factors make yield mapping far more difficult.

KEEPING AN EYE ON SIZE

When considering potatoes, it is not just yield that is important. The size and count of potatoes may often be a better indicator of crop value than simple tonnage.

Estimating the number of potatoes in different size bands effectively excludes unmarketable oversize and undersize potatoes from total yield. It can also help the grower determine the best markets, particularly if they have a mixture of contracted supply and 'freebuy' on the open market.

Understanding size and frequency may be particularly useful when harvesting seed.

"One of the biggest problems we have in managing seed supply is knowing what we have and where we have it," comments Abe Montano, Elders Sales Manager for seed potatoes.

"Knowing what size range we've got helps us market that as best we can."

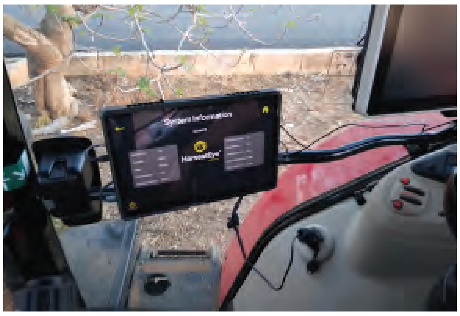
Relatively new to the market, the HarvestEye system uses a camera mounted on the harvesting machine to monitor incoming potatoes. Machine learning and artificial intelligence are used to detect, count, size and calculate per tuber weight.

Applying camera technology during potato harvest is far from simple. The cameras need to operate in a harsh, dusty environment with a shaking belt. Furthermore, the 'harvest' is not potatoes alone, but likely includes clods, rocks, roots, and soil. Nor are the potatoes in a convenient single layer but sometimes stacked and come in many odd shapes.

The HarvestEye system uses AI to identify and separate objects within a single image. Vidyanath (Vee) Gururajan from HarvestEye gives an example of how a computer can be trained to identify the number of cows in a herd.

"We use instant segmentation technology that can identify individual cows, rather than just blobs, using instance segmentation. The same machine learning principal can be applied to potatoes. This allows us to differentiate 'potatoes' from 'not potatoes', such as stalks, soil and the hands of workers," Vee explains.

"One of the biggest challenges is stacking. If there are several layers, the system may count something as a small potato when it is actually the top of a big potato. In this situation the system can be optimised for size accuracy. The size accuracy setting only uses clear images for size band distribution but uses the full count to estimate yield."



Instead of a load cell, the HarvestEye system uses a camera mounted over the belt, plus control panel in the tractor cab.

With thousands of potatoes streaming past the camera, the computer processing power needed is immense. According to Vee, the graphical hardware developed for gaming have proven a game-changer for this technology.

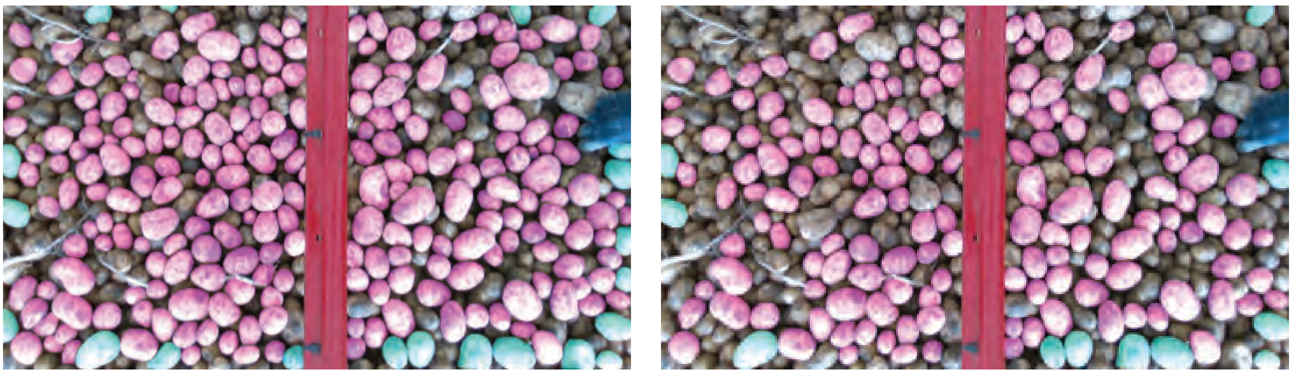
"This is what provides the computing power needed to process millions of pieces of data. The AI system has now been trained with about 2 billion data points, allowing it to accurately model weight from size."

While camera detection occurs on the harvester and monitored using a tablet in the tractor cab, most computing takes place in the cloud. The company claims that detection accuracy is 98% to 99.9%, while the per tuber sizing accuracy is around 98%.

The software allows the user to compare the number of tubers in each size band by year, by variety, and within different areas of the paddock. According to Abe Montano, using this data to decide the best variety for a specific location is a significant benefit.

"We can start to see the varieties that work best in different locations,

The HarvestEye system uses AI to separate potatoes within an image, then applies an algorithm to estimate size and weight.



Stacking is an issue for the HarvestEye system, as it is impossible to know whether what looks like a small potato is actually the tip of a much larger potato. To overcome this, the system combines the full detection image for count (left) with one that only records the size of clearly visible tubers (right). This size-band distribution can be used to estimate total yield.

The HarvestEye system can provide detailed information on tonnage by size band, as well as distribution of different sizes within the paddock.

especially in terms of marketable yield. It also helps with agronomy, working out which areas have been waterlogged, or underwatered, or where a spray has been missed."

The result may not only be better variety selection, but also understanding what parts of the farm need more input in terms of improving soil health, managing irrigation, or better plant nutrition. Alternatively, the grower may choose to cut their losses, and simply not grow potatoes in difficult parts of the paddock.

It may seem a long stretch from the virtual *World of Warcraft* to real life potato yields, however in this instance, farmers have the gamers to thank for significant technology advancements.

It is often said that you cannot manage what you cannot measure. With increasingly sophisticated tools available, growers can have more insight into costs and benefits than ever before.

LEARN MORE ABOUT YIELD MAPPING AND PRECISION AGRICULTURE

Webinar: Yield mapping with HarvestEye
https://bitly.ws/X7X6

Webinar: Precision Ag for the potato industry - Imagery is more than just pretty pictures
https://bitly.ws/X7Xd

Webinar: Precision Ag for the potato industry - practical soil mapping and adoption
https://bitly.ws/X2pQ

REFERENCES

1. Whelan B, Mulcahy F. 2016. Understanding spatial variability in potato cropping to improve yield and production efficiency. Hort Innovation Final Report PT13000.
2. Sun C et al. 2022. A review of remote sensing for potato traits characterisation in precision agriculture. Front. Plant Sci. 13:871859. doi: 10.3389/fpls.2022.871859
3. Salvador P et al. 2020. Estimation of potato yield using satellite data at a municipal level: A machine learning approach. Int. J. Geo-Inf. 9:343. https://doi.org/10.3390/ijgi9060343
4. O'Halloran J and van Sprang C. 2018. Yield monitoring in vegetables using load cells. Queensland Department of Agriculture and Fisheries Fact Sheet. HIA Project VG16009 Adoption of precision systems technology in vegetable production.