FRUITLOOK: A SPACIAL APPROACH TO ASSESS AND IMPROVE WATER USE EFFICIENCY OF VINEYARDS AND DECIDUOUS FRUIT ORCHARDS IN SOUTH AFRICA

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Abstract

Water is a critical resource, which challenges the irrigated agricultural sector to explore innovative solutions to improve the use thereof.New technologies developed, using satellite data, show the spatial and temporal variations of the actual crop water use, growth parameters and nitrogen content at field level and helps farmers to improve their production and reduce the inputs and associated costs.FruitLook uses this technology to offer weekly updates for grape and deciduous fruit producing areas in the Western Cape through the web-portal www.FruitLook.co.za.All users, such as farmers, researchers and farmer advisors could evaluate the service for free during the irrigations season of 2011/12 to 2014/15.

FruitLook makes use of a processing framework that utilises a number of algorithms (e.g. MeteoLook, SEBAL) and satellite (DMC, Fengyun, MSG) and field data (weather) to produce data maps of nine parameters related to crop water use, growth and mineral content.

The accuracy of the parameters, specifically evapotranspiration, is important.Field work was done to estimate the evapotranspiration and was used to determine the data accuracy and further improve the algorithms.

FruitLook is a demonstration project funded by the Western Cape Provincial Department of Agriculture. In the past the Department of Agriculture Forestry and Fisheries (DAFF) and the European Space agency (ESA) have also contributed towards the cost of the project.

Background

In South Africa, a wide variety of driving forces is leading to new claims on water, enhancing the competition for water between users (agriculture, urban sector, industry). Moreover, the National Water Act (1998) states that water should be used efficiently. It firstly has to be reserved for basic human needs and for protecting aquatic eco-systems, meaning that agriculture has received a lesser priority than before. Due to a general lack of water resources in semi-arid and arid zones of the Western Cape, and the fact that basic human and environmental requirements need to be met first, water is an increasingly scarce input in agriculture.

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The fruit producing sector is the major contributor to agriculture in the Western Cape Province of South Africa and includes table and wine grapes as well as the various fruit crops produced. The challenge is to increase agricultural production while reducing water consumption – increase the water use efficiency (kg of produce per m^3 of crop water use). The challenge is to determine the actual evapotranspiration (ET_{act}).

SEBAL technology

Information on crop water consumption is difficult to obtain. Field measurements are expensive and do not show the spatial variation. WaterWatch, a company in the Netherlands developed the Surface Energy Balance Algorithm for Land (SEBAL) technology to calculate the evapotranspiration and water use efficiency of crops through sophisticated remote sensing algorithms.

The Surface Energy Balance Algorithm for Land (SEBAL) model estimates energy and evapotranspiration fluxes from earth observation data at different spatial scales ranging from field to entire catchments. SEBAL has been applied extensively across the world, also in the Western Cape from 2004-2015.

SEBAL involves a set of equations in a strict hierarchical sequence to convert the spectral radiances measured by satellites into estimates of the surface energy balance. SEBAL is based on the simplified energy balance of a surface. Inputs on land characteristics and atmospheric properties such as the vegetation index, surface albedo, surface temperature and cloud cover are derived from satellite data. In addition to the satellite data, SEBAL requires spatially extrapolated meteorological data (wind speed, humidity and air temperature) from local weather stations. SEBAL determines actual and potential evapotranspiration on a pixel-by-pixel basis. Besides crop evapotranspiration, SEBAL estimates biomass production, evapotranspiration deficit, leaf area index and the biomass water use efficiency. In combination with yield data, it can be used to determine the water productivity.

The energy balance of a surface is generally described by

$$LE = Rn - G - H$$

where Rn is the net radiation, G the soil heat flux density, H the sensible heat flux density and LE the latent energy flux density (Figure 1). The latent energy flux density is equivalent to the actual ET from a surface. Both the SEBAL model and the eddy covariance system, estimates all these components of the energy balance and the resultant ET

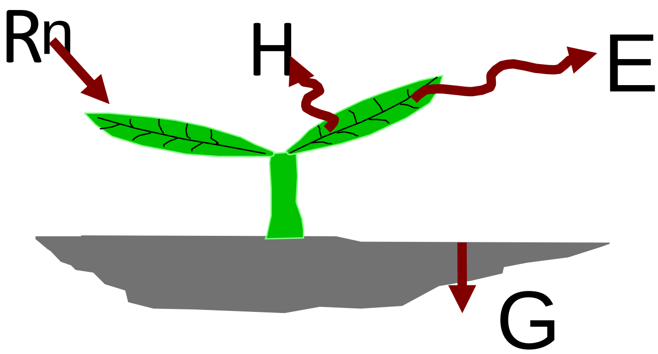

Figure 1: An illustration of the energy fluxes from a surface as used in the SEBAL calculations

Crop nitrogen status is not estimated with SEBAL, but can be determined from the reflectance in the green, red and near infrared spectrum, which are input data to SEBAL. As a result, the nitrogen status can be determined from various satellites' data including HJ-1A, HJ-1B, ASTER, Landsat-7ETM and DMC.

GrapeLook project

Through a retrospective study undertaken in 2008 WaterWatch assessed the application of remote sensing data to optimise irrigation water use of vineyards in a part of the Western Cape Province for the period 2004 to 2007. Irrigators indicated interest in the project and the results, but as the results only became available at the end of the study period, the practical application of the data to assist irrigation management on farm level were not possible.

This led to a real-time demonstration project, called GrapeLook, which was launched for the 2010/2011 irrigation season. The objective of the project was to provide information on a weekly basis to irrigators of grape vineyards to assist them with irrigation and fertiliser management. The project (www.GrapeLook.co.za) provided weekly updates for the period 1 September 2010 to 30 April 2011 for the majority of table and wine grape producing areas of the Western Cape. Information relating to crop water, growth (bio-mass) and nitrogen status was made available using satellite technology

Objectives of GrapeLook project

The objectives of the project were to:

- To use an innovative tool (remote sensing) to increase agricultural production while reducing water consumption, i.e. to sustain and increase grape production with the limited available water resources

- Provide weekly updated information on parameters such as evapotranspiration, evapotranspiration deficits, biomass produced, water use efficiency of biomass production, leaf area index and crop nitrogen status for individual irrigation blocks;

- Provide a forecast of soil moisture change over the five days after satellite image acquisition (to the participating farmers only);

- Disseminate this information through the GrapeLook website to all (farmers, irrigation consultants, etc.); and

- Provide farmers and other users the opportunity to evaluate the benefits the operational service.

The potential benefits of the project to farmers were to:

- To increase sustainability and economic viability of irrigation farming enterprises

- To schedule and monitor irrigation while aiming for sustainable resource management, i.e. development and implementation of on-farm irrigation strategies.

- To determine nitrogen use and actual crop nitrogen needs (to optimize fertilizer applications and to combat over-use).

- To reduce nitrogen leaching into streams and groundwater systems.

Information provided

The field data provided calibration and validation information to assess the outputs of the SEBAL algorithms. Soil moisture measurements was recorded on a continuous basis at various depths in seven grape blocks and submitted to the framework and provided a better insight in how IrriLook,an irrigation advisory tool developed by WaterWatch, that provides 5-day forecasts on soil moisture in the root zone was performing. An Eddy Covariance system in a table grape block in Hex River valley provided information to evaluate the SEBAL estimates on energy fluxes.

A group of participating farmers received forecasts on soil moisture and irrigation water requirements on a weekly basis on block level in graphs. See Figure 2 below. Additional to the website, which was accessible to anyone, a SMS service was set up for the participating farmers. These farmers received regular SMS messages on their cell phone with specific information on one to three irrigation blocks. The SMS service was also used to inform the farmers about upcoming meetings and workshops.

The following information was provided through the GrapeLook website:

Growth parameter	Unit
Growth	
Biomass production	Kg per ha per week
Leaf Area Index (LAI)	m^2 leaves per m^2 soil
Vegetation Index (NDVI)	
Moisture	
Actual evapotranspiration	mm per week
Evapotranspiration deficit	mm per week
Crop factor	
Biomass water use efficiency	Kg per m^2 of water
Minerals	
Nitrogen content in all leaves	Kilogram per ha

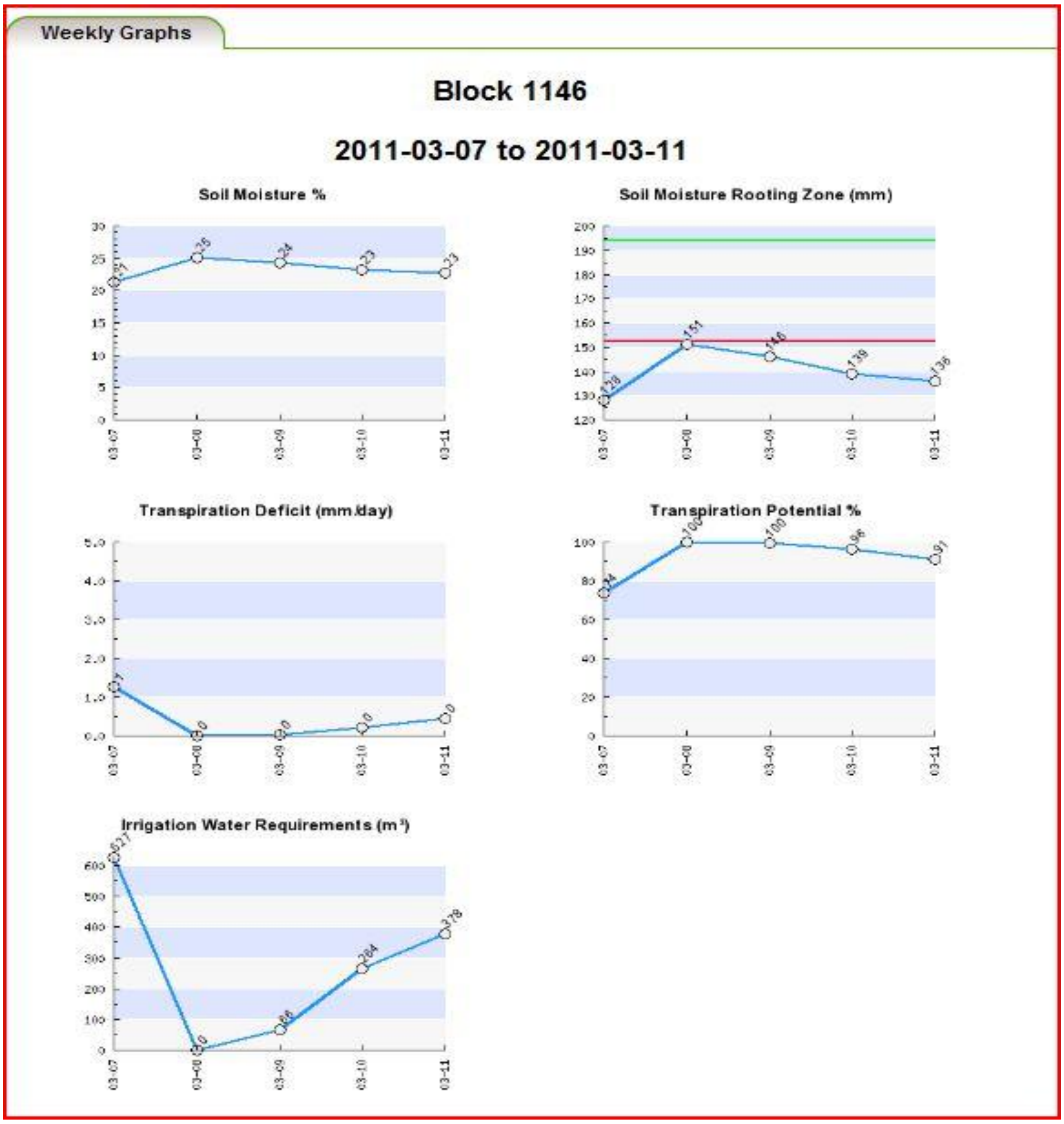

Figure 2: Soil moisture and irrigation requirements provided to participating farmers weekly

Key lessons learnt

The objective of the GrapeLook project was to demonstrate an operational service to users in the Western Cape Province. Should this be successful, the service could be provided to all irrigation areas in South Africa. The following key lessons were learnt:

- An operational service should be reliable in terms of data quality and delivery. There should therefore be alternatives for all input data. For example, it cannot rely on one satellite source as satellites may break down. The development of a 'multi-satellite framework' that works on different satellite sensors can be used to spread the risk
- A system such as GrapeLook requires a framework in which all data is processed similarly and procedures are automated where possible to avoid (human) errors and ensure constant data quality.
- Existing algorithms require continuous calibration and validation. The validation of SEBAL with Eddy Covariance measurements resulted in an improved SEBAL version.

- The success of dissemination of information is strongly correlated with user friendliness, the speed of the website and the availability of a reliable and effective internet service to irrigators in the rural areas. During the demonstration project, a number of measures were taken to increase the website speed, such as subdividing the data into regions to reduce the data load, the removal of small blocks in the soil moisture forecasts and hosting the website data on a faster server. A website with a registration feature (login) will reduce the data transfer size considerably
- The quality of the service provided is very important as farmers question the accuracy of the data. The calibration and validation of the models/algorithms used with in-situ measurements can contribute towards user acceptance of the data provided

The project was funded by the Western Cape Provincial Department of Agriculture with financial support from the Department of Agriculture, Forestry and Fisheries and the European Space Agency. The project was executed by WaterWatch in collaboration with the University of KwaZulu-Natal (UKZN), responsible for field word required to validate the SEBAL generated data.

FruitLook project

The positive response received from grape farmers and irrigation advisors on the GrapeLook project resulted that the project were continued in the 2011/12 irrigation season and extended to cover all fruit crops in the area covered by the satellite image.The project (www.FruitLook.co.za)provided weekly updates for the period 1 October 2011 to 30 April 2012 for the majority of the fruit producing areas of the Western Cape. The project was then repeated for the 2012/13, 2013/14 and 2014/15 irrigation seasons to allow users the opportunity to evaluate the data provided through the web portal.

Objectives of FruitLook project

The main purpose of FruitLook was to provide farmers with an improved knowledge with regards to the temporal and spatial variations on their farm. During workshops and farm visits, farmers received training, e.g. on how information on the spatial variability allows high precision water and fertiliser management and reduces the number of field visits and field samples required. The weekly updates show when blocks need pruning to control vigor, show delayed grow, and identify problems with their irrigation system at an early stage. Comparison of the different parameters between and within seasons helps evaluating farm management practices. FruitLook services provide data on the irrigation efficiency and thus contribute towards improving the water use efficiency (kg of crops produced per m^3 of irrigation water used). It can also assist with reducing labour and input costs, increase product quality, yield and profits.

Changes to web site

In GrapeLook (the 2010/11 season), the end-users could view all the spatial datasets at once through the web portal and navigate to their area of interest. The drawback was that data download of these entire datasets was slow and hence discouraged users of revisiting the website. A strong requirement therefore for the FruitLook was increased website speed to make the data available to all, also users with slow internet connections. For this reason the data portal FruitLook.co.za was created for the 2011/12 FruitLook season. The following major changes were made to result in a faster and more accessible website:

- Reduce the amount of data downloaded and required to see the parameter maps: Due to the user login and area of interest delineation system, only relevant data is downloaded onto users' computers, which greatly improves the speed at which the website operates;

- Reduce general data download from the website by giving minor importance to design: The website speed was improved by simplifying the website design. For example round corners have been removed, as well as shadowing effects.
- During the 2014-15 season multiple changes have been made to the FruitLook platform to improve the user experience. This includes the introduction of a new order system based on predefined field shapes, an easy re-order process of data based on field boundaries from previous seasons and a function to delete fields from an account. An updated version of the FruitLook manual has been made available via a prominent button on the FruitLook website. Furthermore monthly newsletters have been disseminated to inform subscribers on FruitLook news and explain the use of the FruitLook parameters in farm management. In total 989 individuals receive the FruitLook newsletter.

Information provided and potential value adding to farming practices

The special variation that can occur in an irrigation block might indicate an irrigation system that is not delivering a consistent amount of water throughout the irrigation block, an adapted irrigation might be required to meet the soil type variations, plant diseases that impact on biomass production and thus evapotranspiration. See Figure 3 below. A study of all the parameters on which information is provided will assist to get to the reason for the special variability within the irrigation block.

The interpretation of the information provided assists farmers to make management decisions relating to the utilisation of resources such as water and fertiliser. This can result in reduced input costs, improved production and product quality and reduced pollution of water streams and rivers due to a reduced irrigation return flow.

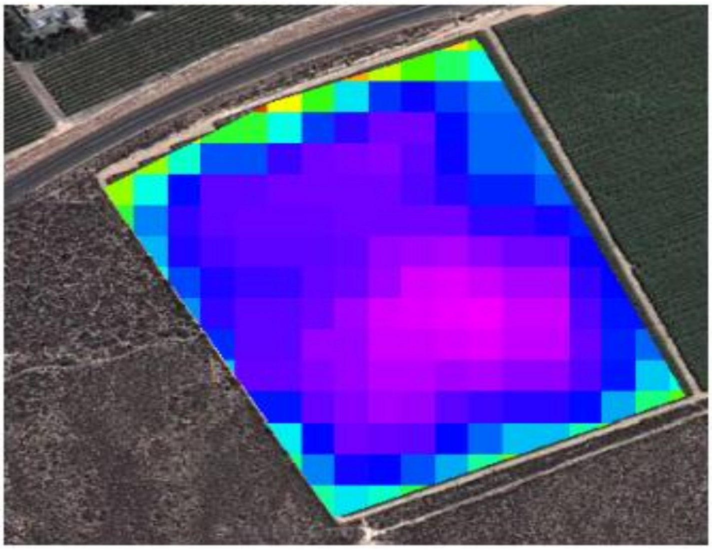

Figure 3: Spatial variation of actual evapotranspiration of an irrigation block

The information can also be used by the Water Users Associations (WUA) to manage the water utilisation at an irrigation scheme level, whilst the farmers will only be interested on the farm level utilisation. Figure 4 provide information of the actual evapotranspiration of a certain area within a WUA control area.

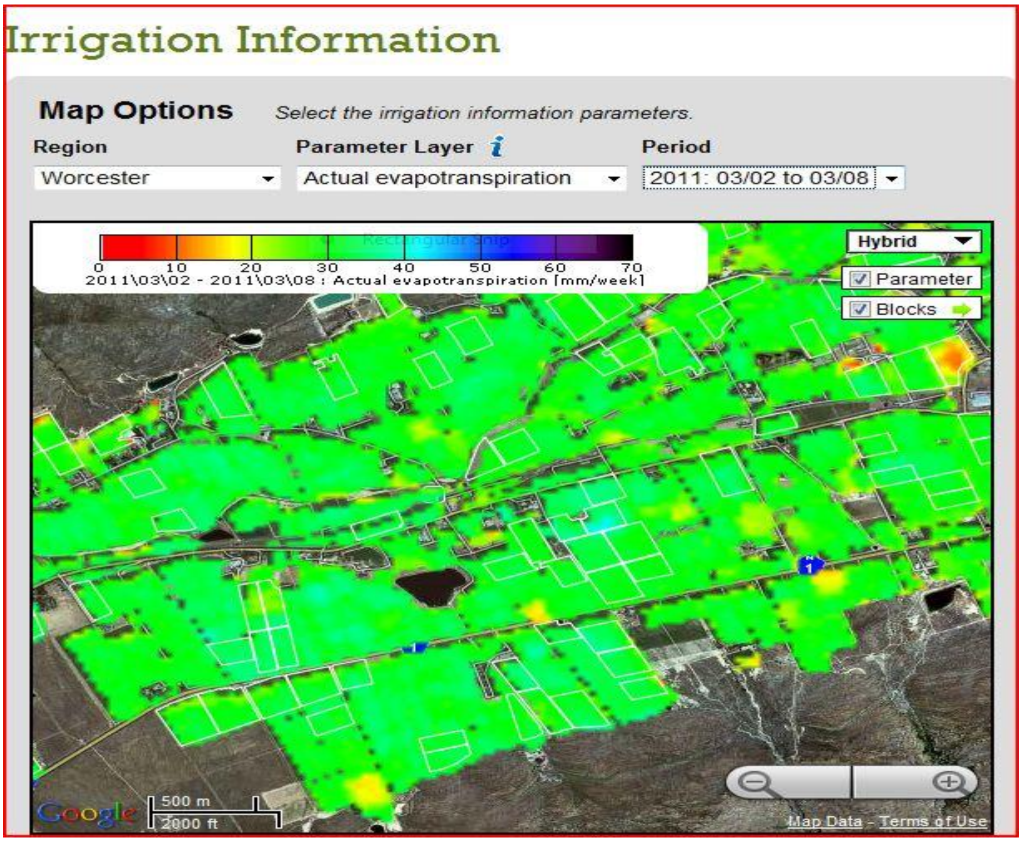

Figure 4: Actual evapotranspiration of table grape blocks in the Hex River Valley

Utilisation of data provided through the FruitLook web site

The actual test for the utilisation of the data can be obtained from the number of irrigation blocks registered on the web portal and the number of returning visitors to the web site.

For FruitLook to be successful, data provided through the web portal need to be useful and be used. Google Analytics is a tool that can be used to analyse website traffic (registration and visits). At the end of the 2014/15project year the total number of subscribers to FruitLook was 828, with the majority of them are unfortunately not regular users of the website. 226 subscribers have registered irrigation block and 989 users are subscribed to the monthly newsletter. A total of 8,287 data orders have been made during the 2014/15 season. These cover 4,921 orders for 2014/15 season data and 3,366 orders for historical data. The 2014/15 data orders cover 39,003 hectares. This number is offset due to some large data orders. The data related to these orders is probably not used directly for improvements in farm resource management. If orders larger than 25ha are excluded the total ordered area equals 15,608 ha. This is probably the relevant area when it comes to describing the impact of FruitLook. This 15,608 ha is approximately 9.6% of the fruit area covered by FruitLook (which is 161,807 ha of fruits based on WCDOA's shapefile of agricultural fields). The subscribers represent different groups of users (farmers, consultants, scientists and students).

	Sum TOTAL (Orders)	Sum TOTAL (hectares)	Average Order Size TOTAL (hectares)		Sum Orders <25ha (Orders)	Sum Orders <25ha (hectares)	Average Order Size <25ha (hectares)

2010/11	1,089	11,664	10.7		1,053	3,512	3.3
2011/12	2,211	24,482	11.1		2,105	7,810	3.7
2012/13	1,970	19,413	9.9		1,896	6,646	3.5
2013/14	2,609	25,663	9.8		2,549	8,363	3.3
2014/15	4,921	39,003	7.9		4,834	15,608	3.2
TOTAL	12,800	120,224	9.4		12,437	41,938	3.4

Table 1: Total orders, hectares and average order size per season. The columns on right hand provide an overview of the ordered hectares without taking orders larger than 25 hectares into account.

Crop Type	Orders	Ordered Hectares	Average Order Size (ha)
Apple	3,029	8,714	2.88
Pear	873	2,392	2.74
Other Deciduous Fruits	112	459	4.10
Apricot	52	151	2.90
Nectarine	99	310	3.23
Peach	197	615	3.12
Plum	219	525	2.39
Other Stone Fruit	51	125	2.45
Citrus	841	4,115	4.89
Berries	3	7	2.37
Red Table Grape	277	780	2.81
White Table Grape	111	310	2.80
Red Wine Grape	907	3,573	3.94
White Wine Grape	975	3,079	3.16
Other Grapes	96	309	3.22
Vegetables	38	333	8.77
Other Crops	243	1,474	6.07
TOTAL	8,123	**27,280**	**3.36**

Table 2 Total orders, hectares and average order size per crop type from data orders made during the 2014/15 season. Only orders smaller than 25ha are taken into account. This table includes both data orders for the 2014/15 season as well as historical orders.

The total amount of FruitLook website uses from 1 October 2014 to 30 June 2015 was 8,317. In comparison between 1 October 2013 and 30 June 2014 the total number of sessions was 2,727. During the 2014/15 season the website has been visited on average 212 times per week. The peak period lies in November and December during which the website was visited close to 400 times per week. The average amount of individuals visiting the website per week during the monitoring period was 133. Hence, on average the FruitLook website was visited ± 1.6 times a week per individual user.

The bounce percentage is 30.1%, which means almost one out of every three visits consists of just looking at the homepage before leaving the FruitLook website. On average users spend ± 10 minutes per visit on the website during which they view 10.5 pages. When the bounce percentage is taken into account, the time spend by genuine users of the website will be longer. This can be interpreted as an indication of users taking their time to look around and are actively working with the data available.

Google Analytics also provides information on geographical distribution of visitors. Most (72% of the total visits of 8293) originated from South Africa continent. Most other visits originated from Europe (13%) mainly from The Netherlands (10%,). These probably consist of website visits from the project team. There were also a number of visits from Belgium and USA (3% each) and Russia (1%). Other visitors (8%) were from other grape and fruit growing countries.

FruitLook questionnaire

A questionnaire on FruitLook impact has been disseminated at the end of the FruitLook monitoring period. The questionnaire focused on the usability of FruitLook in water management and the impact of FruitLook on farm resource management in general. In total 27 people responded. FruitLook was deemed most useful to detect over- or under irrigation, for the placement of soil moisture probes, the detection of drainage problems and post-season evaluation of irrigation efficiency. In this questionnaire over 60% of the respondents indicated FruitLook positively affected their water management by 10% or more. More than 40% of the respondents indicated due to FruitLook they saved at least 10% irrigation water; 10% even indicated their savings were higher than 30%.

Conclusion

The GrapeLook and FruitLook projects indicated that an innovative tool (remote sensing) can be used to provide valuable information of important growth parameters that can result in an increase of agricultural production while reducing water consumption, i.e. to sustain and increase grape production with the limited available water resources. The actual increase in water use efficiency can only be calculated after running the project for a few years and then also taking climatic variations into account.

References

Bastiaanssen, W.G.M., S. Thiruvengadachari, R. Sakthivadivel, D.J. Molden, 1999. Satellite remote sensing for estimating productivities of land and water. International Journal of Water Resource Development 15, 181–196.

Klaasse, Annemarie, Wim Bastiaanssen, Caren Jarmain, and André Roux, 2008. Water use efficiency of table and wine grapes in Western Cape, South Africa. The spatial and temporal variation of water use efficiency in grape cultivation using remote sensing technology. WaterWatch report: 80 pp.

Klaasse, Annemarie, Caren Jarmain, Marije ten Napel, Wim Bastiaanssen, Steven Wilmink and Maurits Voogt, 2011. GrapeLook: space based services to improve water use efficiency of vineyards in South Africa. Final report, ESA Contract 4000102531/10/N/AD, Noordwijk

Bastiaanssen, W.G.M., M. Menenti, R.A. Feddes and A.A.M. Holtslag. 1998. The Surface Energy Balance Algorithm for Land (SEBAL): Part 1 formulation, J. of Hydr. 212-213: 198-212.

Bastiaanssen, W.G.M., E.J.M. Noordman, H. Pelgrum, G. Davids, R.G. Allen, 2005. SEBAL for spatially distributed ET under actual management and growing conditions. J. Irr. Drain. Eng. 131, 85-93

Jarmain, C., Everson, C.S., Savage, M.J., Mengistu, M. and Clulow, A.D. 2009. Refining Tools For Evaporation Monitoring In Support Of Water Resources