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# So, how did your potatoes grow?

It is frustratingly still possible to reach the end of a growing season and be unsure why a potato crop has not performed as well as expected. At the same time, potato yields can be highly variable, differing at field, farm and national levels. Whilst some of the variation in crop productivity is related to differences in the weather or differences in end-market specifications, much of it is unaccounted for, and likely contributes to the plateau in, national yields around 45 t/ha. One step towards reducing the unexplained nature of yield variation is to more closely monitor crop growth during the season. Yet this is challenging with potatoes and other root crops, since the saleable biomass develops beneath the soil. However, we are exploring how variation in above-ground growth during the season can help explain variation in yield, and also be used to predict yield before harvest by applying the NIAB CUF Potato Yield Model.

## Focus on canopy

As the most visible structure of the crop, the potato canopy can offer valuable insight into potato growth and variation. It is the site of both light interception and photosynthesis, fuelling further growth. There is a strong relationship between light intercepted and total biomass produced by a crop, which was first quantified by John Monteith in the 1970s. The Scottish scientist showed that, when well fertilised and with adequate supply of water, dry matter accumulated by a crop strongly correlated with radiation intercepted by the foliage in barley, apples, potatoes and sugar beet. Then later, good evidence for a linear relationship between total plant biomass and potato tuber yields was found across a range of potato cultivars, planted at a range of spacings and dates. This formalised the basic relationship which has long been known to underpin crop yields – that intercepting more light, enables more photosynthesis, greater crop growth and higher yields.

Multiple methods can be used to either measure or estimate light intercepted by crop canopies and the three most widely used are direct measurements with solarimeters or ceptometers, leaf area index (LAI) and percentage ground cover (GC). Each has the potential to record changes in the ability of the crop to intercept light throughout the growing season.

### Sarah Roberts, NIAB CUF Research Associate

Sarah has recently completed her PhD which focused on quantifying potato canopy growth. Funded by CUPGRA the research captured the effect of common changes in potato agronomy – such as plant spacing and planting date – upon whole canopy growth. She monitored field experiments across three years with destructive mid-season harvests to calculate leaf area index (LAI), which included many hours in a barn stripping leaves to collect that data. The conclusion that LAI was a poor predictor of the duration of near-complete canopy cover and yield, means that future experiments of this kind will not need to include the laborious measurements of LAI carried out here.

## Solarimeters and ceptometers

These metre-long light sensors can be installed beneath the canopy, at soil height, and detect the proportion of total light (all wavelengths; solarimeters) or photosynthetically active radiation (wavelengths 400-700 nm; ceptometers) which passes through the canopy. Yet this is an expensive way to measure light intercepted by a whole crop as each device is costly and samples only a small area, so the use of solarimeters and ceptometers is typically limited to small scale experiments.

## Leaf area index

Leaf area index is the total one-sided area of leaf material per unit of ground area. Initially in potatoes, increasing LAI directly increases light interception, then as leaves start to overlap (around LAI of 2) each new leaf contributes less to overall light interception. The proportion of total light intercepted increases after complete ground cover (approximately LAI of 3), maximising light intercepted around LAI of 4.

Leaf area index can be measured directly with destructive harvests (time consuming and labour intensive) or indirectly using image analysis software to calculate LAI based on light distribution within the canopy and the typical distribution of leaves within the canopy. However, the indirect methods were originally developed for estimating LAI in forest canopies and have not been optimised for potatoes, resulting in potentially misleading values.

## Ground cover

Canopy 'size' can also be represented by the proportion of bare soil covered by green (and photosynthetically-active) leaves in a given area. A range of different methods can be used to measure GC, ranging from the low-tech (hand-held grids) and small scale (smartphone apps) to farm-level drone and satellite-based image capture. Whilst photographic methods can dramatically increase the sample area, care needs to be taken with image processing.

Ground cover is the focus of the rest of this article since it has the greatest potential for widespread data capture – both in research and on-farm – due to the low data-input requirements and scalability of analysing data collected not only on the ground, but from low-Earth orbit.

## The output

Once the GC measurements have been taken, a curve is fitted and then used to describe growth, both across the whole season and for specific periods of growth (Figure 1). This allows field observations of differences in canopy cover to be quantitatively compared – determining both how large the differences are and whether they are significant. For example, early canopy expansion (between emergence and 25% GC) is faster at higher stem densities, but stem density tends to have little effect upon integrated ground cover (a summary variate, reflecting maximum GC reached and duration of canopy cover).

Differences in varietal canopy production can be seen and are linked to differences in yield (Figure 2). Canopy data can also be used to identify stresses upon the crop, for example soil compaction can have a severe stunting effect upon canopy growth, dramatically slowing canopy expansion (Figure 3) since the reduced rooting of the plants means that water and nutrient uptake rates cannot support rapid canopy growth. Waterlogged soil can also have a severe impact on both canopy growth and final yield and an extreme example is shown in Figure 4.

## Caveats

There are, however, other factors which can influence the relationship between intercepted light and final tuber yield. These include:

- Varietal determinacy – the propensity of a variety to continue producing leaves after flowering. There is greater initial investment in the canopy in indeterminate varieties, enabling longer canopy duration and potentially greater yields if the season is long enough.
- Nitrogen availability – most potato varieties respond to additional N by producing a higher canopy biomass. This can extend canopy life, but the season must be long enough to get a good 'return on investment'.
- Season length – duration in between planting and harvest. Harvesting a crop before canopy senescence

**Figure 1. Example fitted ground cover curve, labelled with calculated canopy descriptors. Raw data points in pale purple**

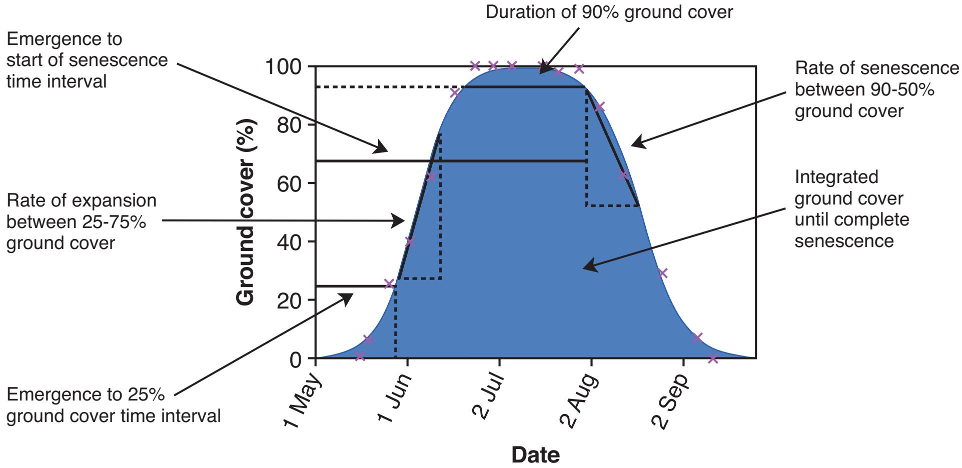



**Figure 2. Example ground cover curves. Mean GC values taken from 2018 plant density experiment. Mean total fresh weight tuber yields: Estima: 54.3 t/ha and Maris Piper: 64.1 t/ha**

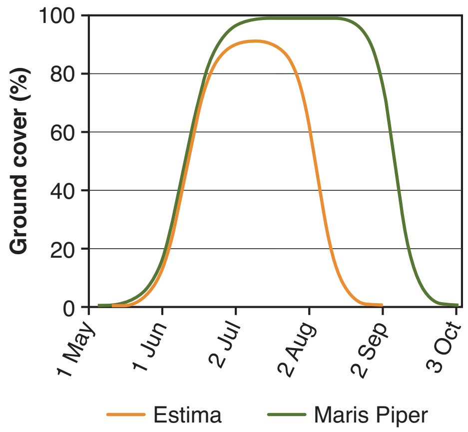
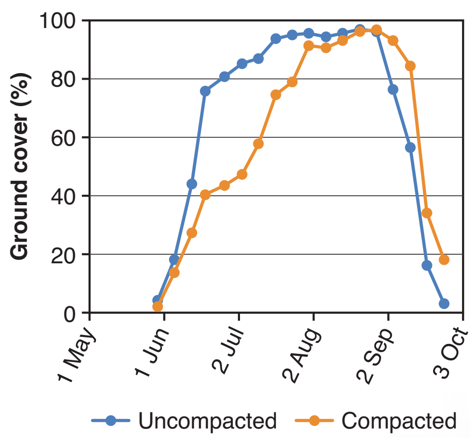



**Figure 3. Example of the effect of severe soil compaction on Maris Piper canopy growth. Mean total fresh weight tuber yields: compacted: 43.9 t/ha and uncompacted; 49.6 t/ha. Curve not fitted due to stunting of canopy expansion under compacted conditions**



prevents reallocation of resources within from the leaves to the tubers, so a greater proportion of the plant biomass remains in the canopy.

All of these factors influence crop harvest index (HI) – the ratio of total biomass to harvestable biomass. It is important to note that bigger canopies are not always best. Figure 5 shows that for both Estima and Maris Piper HI is lower at the higher rate of nitrogen applied at the early harvests, but that as the season continues the difference in HI between high and low nitrogen in Estima decreases before the gap in Maris Piper. This suggests that different varieties reallocate resources from haulm to tubers at different points in the growth season and that this occurs earlier in determinate (Estima) than indeterminate (Maris Piper) varieties.

A number of other factors (Figure 6), can also influence the relationship between intercepted radiation and yield, making it difficult to directly compare canopy growth and yield between different crops, but that once these have been accounted for canopy cover can be used to understand variation in tuber yields.

## Ultimate goal

By increasing the amount of data which can be collected from individual crops we hope to be able to identify the factors under grower control which, together, can result in the large amount of variation in yields between farms. Some of these differences will be accounted for by soil type, rotations, manure and nitrogen fertiliser use – factors expected to effect yield – but other variation is also expected to result from between-farm differences in practice, which have been shown to be a significant source of yield variation in the Yield Enhancement Networks (YENs) of other crops, such as wheat. In 2020, we worked with ADAS to pilot the Potato YEN, funded by WRAP and AHDB, giving growers a chance to benchmark their crops against similar crops and identify opportunities improve on-farm practice. Hopefully in the future the Potato YEN will allow more crop management data to be collected enabling us to identify further sources of variation in potato growth.

**Figure 4. The plot in foreground was heavily waterlogged throughout the season and produced a stunted canopy and correspondingly low yield. A Mid-season photograph of waterlogged (foreground) and non-waterlogged (background) plots. B Canopy development throughout the season of waterlogged (green) and non-waterlogged (blue) plots. Fresh weight tuber yields were 25.1 and 57.3 t/ha in waterlogged and non-waterlogged plots respectively**

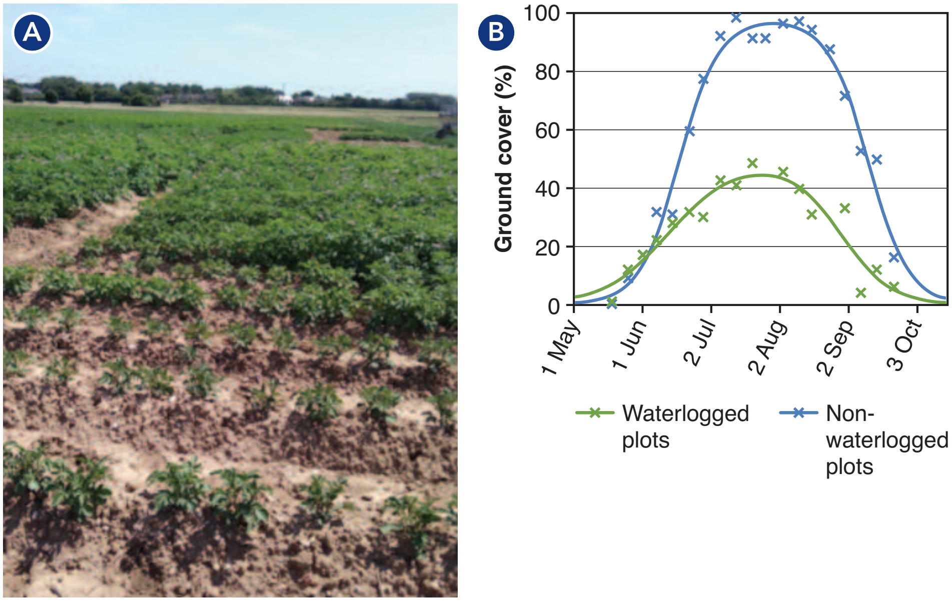



**Figure 5. Change in dry matter harvest index (HI) at harvests throughout the season, for both cultivars, at differing nitrogen rates. Error bars represent S.E. (27 D.F. for all harvests in both experiments, except H2, Expt 1 and FH, Expt 3, both 26 D.F.)**

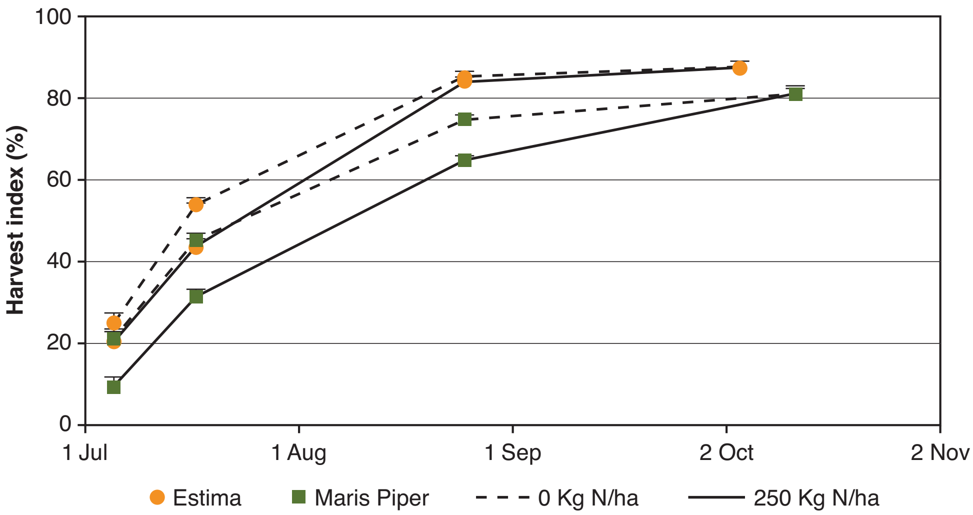



**Figure 6. Illustration of the link between canopy and potato yield, with canopy size modifiers and yield modifiers**

* Including degree of compaction, organic material, soil type and microbiology