

Potato yield forecasting from satellites

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Remote sensing has for long been used to assist producers in precision farming. It allows the monitoring of crop vegetation over large areas and enables the assessment of crop health and vegetation vigour, which facilitate timely management interventions, such as pest and disease control, fertiliser application, weed control, and irrigation. Satellite images can, for example, be linked to geographic information system (GIS) yield maps or soil nutrient status maps to identify and manage problematic areas in crop fields. Such interventions can improve crop growth and ultimately increase final yields.

Scientists are also using remote sensing for applications such as the monitoring of plant growth (aboveground biomass production, canopy cover percentage, and leaf area index estimation), assessment of plant water and nitrogen status, and crop yield prediction. The value and uses of satellite imagery are therefore endless.

Accessibility for farm use

Currently, satellite images are more freely available and affordable to end users, expanding their potential uses even further. For example, the visit interval of the two Sentinel satellites is once every five days, which means that images are now more readily available and therefore could possibly be used for more in-season crop management decisions.

In a previous *CHIPS* article, we reported on various available satellite indices and how such indices may potentially be used as on-farm management tools. Examples include

the normalised difference vegetation index (NDVI), leaf area indicator (LAI), photosynthetic activity index (PAI), and moisture stress index (MSI).

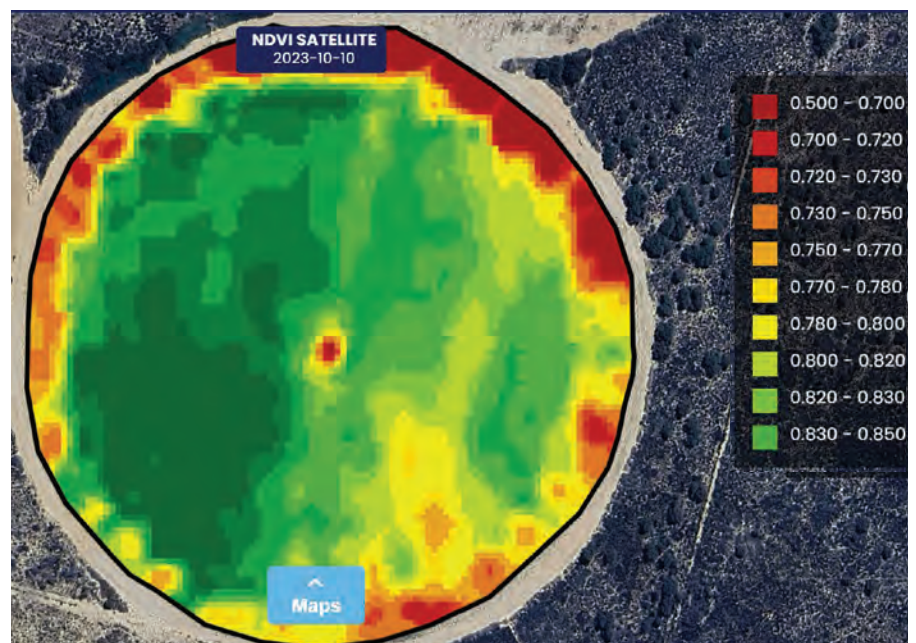
These satellite-derived indices have since been extensively evaluated on farms in various potato production regions, such as Limpopo, the Sandveld, and the Western Free State. From that study, we concluded that only some of these indices have the potential to become useful tools for on-farm management of potato crops for various reasons.

For example, PAI provides an indication of the intensity of greenness of crop foliage and has been proposed as a tool to manage nitrogen (N). However, we discovered that although PAI values do respond to changes in crop colour, they are also affected by many factors other than plant N status, such as heat and drought stress. Similarly, MSI responds to severe water stress, but the index

responds too slowly in periods of mild water stress, which may already lead to yield losses in drought sensitive crops, such as potato.

Despite the limitations mentioned, some indices showed potential for use as tools for management decisions in applications, such as early yield forecasting and irrigation management. The most commonly known crop indicator is normalised difference vegetation index (NDVI), which has shown potential for the development of management information on both the farm and at higher levels. For example, at farm level, NDVI can be used to estimate canopy cover at any stage, which can be useful for estimating daily irrigation requirements, if it is used in conjunction with other inputs such as daily weather data.

At regional or national level, it has been shown that NDVI can be used for remote identification of crop types.



An example of an NDVI image of a potato field.

This can be useful for estimating the areas planted to a specific crop and to estimate the planting dates of those crops in a specific production region. Furthermore, recent research has also shown that NDVI can be used to assess crop canopy growth and development, which can help to make early yield estimations for a specific potato crop.

Canopy growth & yield estimations

NDVI is an indicator of crop health and vigour, and is primarily defined in terms of the density of green vegetation of a crop. This indicator is strongly influenced by the fraction of soil that is covered by vegetation and the chlorophyll content of leaves. A high (NDVI > 0.70) index value indicates healthy and actively growing vegetation, whereas the opposite is true for low (NDVI < 0.50) index values. The NDVI of a cropped field normally ranges from 0.2 just after emergence to approximately 0.85 at full canopy cover.

NDVI is directly associated with aboveground biomass and previous research has shown good correlations between crop canopy size (for example green canopy cover, leaf area index and the fractional interception of solar radiation) and NDVI. It is also known that a well-developed canopy that completely covers the soil surface for long periods is needed to ensure high yields. Therefore, it is possible to make early yield estimations from canopy size measurements (actual in-field measurements or from remote sensing) during the crop growing season.

According to the literature, previous attempts have indeed been made to establish empirical relationships between potato yield and remotely sensed satellite-derived vegetation indices, such as NDVI and soil-adjusted vegetation index (SAVI), with varying levels of success.

Estimations in action

Consequently, a study was conducted on selected commercial potato farms in Gauteng and the Western Free State to assess

the viability of making crop yield estimations from remotely sensed data during the crop growing season. Detailed ground measurements and satellite remote sensing observations were conducted in eight fields in these two regions during the summer season.

To measure the crop growth and canopy state variables, including leaf area index (LAI), fraction of intercepted photosynthetically active radiation (fiPAR) and green canopy cover (GCC) percentage, four points in each field were marked. Destructive harvesting of potato plants was performed around each marked point every three to four weeks until vine kill-off and final tuber yield was determined at harvest. A total of 28 yield points were sampled across all fields.

Sentinel-2 time-series NDVI data for each marked point in each quadrant of all fields were obtained from GEOTERRAIMAGE (*geoterraimage.com*). To determine the most optimal time for accurate tuber yield prediction using NDVI, mean NDVI values for various ten-day periods between emergence and 105 days after planting (DAP) were correlated with the final tuber yields. In addition, the mean NDVI for the entire season was correlated with the final tuber yield.

Empirical linear equations generated between seasonal mean NDVI and final tuber yields for the entire season were validated using independent data sets from the Sandveld and Limpopo potato production regions, comprising a total of 63 potato fields.

Yield forecasting results

Tuber yield was correlated with the ten-day mean NDVI values observed from potato emergence (approximately 23 DAP) until the crop was killed off (±105 DAP). The degree of agreement (correlation coefficient, R²) between tuber yield and NDVI showed an increasing trend from emergence to vine kill-off (*Figure 1*). The highest R² values ranged between 0.76 and 0.80 for correlations between final tuber yield and ten-day mean NDVI values observed between 66 and 105 DAP, suggesting that the accuracy of yield forecasts improved as the season progressed.

The empirical linear regression functions between actual final yields and mean NDVI values over the different ten-day periods from 66 DAP onwards are presented in *Figure 2*. These results imply that already during the growing season and weeks before harvest,

Figure 1: Variation in correlation coefficient (R²) of the regression analysis between potato yield and NDVI during the growing season.

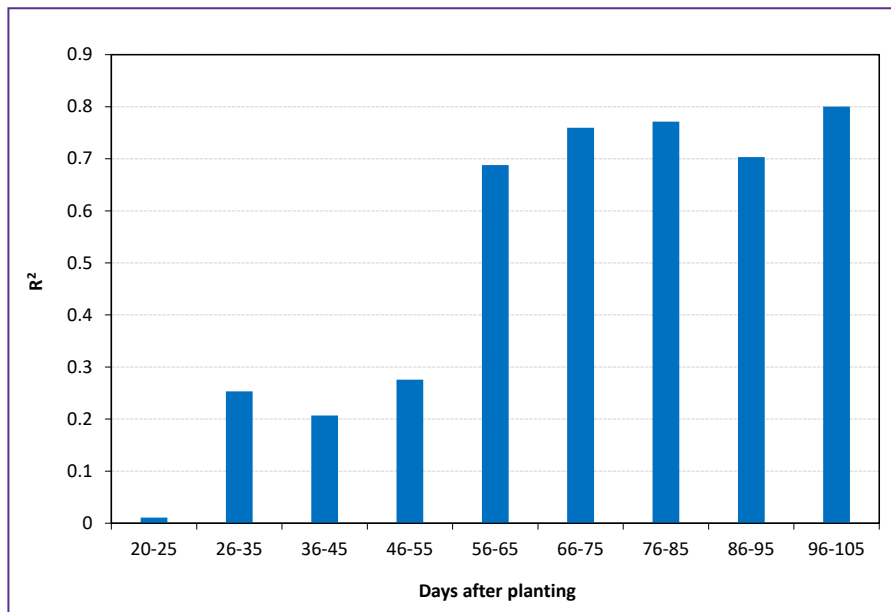
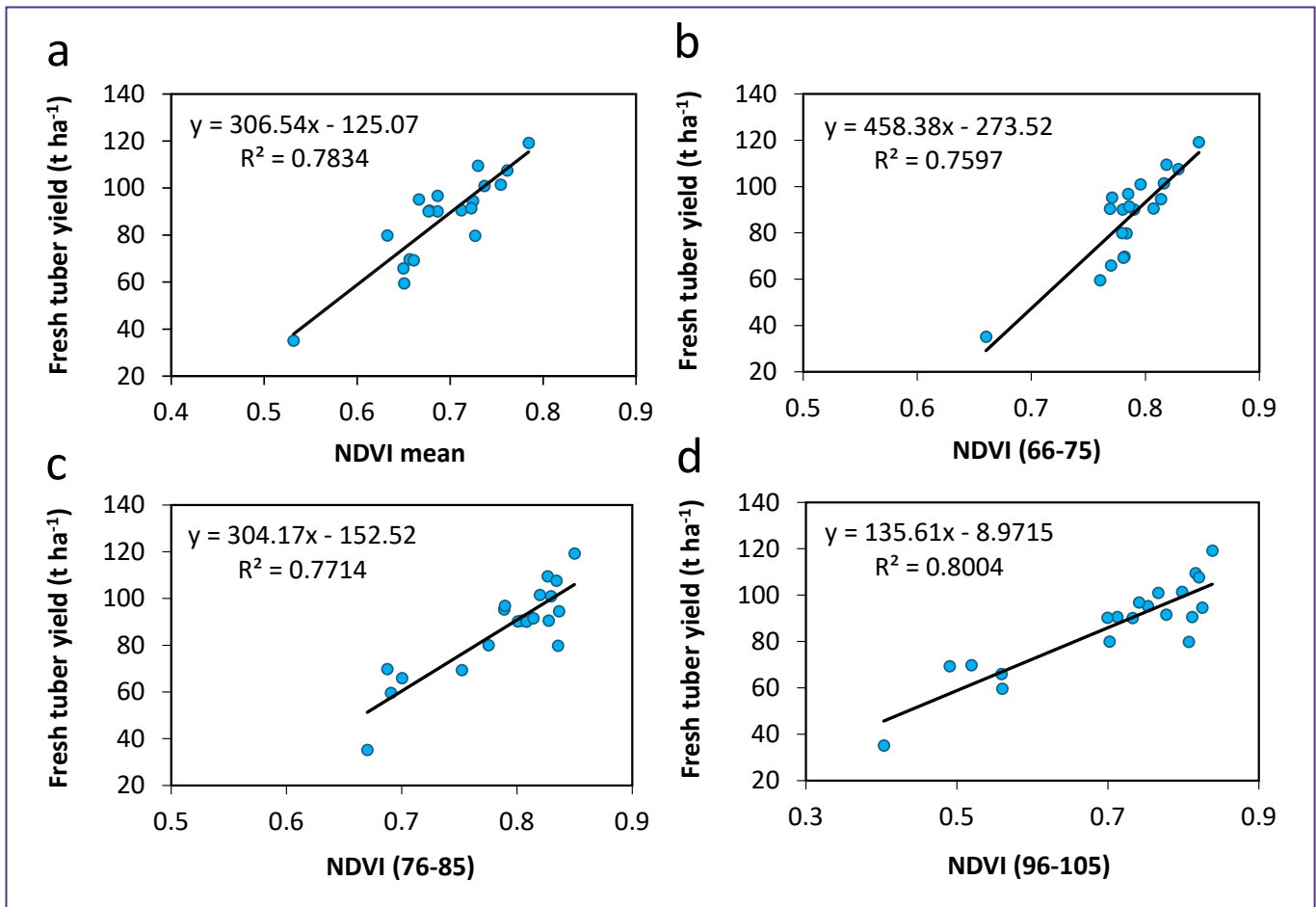


Figure 2: Linear regressions between tuber yield and mean NDVI values for various ten-day periods observed between 66-75 DAP (a), 76-85 DAP (b), 96-105 DAP (c), and seasonal mean NDVI (d).



potato yields can be estimated with reasonable (76 to 80%) accuracy from the ten-day mean NDVI values observed as early as 66 to 75 DAP. The correlation between potato yield and seasonal mean NDVI (between 20 and 105 DAP) for all fields also gave good results, with a correlation coefficient (R^2) of 0.78.

Multiple linear regression (MLR) models were also fitted to the data using mean NDVIs for the various ten-day periods observed between 56 to 105 DAP, as well as the seasonal mean NDVI and five independent variables, including N, P and K fertiliser rates. The best MLR models had R^2 values greater than 0.80, suggesting that yields may also be successfully estimated by including variables such as fertiliser application rates.

Both the linear and multiple linear regression equations predicted the observed yield of independent data

sets with acceptable accuracy, with R^2 values greater than 0.75. These results show that NDVI-based equations have the potential to provide accurate yield predictions of potato already relatively early on during the growing season.


Conclusions and recommendations

Linear and multiple linear regression models based on NDVI values observed during the potato crop growing seasons showed the potential to predict tuber yield with acceptable accuracy (more than 75% certainty). The results further suggest that reasonably accurate tuber yield predictions from NDVI can already be made from as early as 66 DAP.

Although the generated empirical yield prediction equations showed acceptable accuracy under the conditions of this study, the equations may provide different accuracies for different cultivars and under different

production conditions from those observed during the current study. Therefore, further testing of the generated equations under various production conditions will be required to ascertain their transferability and robustness. Future work is recommended to also investigate the inclusion of a mechanistic crop growth model for a universal approach to accurate yield forecasts.

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