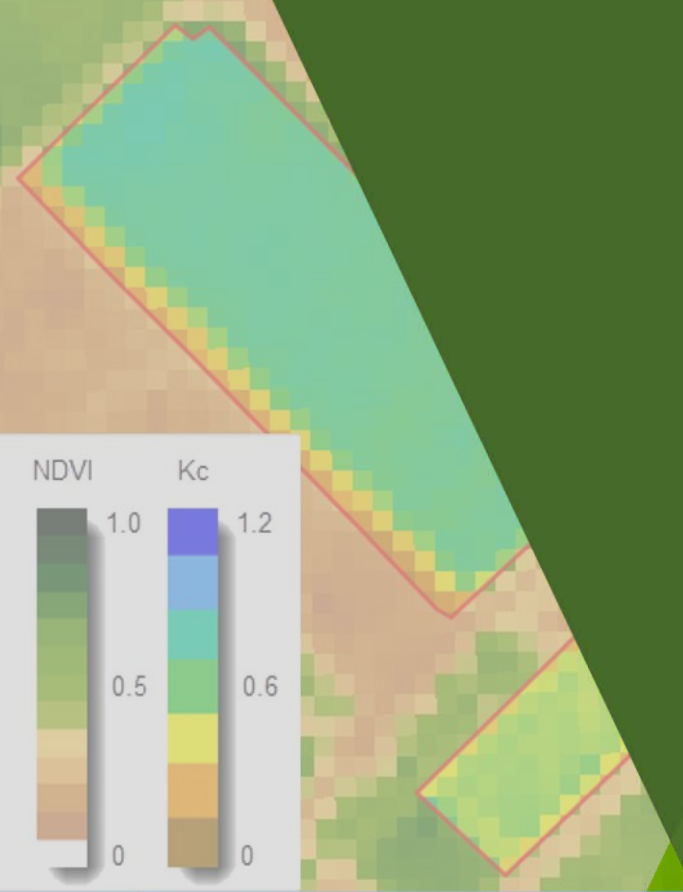


# Reference Guide for IrriSAT



## My IrriSAT account details

Gmail account: \_\_\_\_\_

Password: \_\_\_\_\_

## Contents

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# A quick guide to the use of the cloud based IrrisAT app

Supporting materials for IrrisAT Cotton workshops

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Australian Government  
Cotton Research and  
Development Corporation



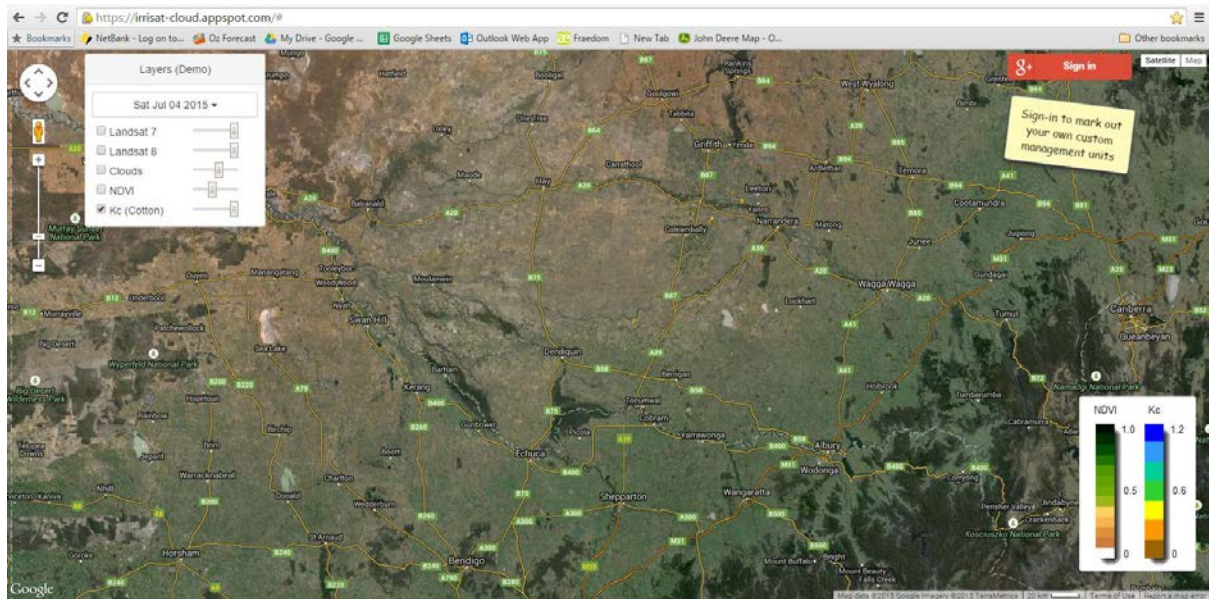
Department of  
Primary Industries

The material contained in this document is supporting material for the IrriSAT Cotton Workshops. This guide provides a quick step by step tutorial for using the cloud/online based IrriSAT app which is being created as part of the Cotton RDC funded project *Benchmarking water use efficiency and crop productivity in the Australian Cotton Industry*.

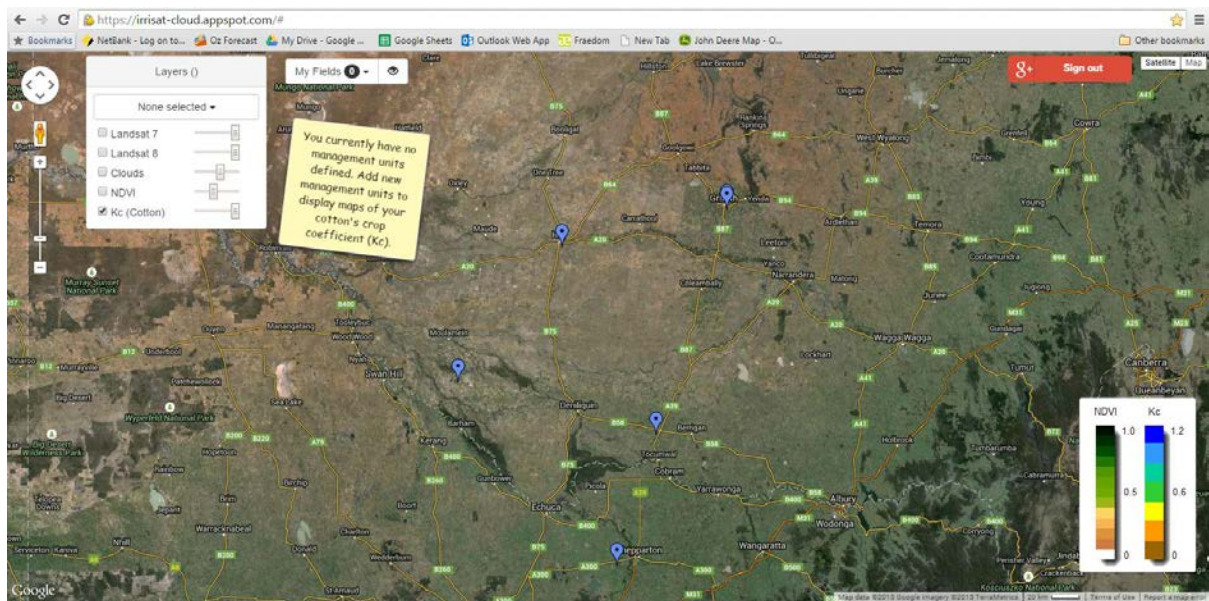
The cloud based IrriSAT app automates satellite processing and information delivery of Landsat data and provides water management information across a range of scales. The IrriSAT app can be found at <https://irrisat-cloud.appspot.com/> and accessed on most web enabled devices – iphone, ipad, PC, etc.



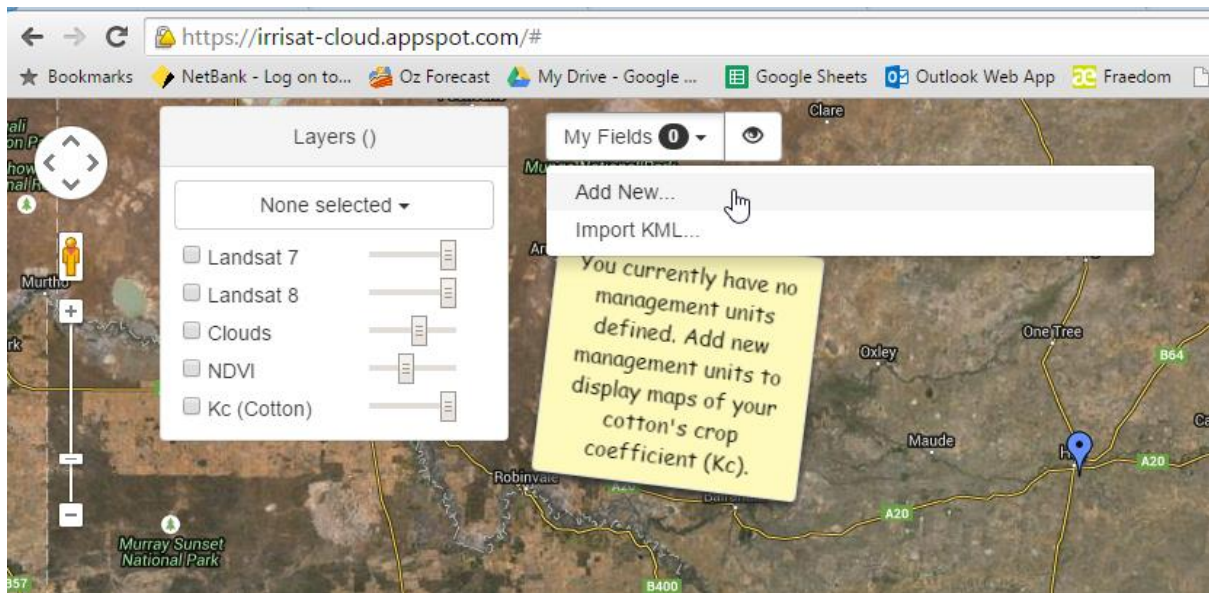
**Step 1:** Open your web browsers and navigate to the IrrisAT app website <https://irrisat-cloud.appspot.com/> you should see the following screen displayed.



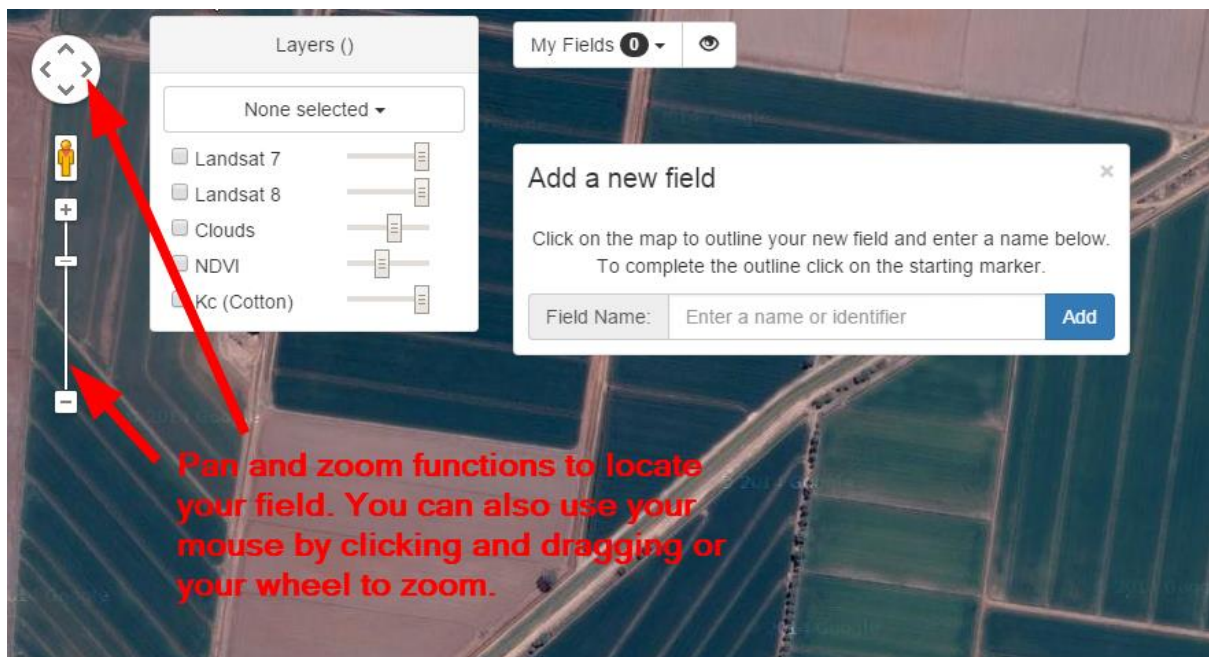
**Step 2:** Now click on the red google “Sign in” button on the right upper corner of the screen and log in with your google account. If you don’t have a Google account then you can create a free account here: <https://accounts.google.com/signup> Once signed in you will see a guide note asking you to add management units



**Step 3:** Now add some management units, which are simply areas you are interested in looking at crop coefficient and water use data from. To do this click on the down arrow next to “My Fields” and select the “Add New...” selection as shown

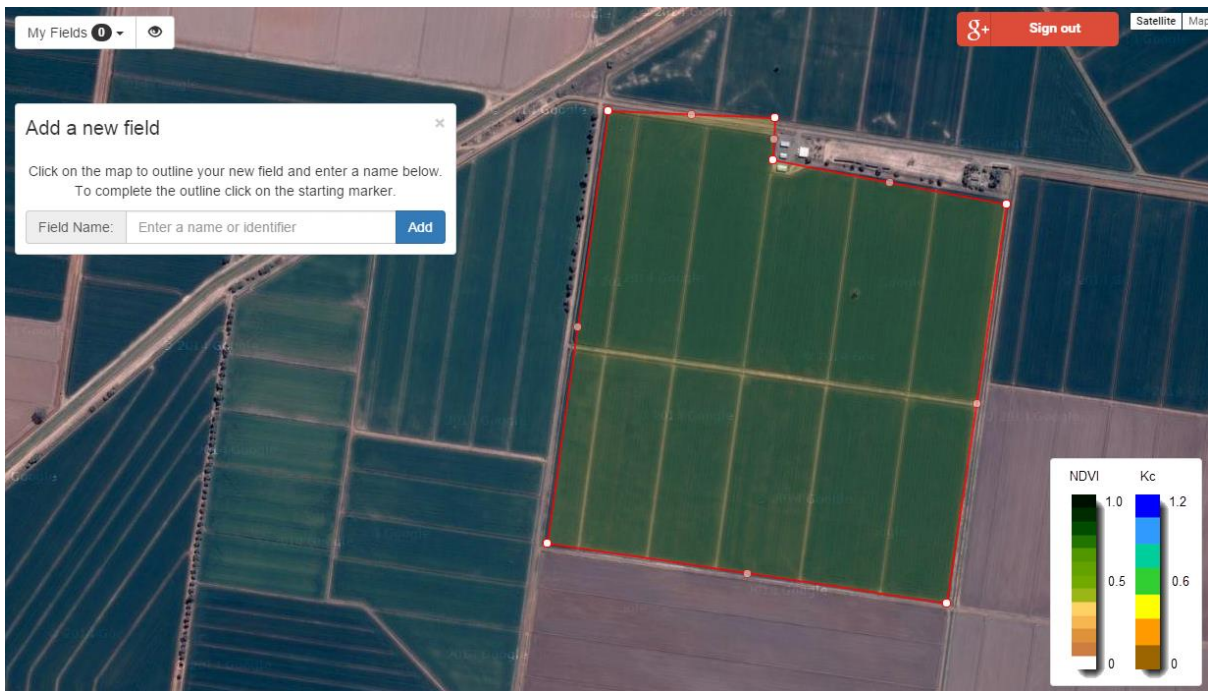


**Step 4:** You will now be presented with the following option to add a new field as shown. You can use the pan and zoom functions (Left side on the screen) to locate your field of interest or your mouse wheel and hold and drag.

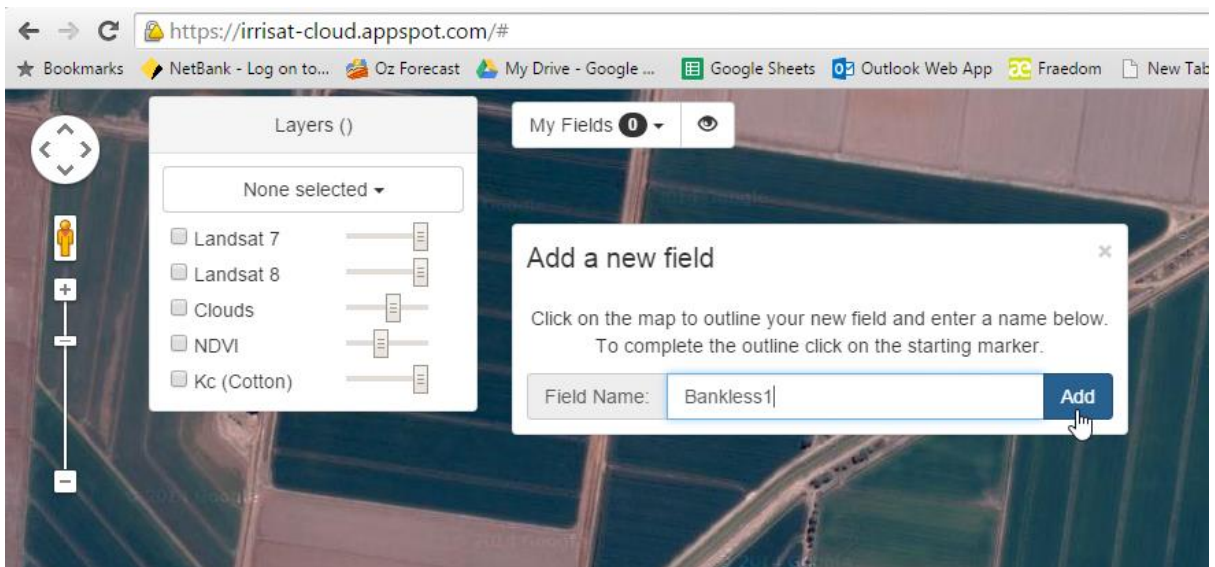


**Step 5:** Now click on the corners of your field to outline it as shown. When finished click on the starting point and a polygon covering your field will be shown.



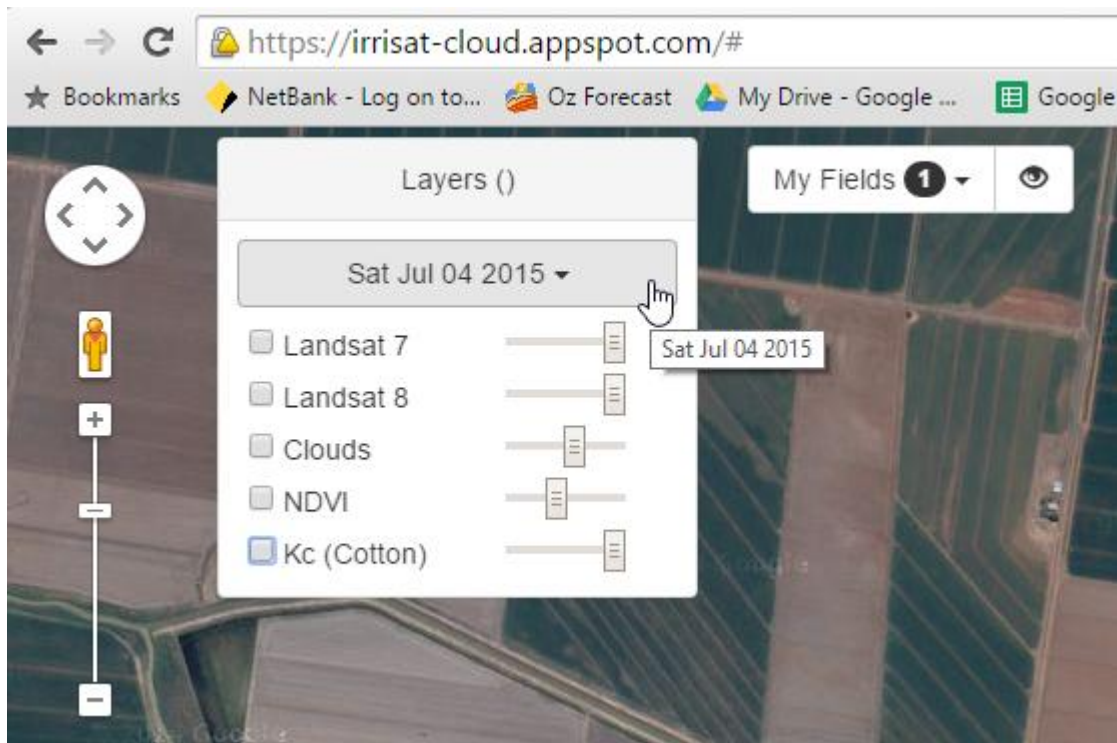


**Step 6:** Now add a field name and click the “Add button”

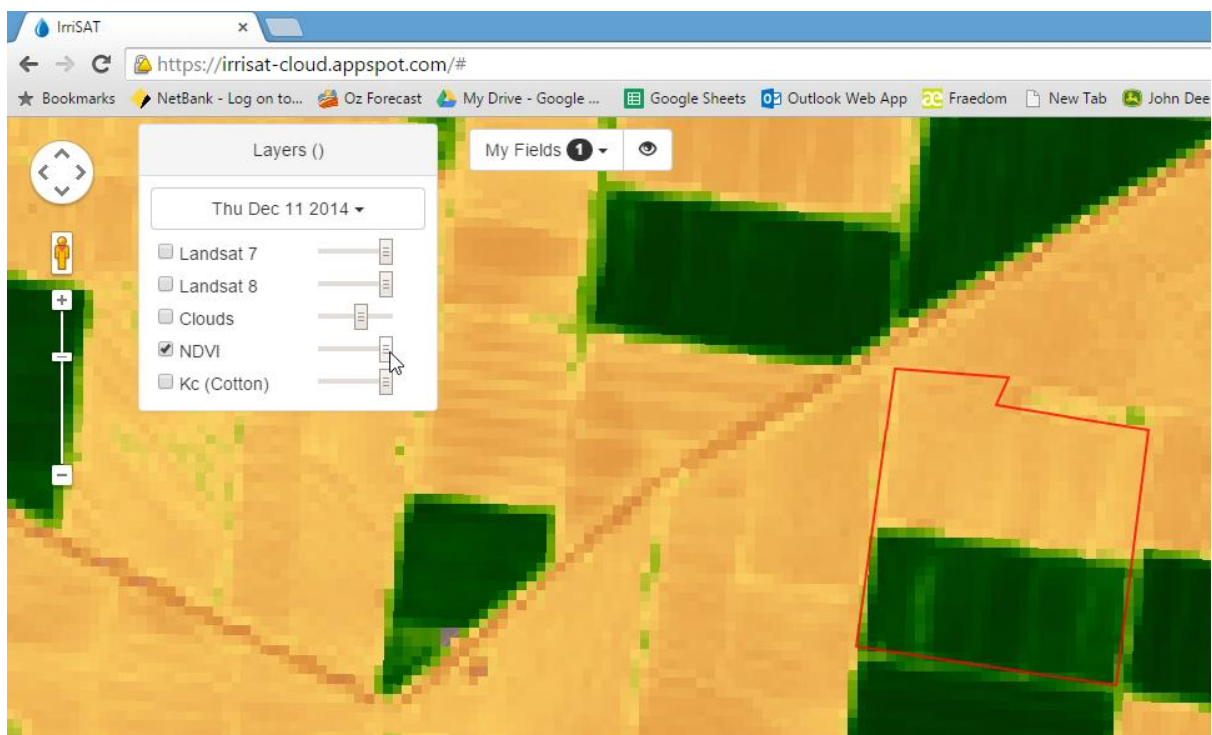


You will now see that a field has been added and also that the date selection drop down is showing a date and is now operational.





**Step 7:** Now click on the NDVI tick box and drag the transparency slider across to the right as shown. Select a date in the growing season. You will now see the NDVI data shown. Have a play with different dates and moving around the countryside to see the irrigated crops and changes over the season in NDVI values by changing dates.



**Step 8:** Now click on the Kc tick box. This will display the crop coefficient for the fields you have drawn.



Note the top half of the selected bays haven't been irrigated and show a much lower NDVI and Kc values. You can also use the slider bars next to the tick boxes to fade in and out the NDVI and Kc layers over the data.

**Step 9:** OK now add another field following the above steps that is irrigated. You can tell these by the high NDVI values. You can see now two fields are now saved in the user profile.



Note: Once saved these fields are housed on the cloud, hence you can access them from any web enabled device i.e. an ipad in the field etc

**Step 10:** Now click on the new field we have defined. This IrriSAT app will now calculate seasonal daily crop water use for the field. It will automatically retrieve the crop coefficient time series and link to the nearest IrriSAT weather station time series and automatically display crop water use information. This may take a few seconds as it's a lot of data to process "on the run". You should now get a screen showing crop coefficient charts and crop water use charts as shown below.



**Step 11:** Now you can export the data if you wish by clicking on the data tab as shown below from each of the charts. This will allow you to save the file as a .CSV file which can be opened in Excel.

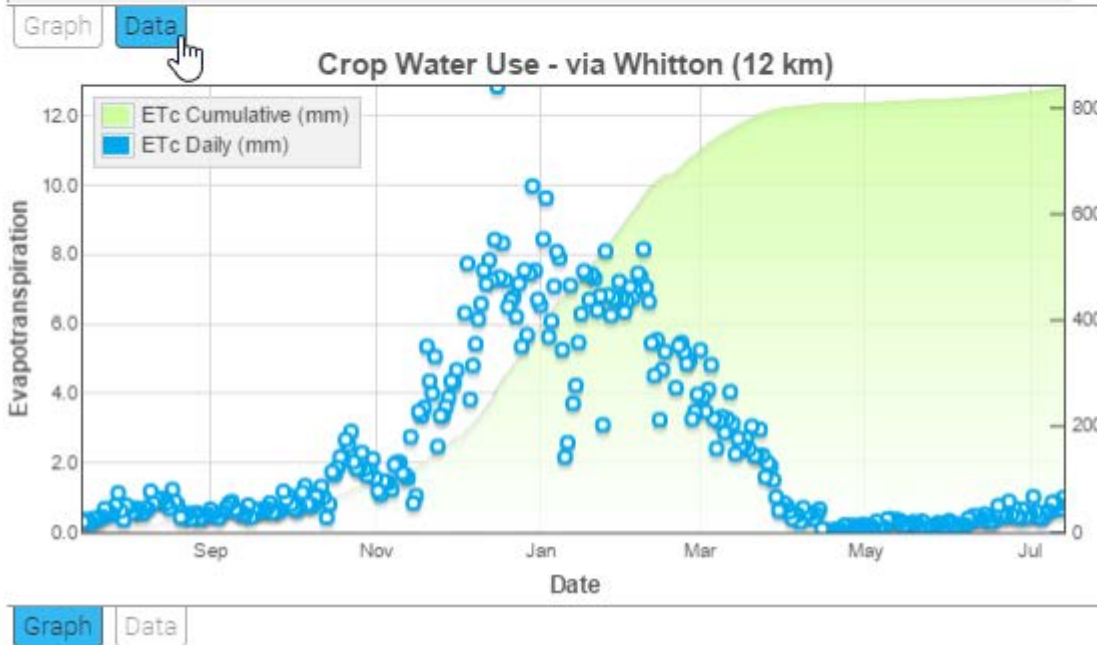


## Irrigated Full (35.5 ha)

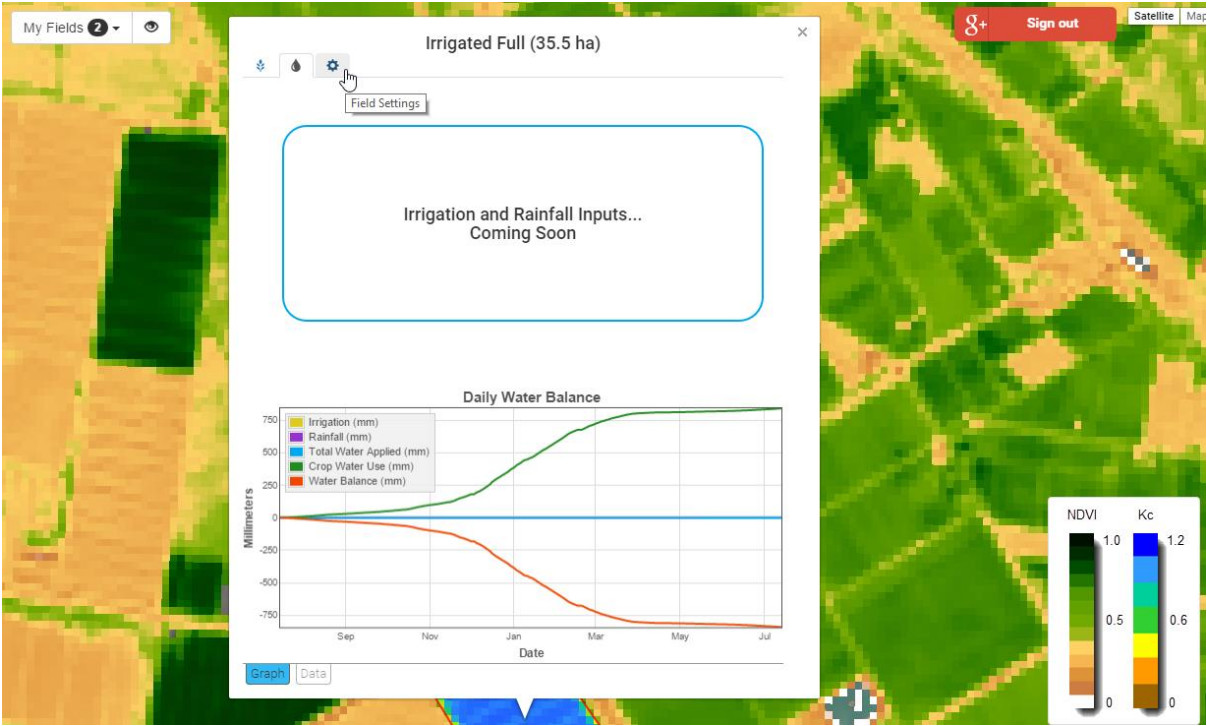
×

Download CSV Select all

	Field Visibility (%)	Kc (Average)	Kc (StdDev)	Kc (Min)	Kc (Q1)	Kc (Median)	Kc (Q3)	Kc (Ma:
12/07/2014	64.01674	0.30448	0.10641	0.19735	0.23942	0.26736	0.31404	0.823
20/07/2014	10.66946	0.5648	0.13028	0.28076	0.46685	0.54941	0.70781	0.800
28/07/2014	10.87866	0.51475	0.1418	0.28692	0.41321	0.47659	0.58007	0.903
05/08/2014	8.159	0.49199	0.10777	0.33375	0.42317	0.48117	0.54337	0.775
13/08/2014	0	-999	-999	-999	-999	-999	-999	-999
21/08/2014	86.40167	0.21618	0.13184	0.04645	0.13904	0.19316	0.24046	0.854
29/08/2014	97.28033	0.19927	0.12702	0.087	0.13489	0.15428	0.19694	0.929
06/09/2014	100	0.20483	0.09543	0.14057	0.16222	0.17358	0.19729	0.826

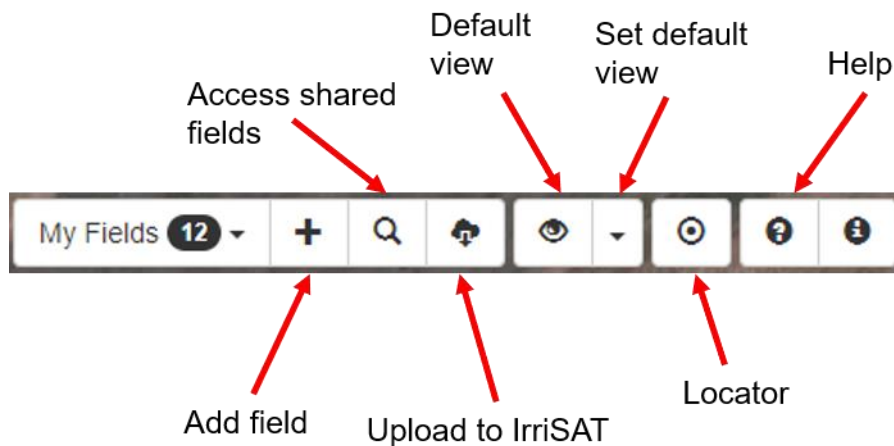


**Future Steps:** (Adding irrigation applications and soil water deficient traces). Functionality to add your irrigation amounts and run a soil water deficit trace are currently being implemented in the IrrisAT app. These will be available in the 2015/2016 growing season. These functions will be accessed by clicking on the “Rain drop” and “Cog” icons as shown below. Stay tuned for more to come on this over the next few months.



## Tools and settings overview

### Toolbar



#### **Add Field**

Select the plus icon to create a new polygon around your field. Details of this process are covered in the quick guide to the use of the cloud based IrriSAT app.

#### **Access shared fields**

Select the magnifying glass icon to discover fields that have been shared with you by other irriSAT users. Details are explained in this guide.

#### **Upload to IrriSAT**

The cloud icon allows you to upload .kml files from Google Drive or your device. This may be beneficial if you have GPS points that designate your field and you would like to more accurately pinpoint your field dimensions in IrriSAT.

#### **Default view**

Selecting the eye icon will return you to the default view set with your google account.

#### **Set default view**

Navigate to a desired location by zooming, clicking and dragging. Select the down arrow and click "set current view as default". Every time you open IrriSAT it will automatically jump to this location.

#### **Locator**

Select the target icon to jump to your current location. (Note: you must allow google to access your location for this to work)

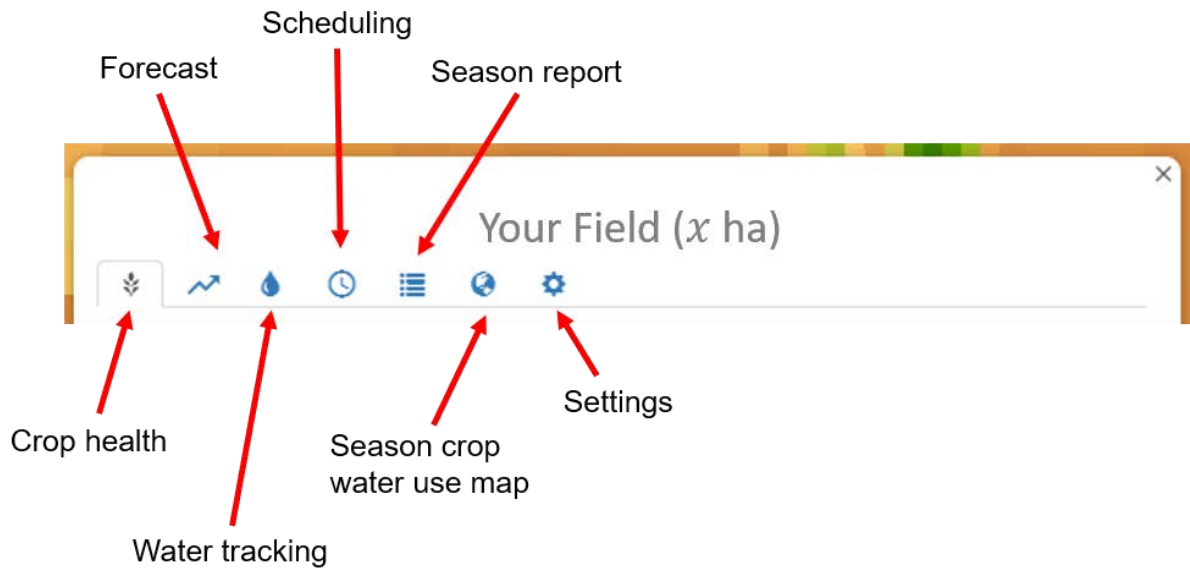
#### **Help**

Video tutorials, the quick guide, and reference information can be found here.



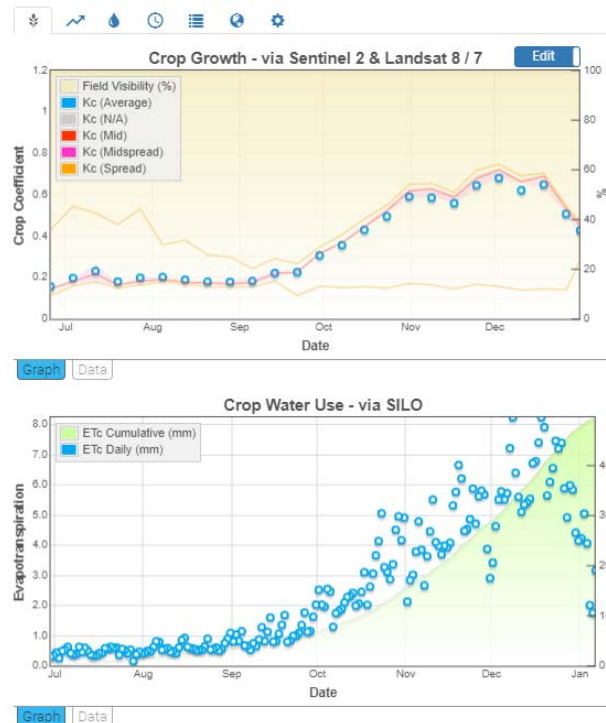
## Field icons

Access field information and settings by selecting your field.



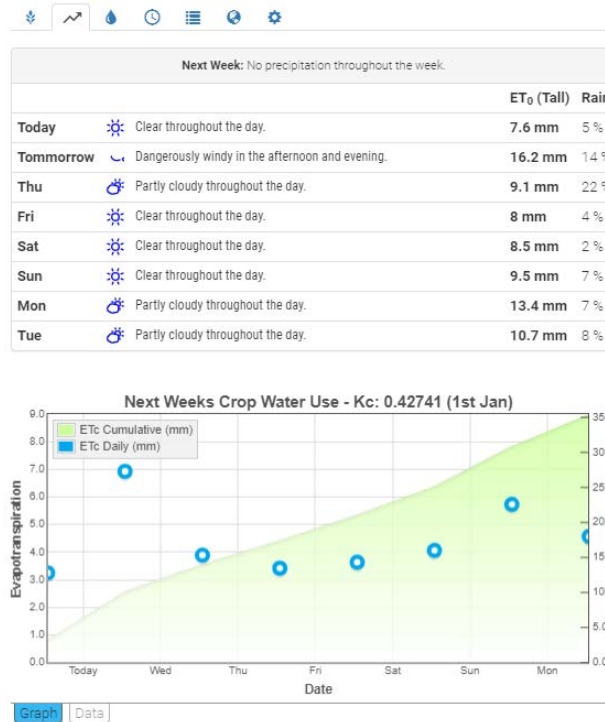
## Crop health

Seasonal data shown in two graphs. The upper graph shows the weekly crop coefficient (Kc) calculated by IrrisAT for the whole field (Note: crop coefficient is an average for the entire field). The lower graph shows estimated crop water use (ETc) for each day, and cumulatively for the entire season.



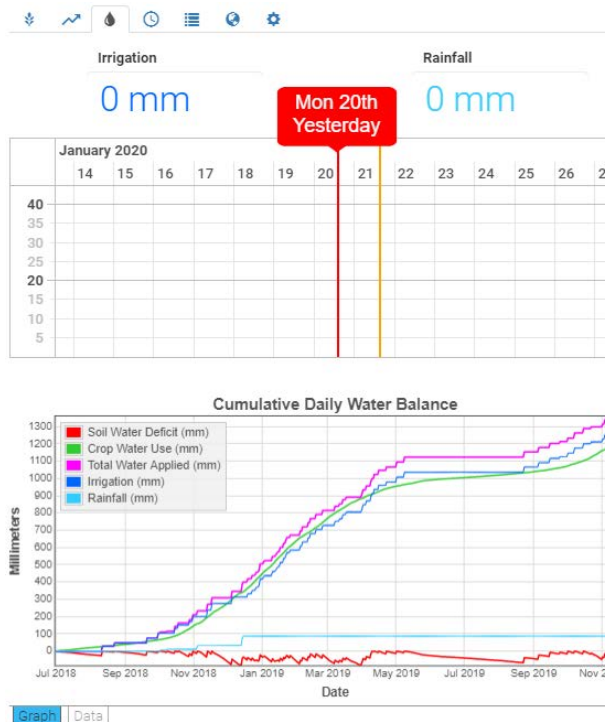
## Forecast

Lists ET<sub>0</sub> values for the coming week and graphs predicted crop water use (Daily and cumulative ETc).



## Water tracking

In this tab you can add irrigation events and rainfall data. Adding water (irrigation/rainfall) adjusts the lower graph which shows the amount of water in the soil, crop water use, and water applied—cumulative daily water balance.



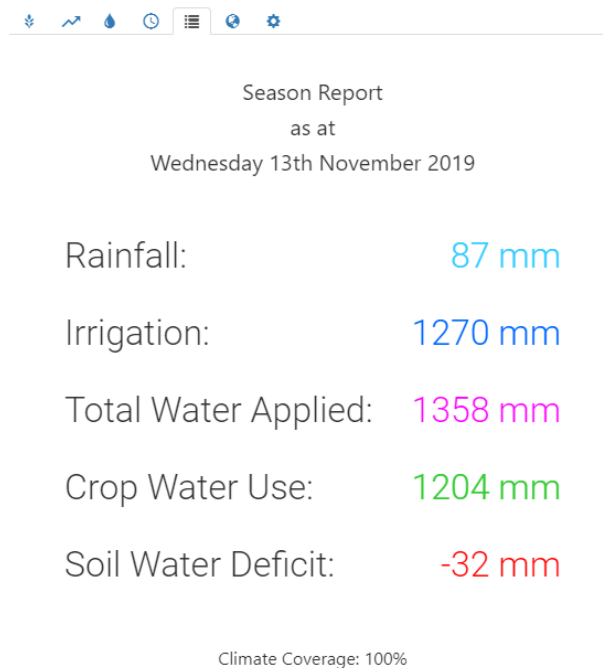
## Scheduling

Tracks the soil-water deficit based on crop water use and water applied to the field and provides a prediction for when the refill point will be reached. To use this function you must set a refill point in the settings tab. Instructions for this process are given later in this guide.



## Season report

Provides a summary of the season's rainfall, irrigation, crop water use and soil water deficit.





### Season crop water use map

Downloadable map of crop water use (ML/ha) for the season (based on cumulative ETc).



### Settings

Access field settings and sharing function.

The form is titled "Field Settings" and contains the following fields:

Category:	Grapevines	Apply
Field Name:	SHC	Apply
Reference ET:	Nearest Available Source	Apply
Rainfall:	User Defined	Apply
Planting Date:	01-07-2018	Apply
Harvest Date:	06-11-2019	Apply
I.S.W.D. (mm):	0	Apply
Refill Point (mm):	28	Apply
Share With:	IrriSAT Users E-Mail Address	Add 1

## Field Settings

Access the settings by selecting your field and clicking the cog icon. To save any changes to field settings, remember to click "Apply".

Irymple (3.6 ha)

Field Settings

Category:	Uncategorised	Apply
Field Name:		Apply
Reference ET:	Nearest Available Source ▾	Apply
Rainfall:	User Defined ▾	Apply
Planting Date:	Undefined	Apply
Harvest Date:	Undefined	Apply
I.S.W.D. (mm):	0	Apply
Refill Point (mm):		Apply
Share With:	IrrisAT Users E-Mail Address	Add 0 ▾

IrrisAT Owner: gmailaccount@gmail.com

### Category

Adding categories can be an easy way to sort common fields. Fields are grouped in to their categories in the drop-down list in the main toolbar "My Fields". (e.g. wine grapes/citrus)

### Field Name

You will have named your field when it was first created. You can change the name here.

## Reference ET

The dropdown will provide you with options for selecting where weather data is retrieved from. They will appear as “Nearest Available Source” or “SILO”, or sometimes you will be able to select specific weather stations.

SILO is a database which uses spatial mathematical techniques to calculate the weather in places where no data is observed. Daily observation data is accessed from weather stations and used to construct a grid providing national coverage for weather data.

## Rainfall

The rainfall setting determines how rainfall data is added so you can track soil water deficit. By default, it will be set to “User Defined”, meaning rainfall data will only be added if you add it manually. The drop down will allow you to select alternative options, “Nearest Available Source”, “SILO”, or a specific weather station.

You can still add or change rainfall data if you have more locally accurate figures than the values provided by your chosen weather source.

## Planting Date

“Planting date” marks the start of the irrigation season or planting of an annual crop. All reporting by IrriSAT (water tracking, seasonal water use reports) will use this date as the starting point.

If no planting date is set, IrriSAT will report data for the past 12 months from the current date.

## Harvest Date

Harvest date marks the end of an irrigation season or harvest of an annual crop. For permanent plantings it should not represent the actual harvest date. If you do not provide a harvest date, either the current date will mark the end of data, or 12 months on from the planting date.

By using past planting and harvest dates you can retrieve seasonal reports and daily crop water use for past seasons.

## I.S.W.D (mm)

Initial Soil Water Deficit (I.S.W.D) specifies an offset to the soil water deficit on the planting date.

IrriSAT assumes that on the planting date, the soil is at field capacity, giving I.S.W.D. a value of zero. If it is not full you can specify a deficit of  $X$  mm.

It may be preferable to set your planting/season start date to a day you know the soil profile is full (e.g. after the first full irrigation of the season).

## Refill Point

Specifies lower limit of water available in the soil root zone. This will be the Readily Available Water (RAW) for soils on your property—the amount of water that a plant can easily extract from the soil.

If you have a drip irrigation system in a vineyard the refill point will be approximately 1/3 of the RAW, which will probably fall between 8 and 15mm.

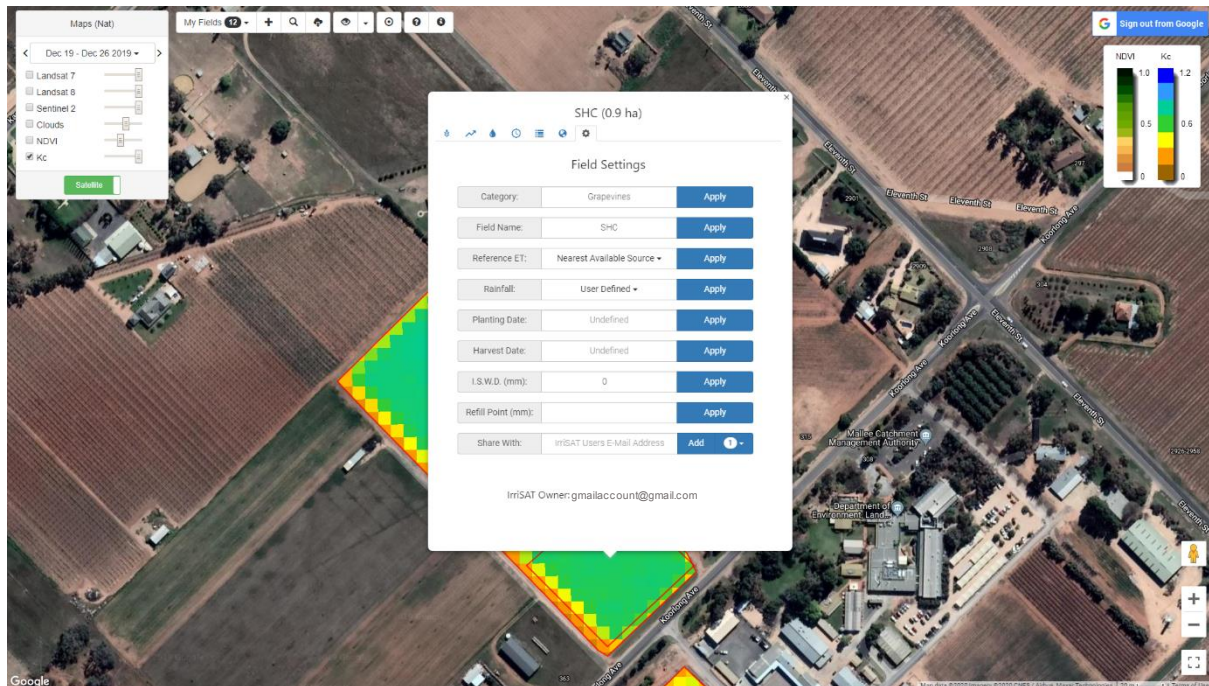
## Share with

Share your fields with other IrriSAT users so they can view or edit your data. Explanation of this function is described later in this manual.

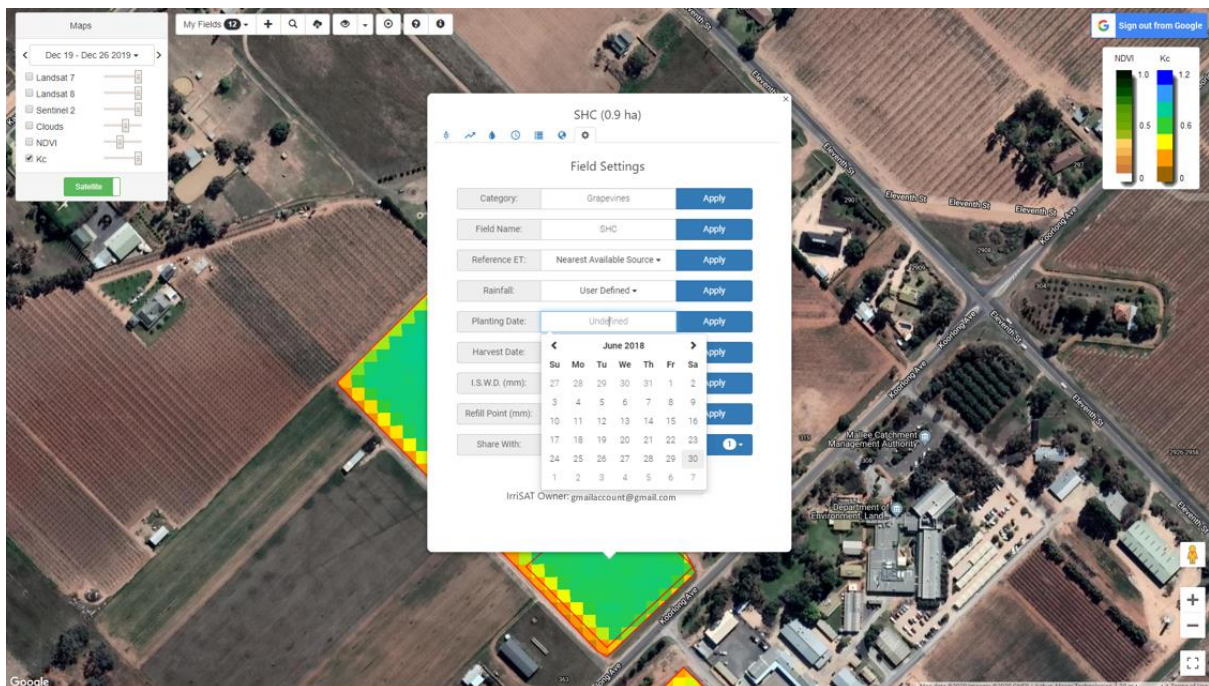


## USING IRRISAT WATER TRACKER

**Step 1:** Click on your field and navigate to the field settings page by clicking on the settings (cog icon). You should see the following screen.



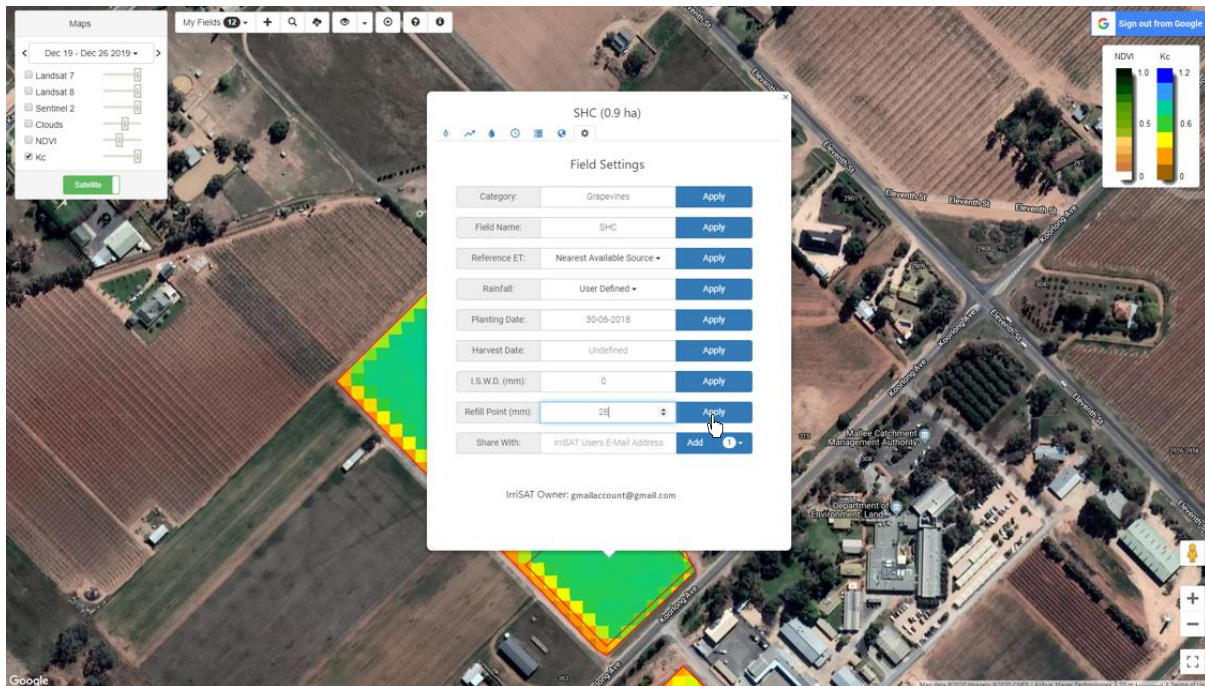
**Step 2:** Set the planting date to the start of your growing/irrigation season and click “Apply”.



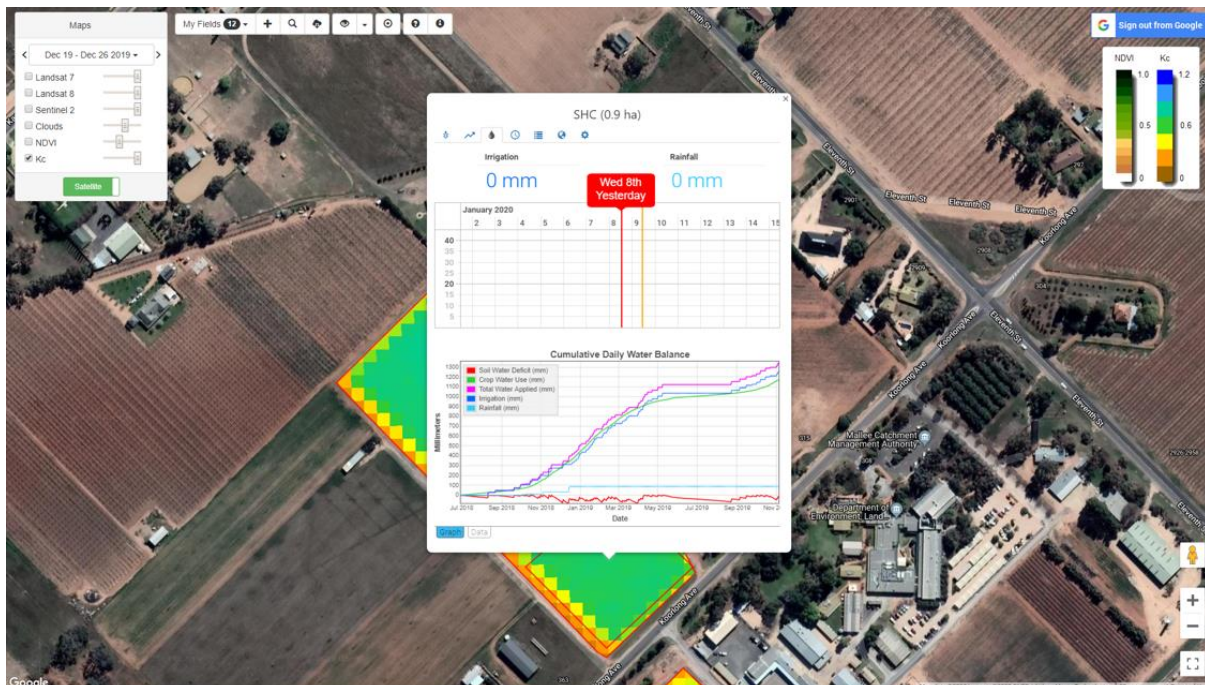
**Step 3:** Set a soil water deficit if the water in the root zone is *not* at field capacity on the planting date and click “Apply”.



**Step 4:** Set a refill point and click “Apply”.

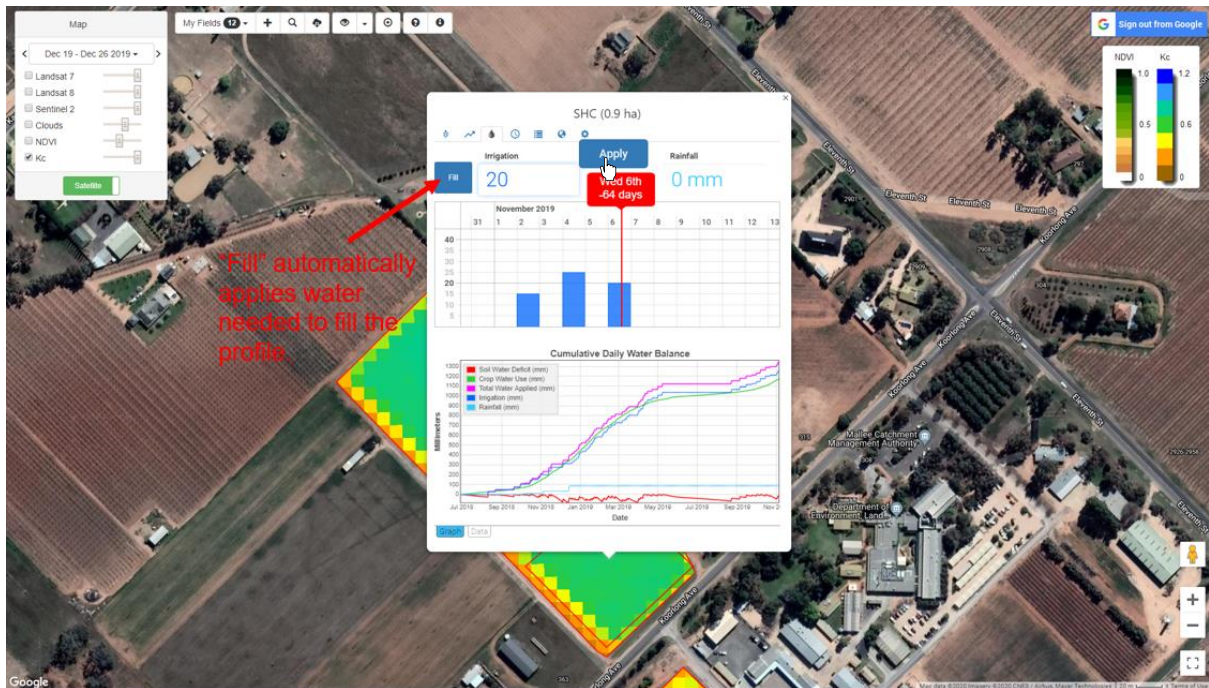


**Step 5:** Navigate to the tab with a raindrop icon. The top graph is used to log of your irrigation data, and rainfall events. The bottom graph shows cumulative daily water balance from the start of the season (i.e. the planting date you set).





**Step 6:** Now add irrigation events (in mm) to the top graph. Click and drag on the graph to move back and forward through the dates to add past irrigation. Type your irrigation and click “apply”.



You can now see your irrigation event added to the graph. The cumulative daily water balance adjusts automatically as you add irrigation events and rainfall.

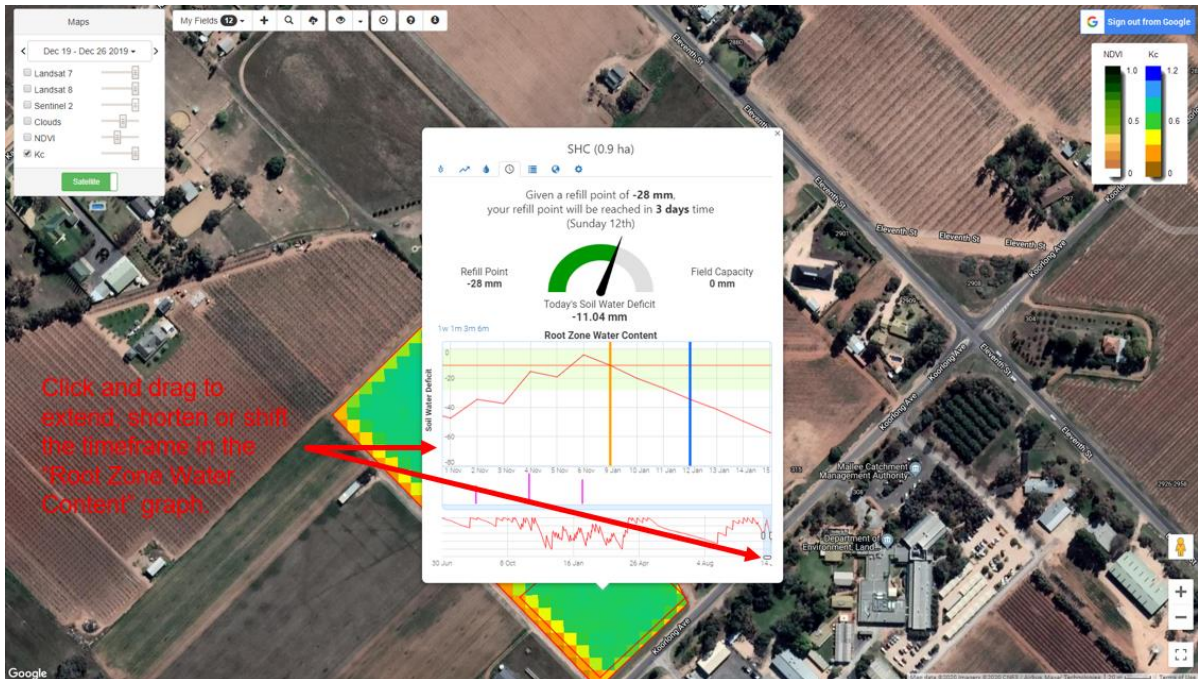
**Step 7:** To add rainfall events, navigate to the date of interest and type rainfall in to the box on the top right and click “apply”. Rainfall will appear in pale blue on the graph below.



Note: IrriSAT automatically sets a field setting so rainfall must be entered by the user. However, you can change this under field settings (cog icon) to use SILO data or weather station data if you are comfortable with the readings from your nominated weather station.



**Step 8:** Click on the clock icon to navigate to the scheduling tool. This page shows you today's soil water deficit, time until refill point is reached, and a log of soil water deficit over time.



**Step 9:** Click on the list icon to access the seasonal report.





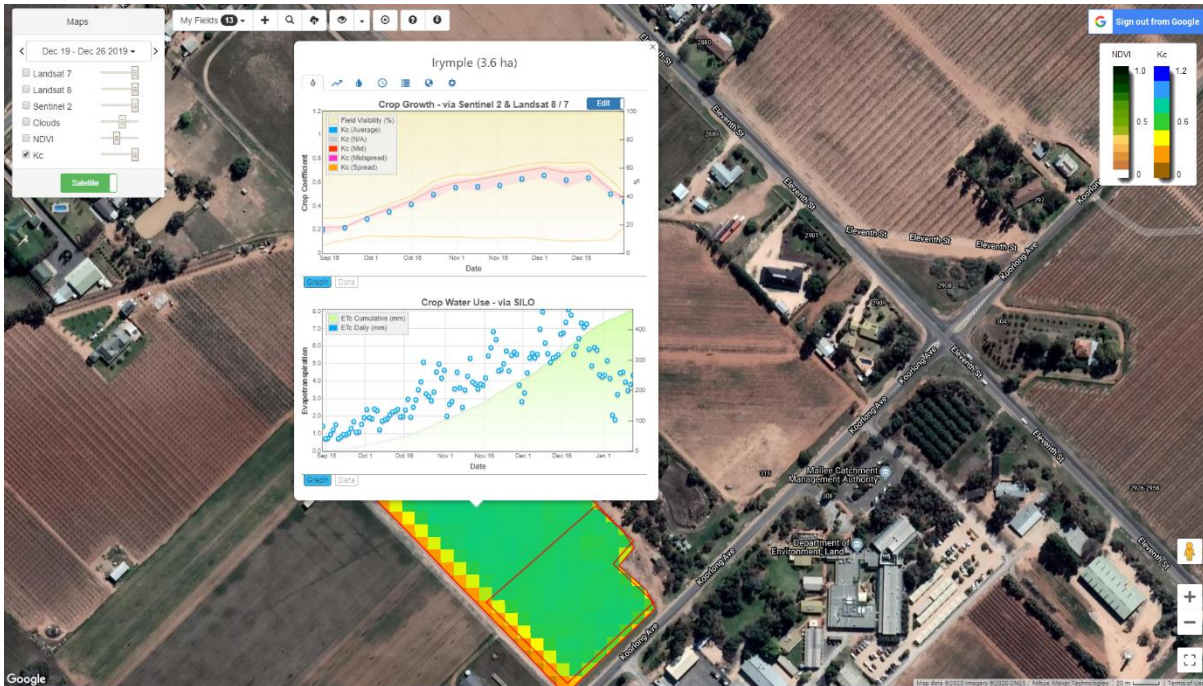
**Step 10:** Click on the globe icon to view the seasonal crop water use map.



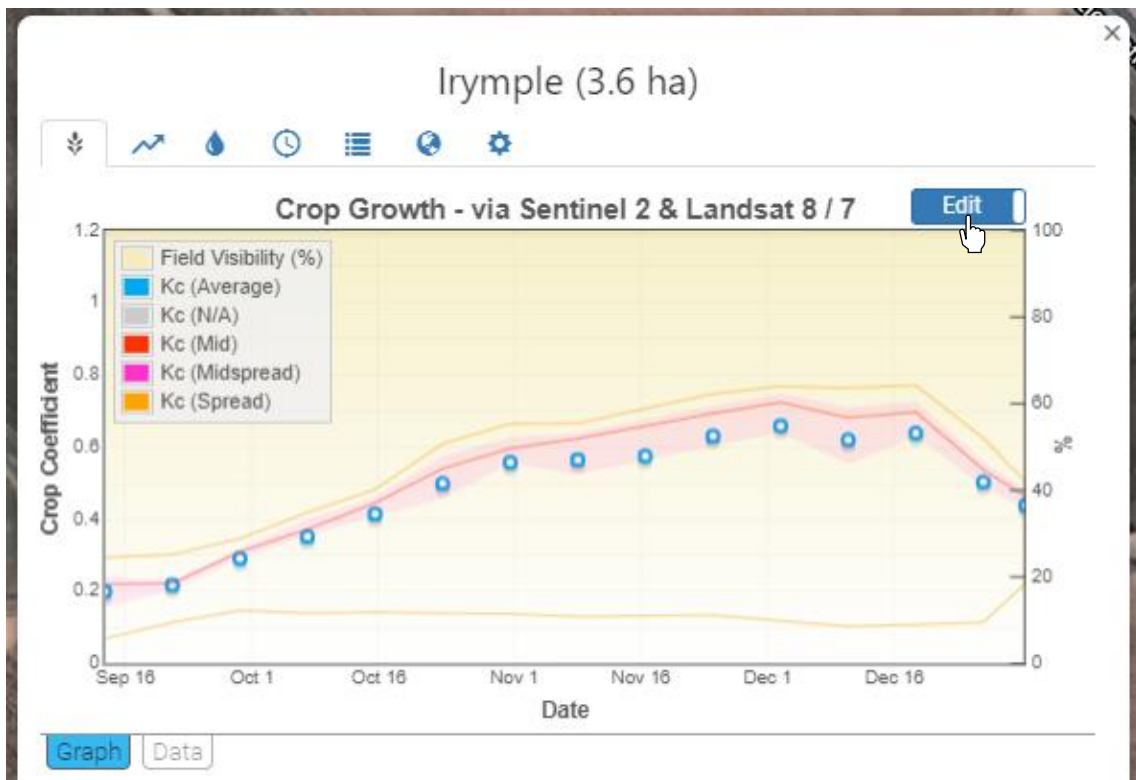
## CHANGING KC VALUES

Poor visibility in satellite imagery can give erroneous results for crop coefficients. This might be relevant when imagery is taken when there is high levels of dust or smoke in the air. This means crop water use might be underestimated. If there is an outlier, you can manually change the Kc values.

**Step 1:** Click on your field to show crop coefficient charts and crop water use charts.

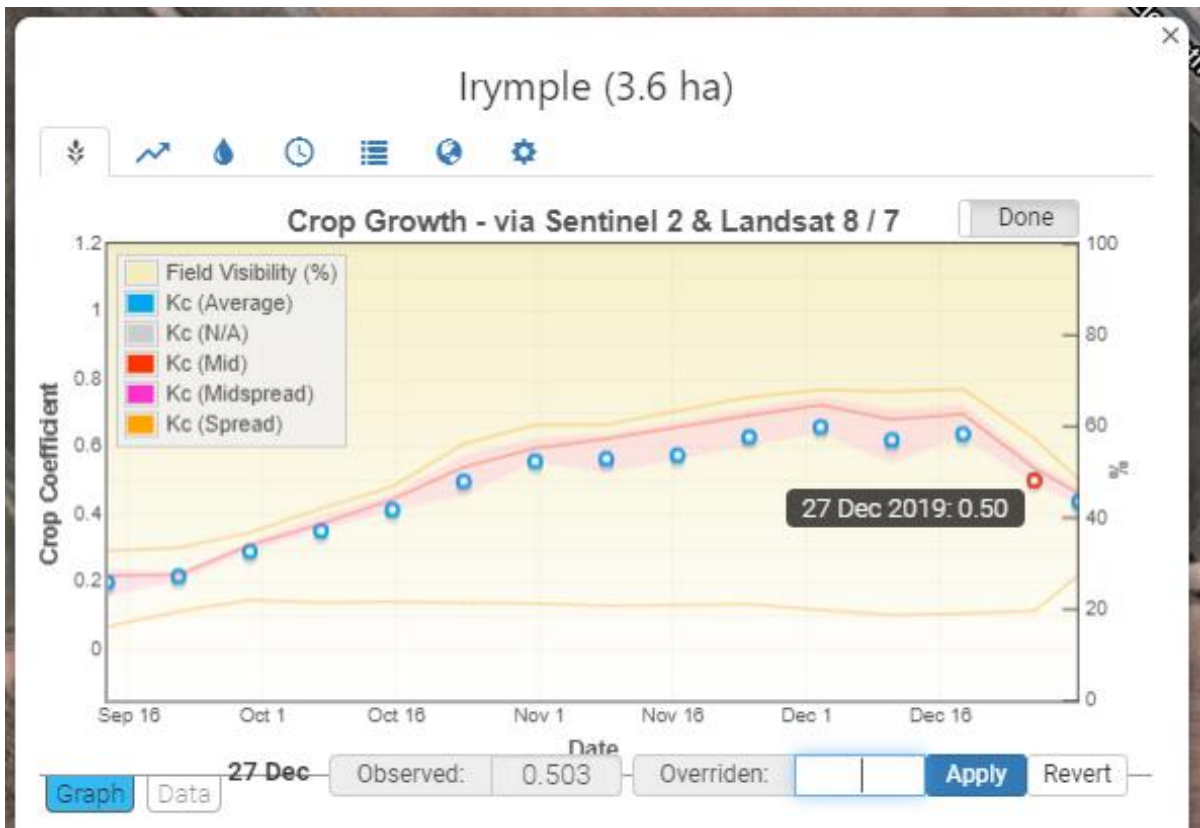


**Step 2:** Click "edit".



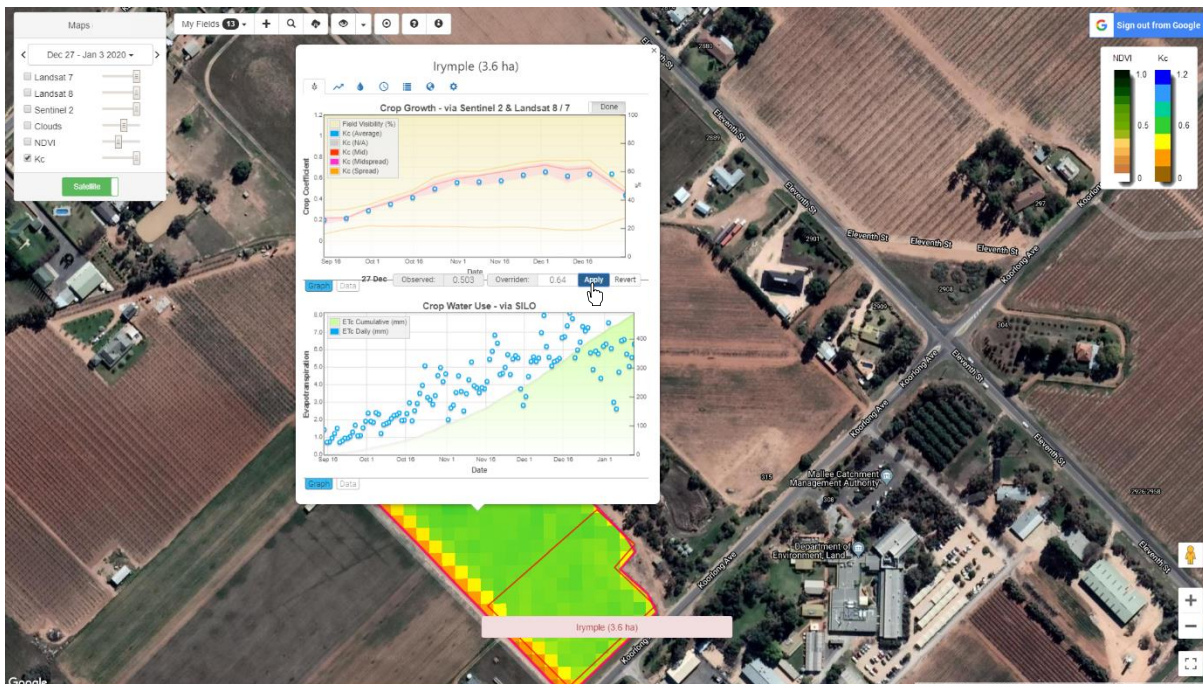


**Step 3:** Click on the point you want to change.

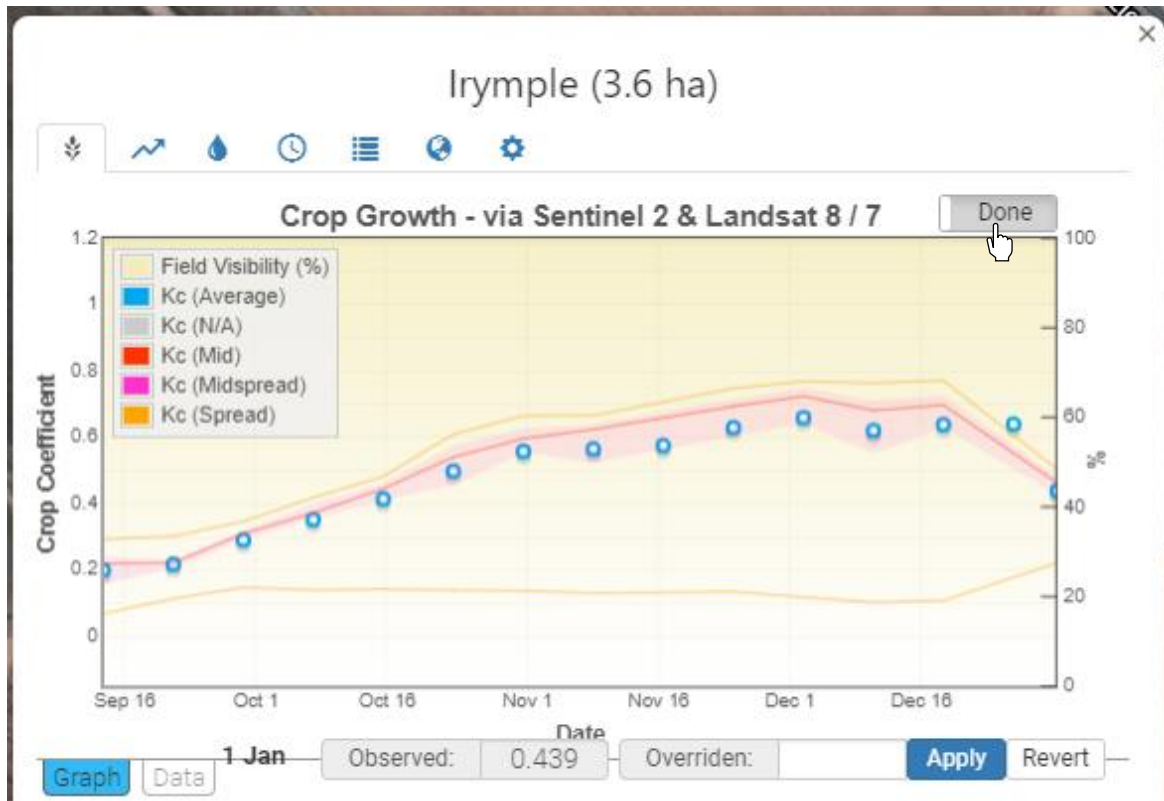


You will notice below the graph, a box showing the current (“Observed”) Kc. Beside it is a box for you to enter the new (“Overridden”) Kc.

**Step 4:** Enter the new Kc value and click “apply”. Notice the daily ETC values in the lower graph for the week of 17 November shift automatically with the change in Kc.



Step 5: Turn off edit mode by clicking "done".

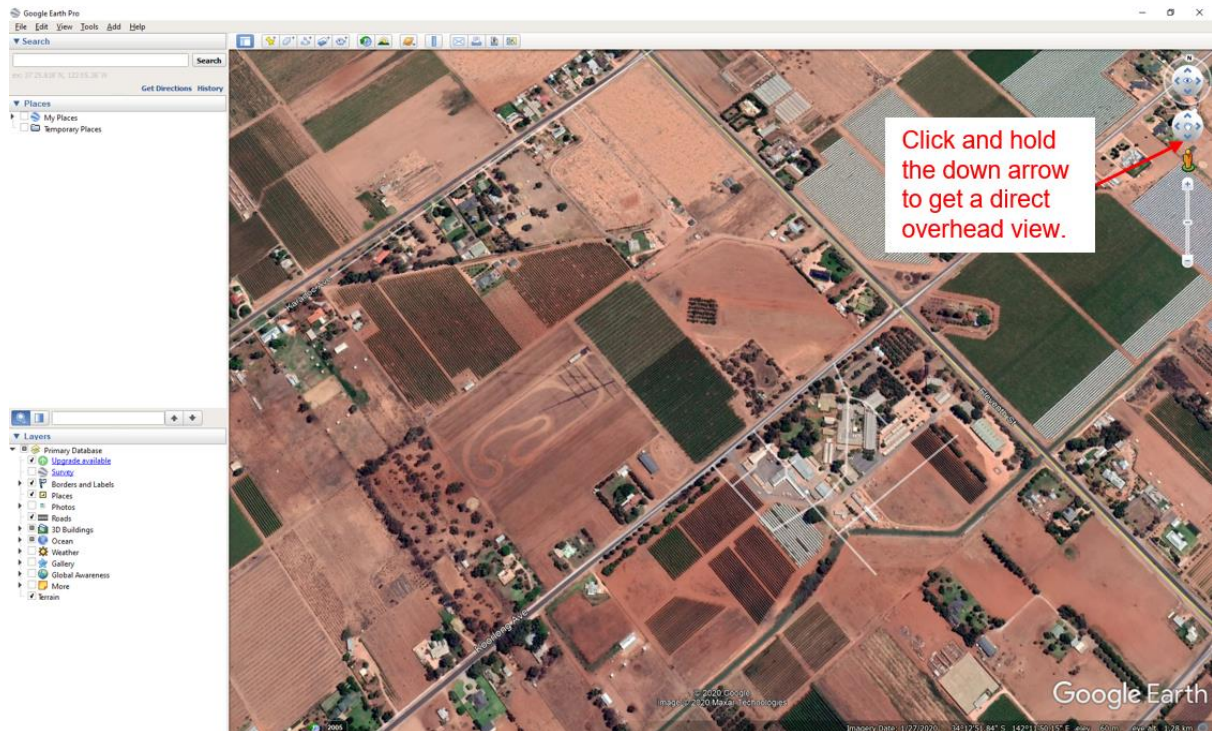




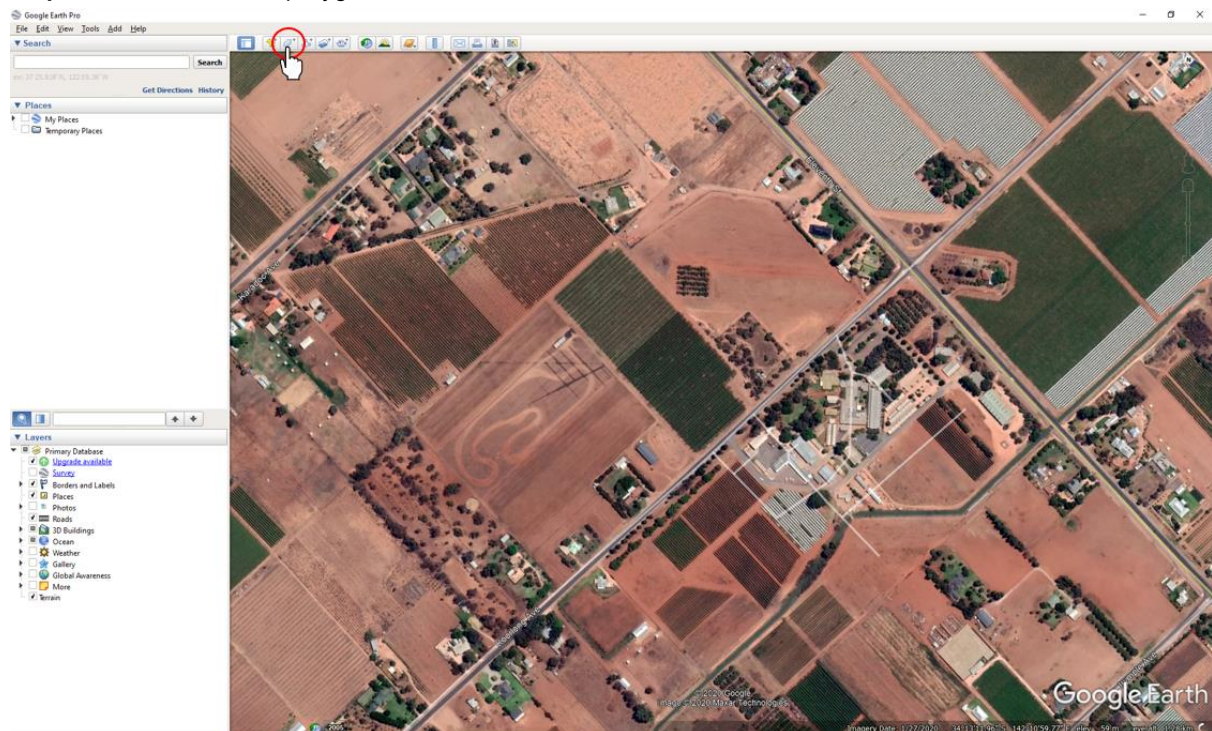
## UPLOADING KML FILES FROM GOOGLE EARTH

Setting up your field in IrriSAT can be difficult, especially if a mistake is made. An alternative approach is to create your field boundaries in Google Earth, which allows you to edit as you go, and import that field in to IrriSAT.

**Step 1:** Open Google Earth and navigate to your property.

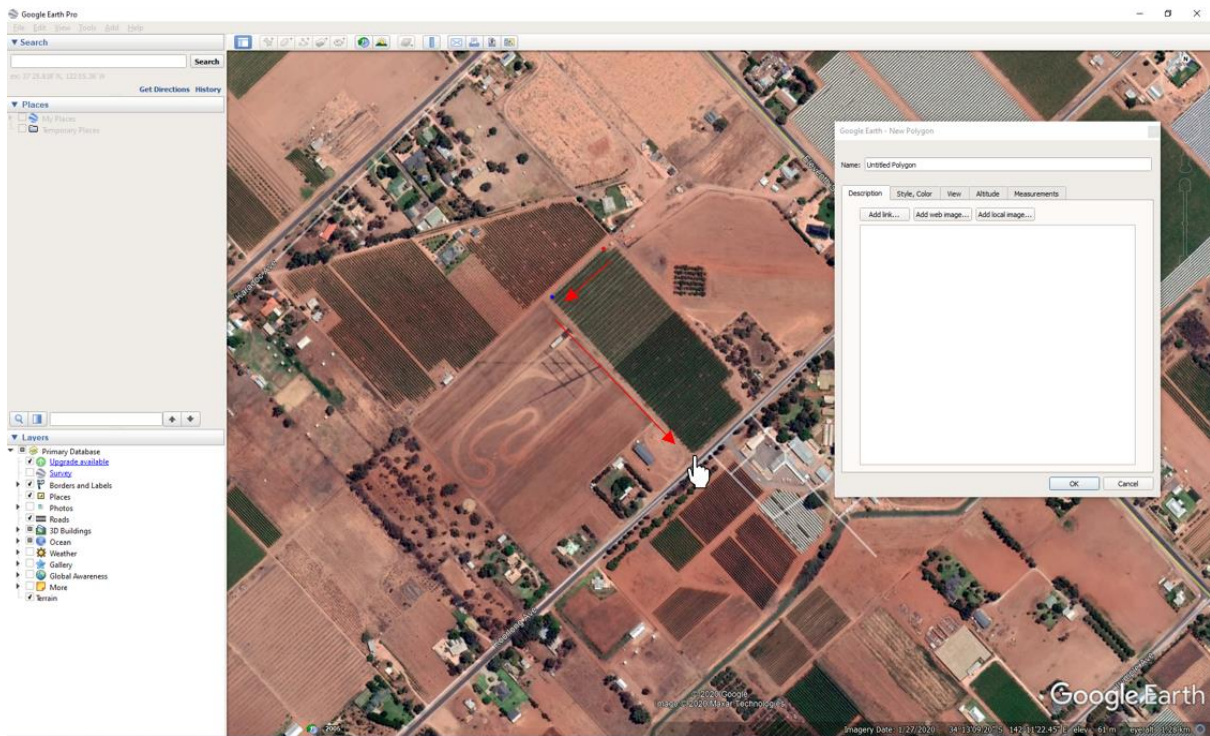


**Step 2:** Click on the “add polygon” icon.

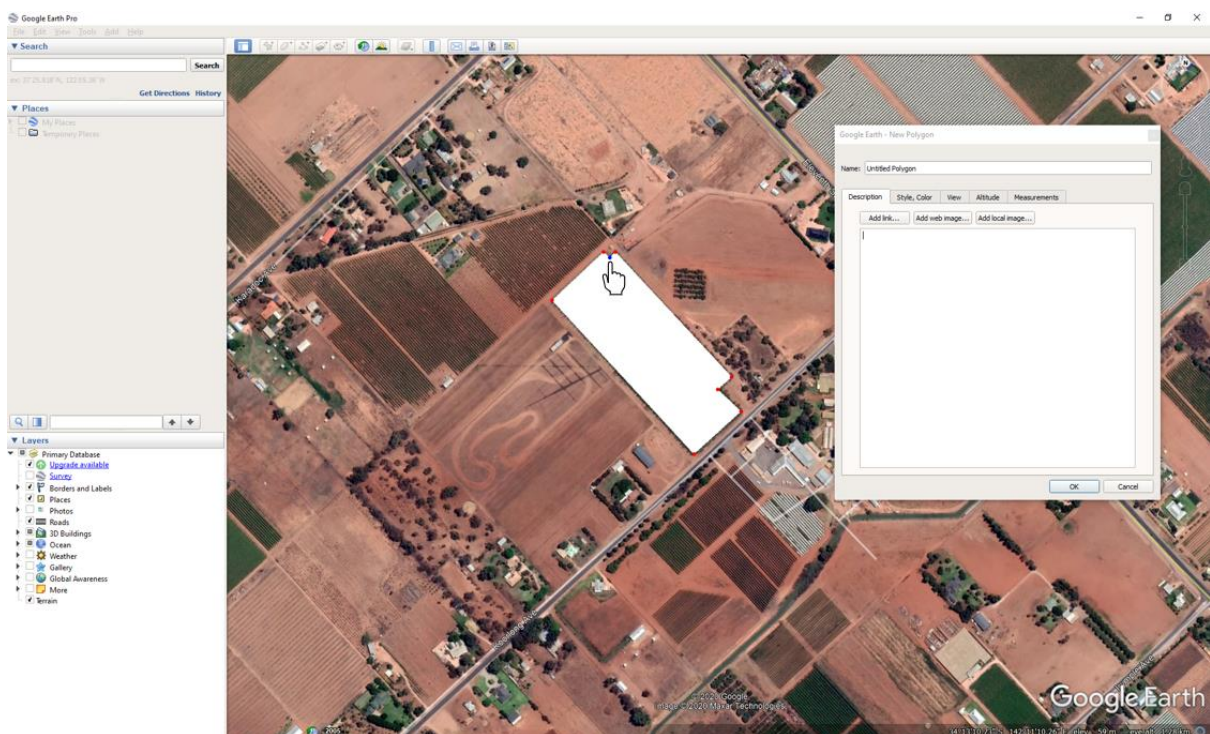




**Step 3:** Click around the corners of your field to create a polygon.

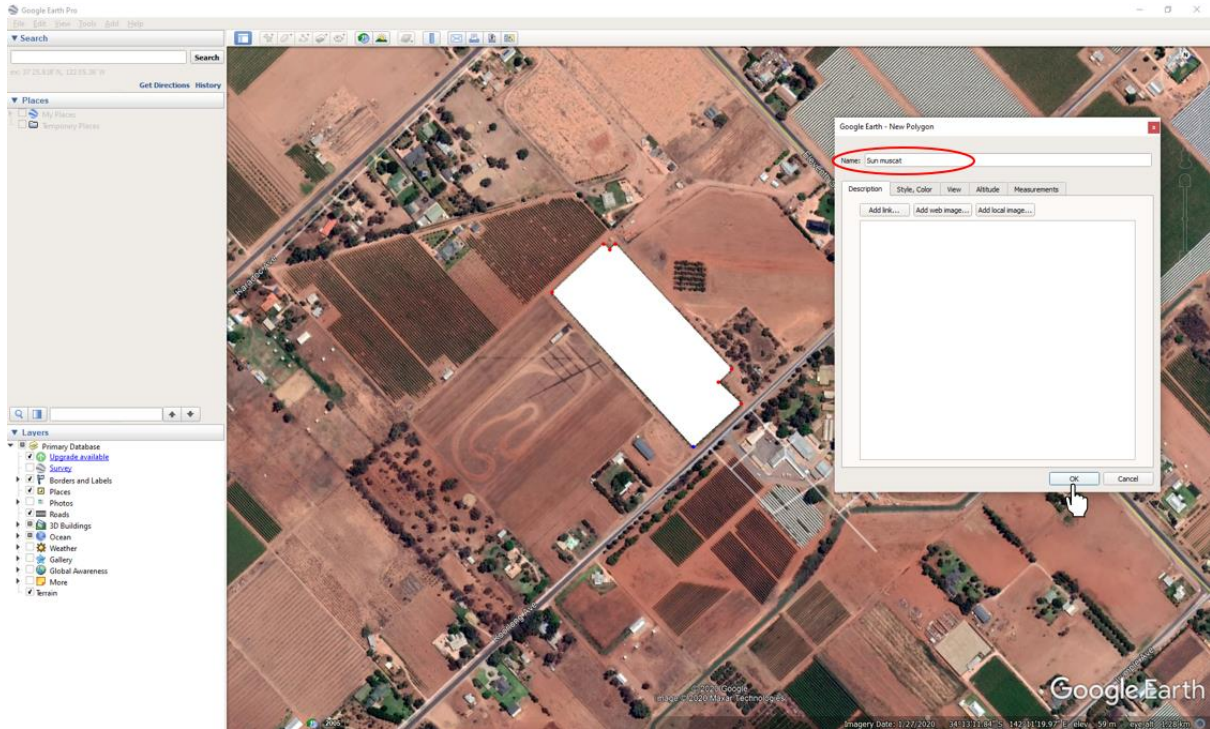


To move any of the corners click and drag the dot at the corner you want to change. To delete a corner click the dot and press "delete" on your keyboard.

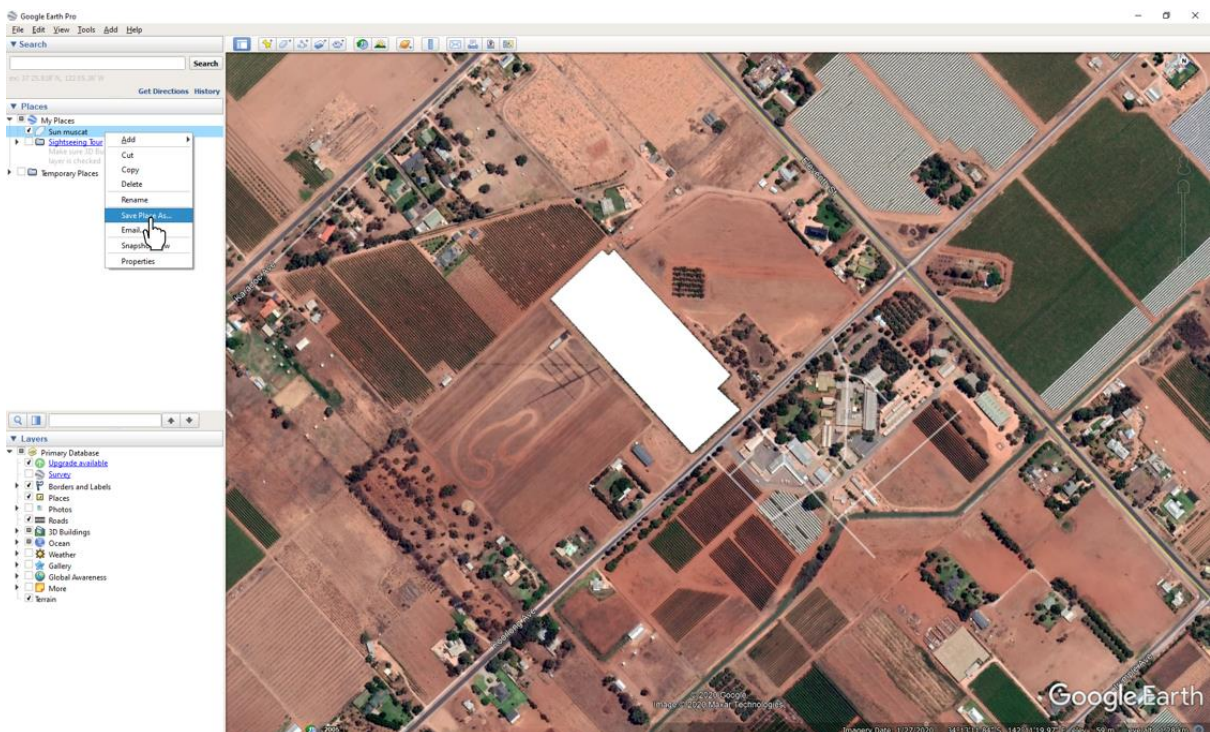




**Step 4:** Now add a field name and click “Ok”.

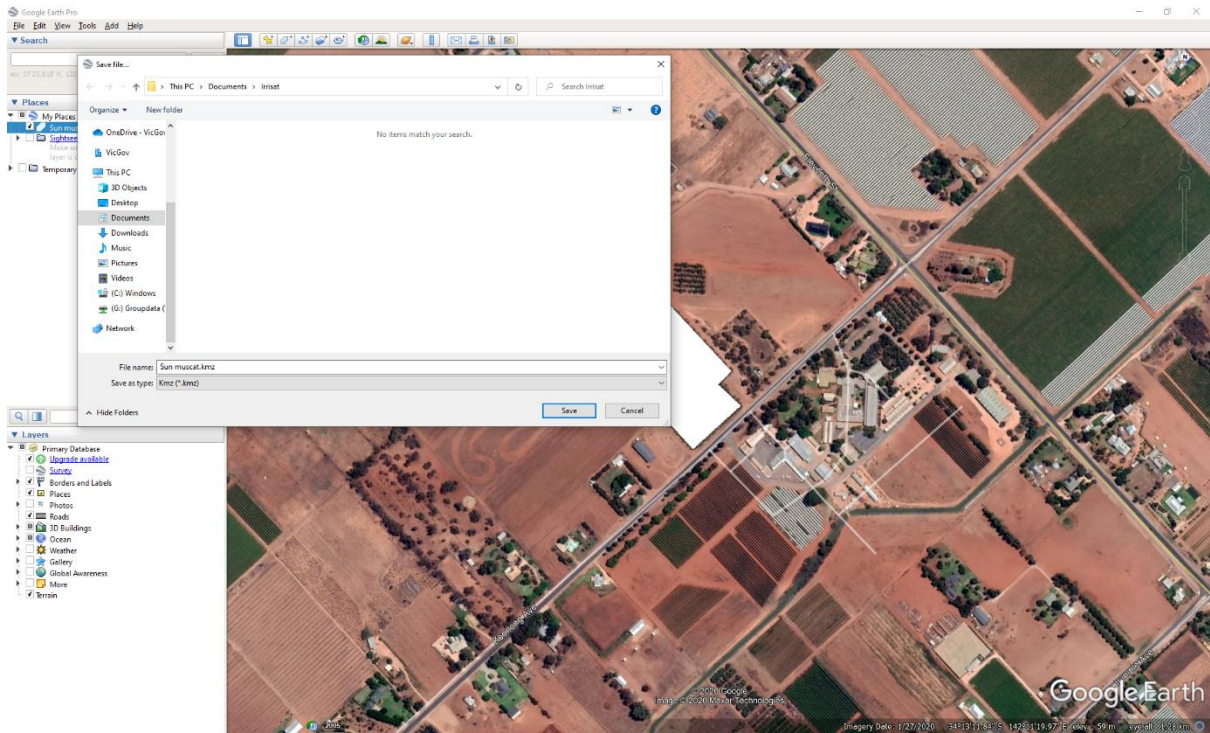


**Step 5:** Find your new polygon in the “Places” box. Right click on the name and click “Save Place As”

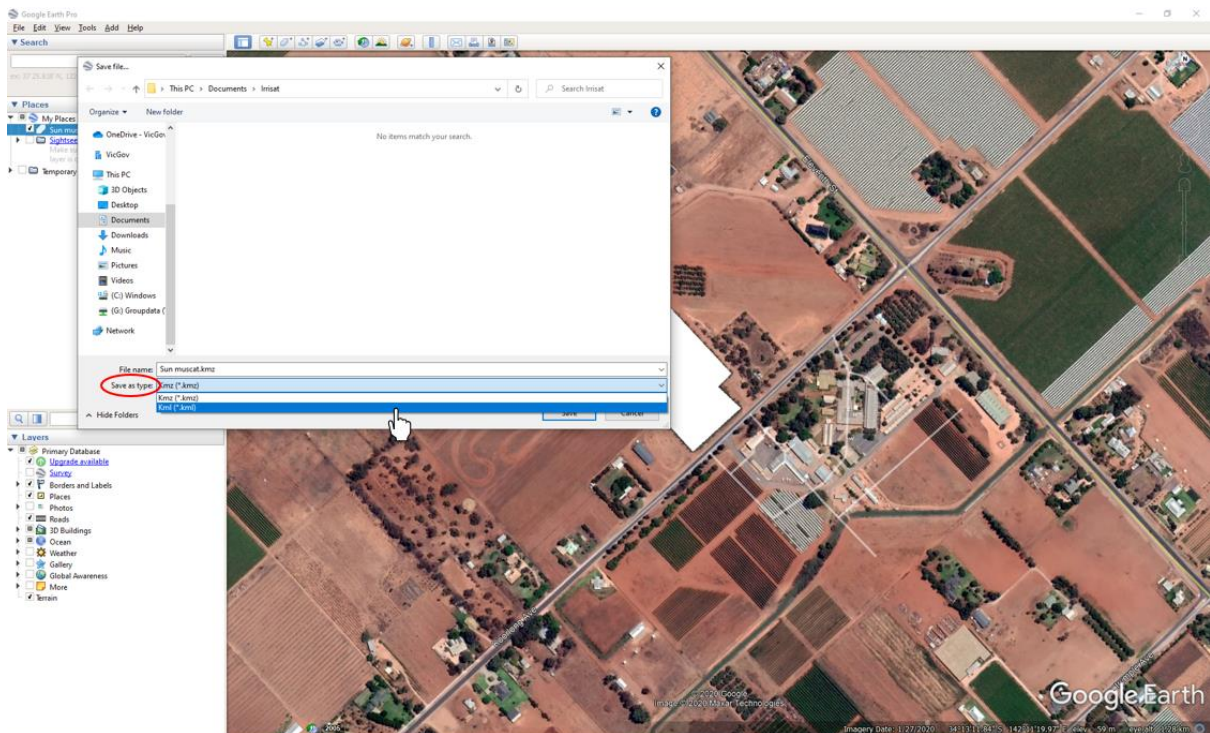




**Step 6:** Choose a location on your computer to save the file. You will need to remember this location.

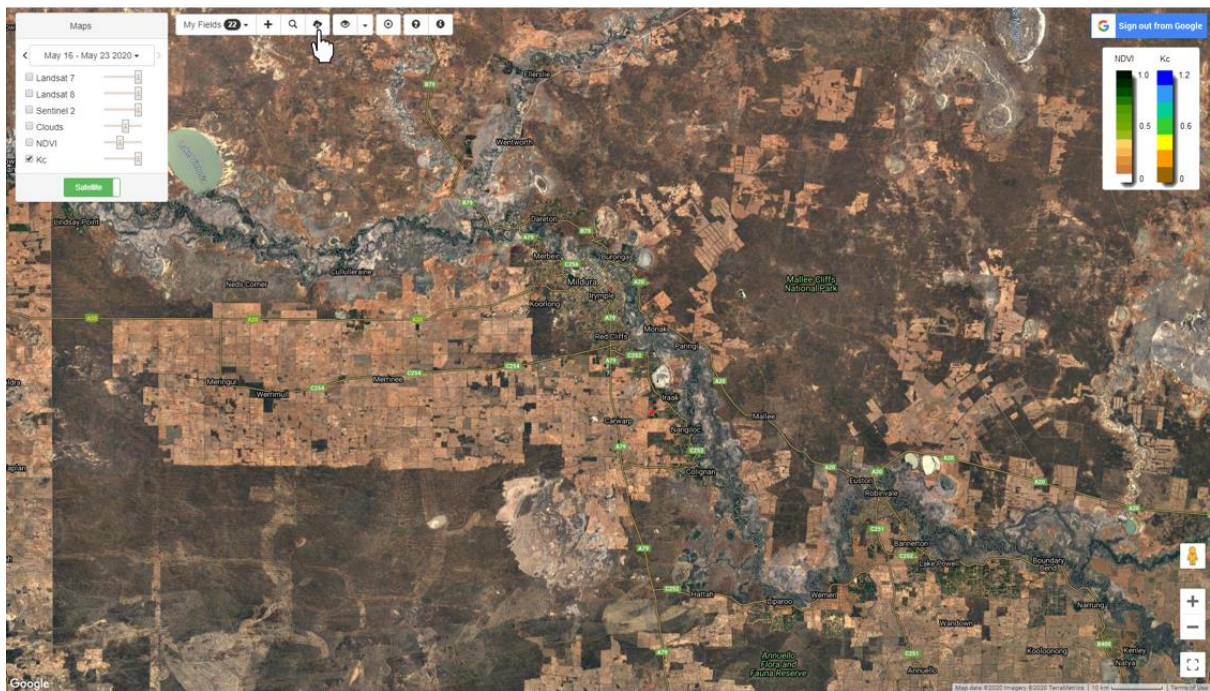


**Step 7:** Change the “Save As Type” to Kml using the drop-down box. Then click Save.

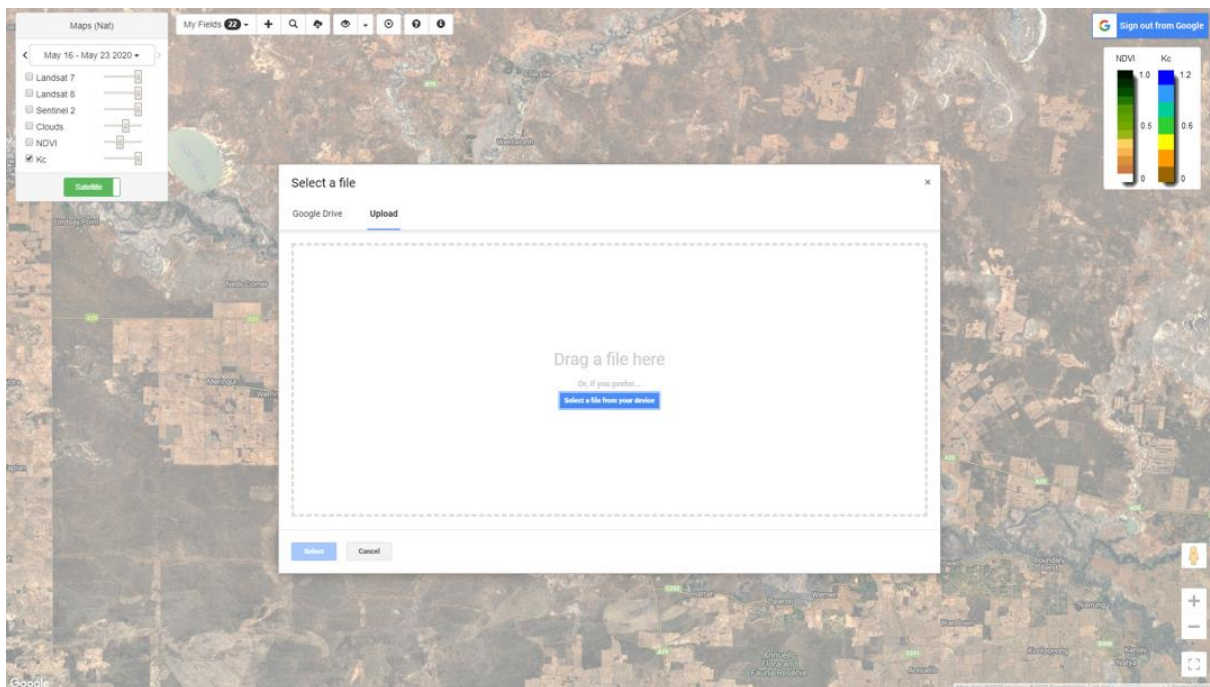




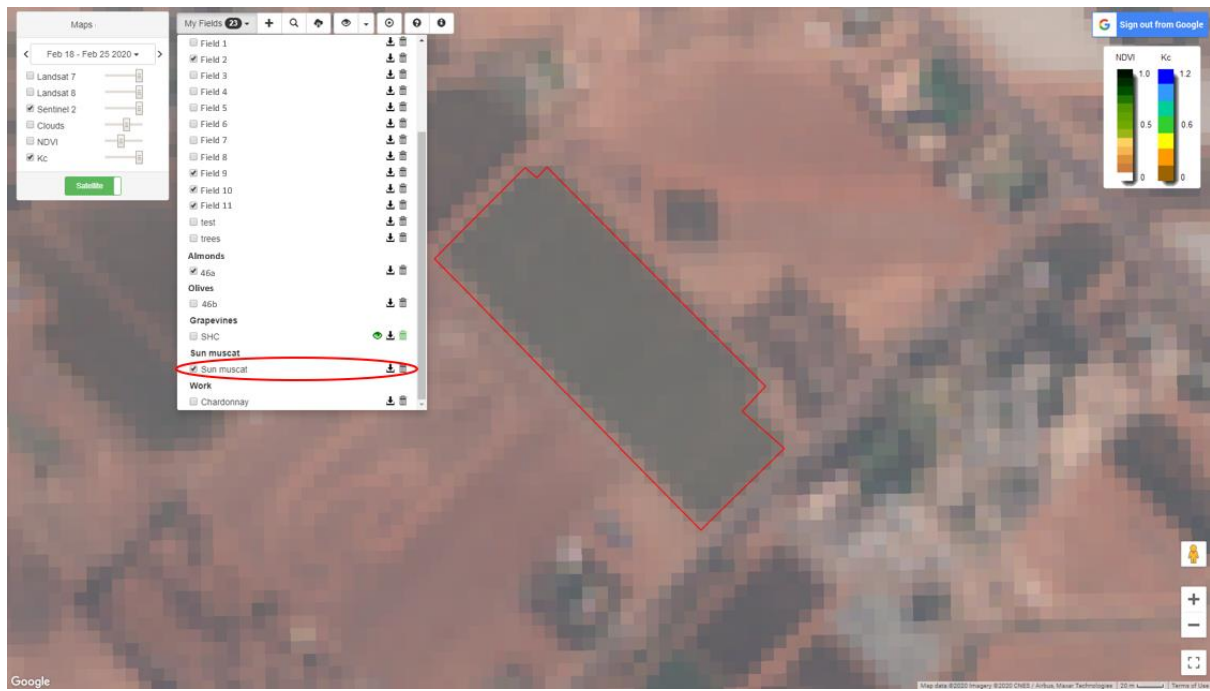
**Step 8:** Open <https://irrisat-cloud.appspot.com/> and click on the cloud icon.



**Step 9:** Click upload and add your kml file.



**Step 10:** Click on “My Fields” to find your new field.

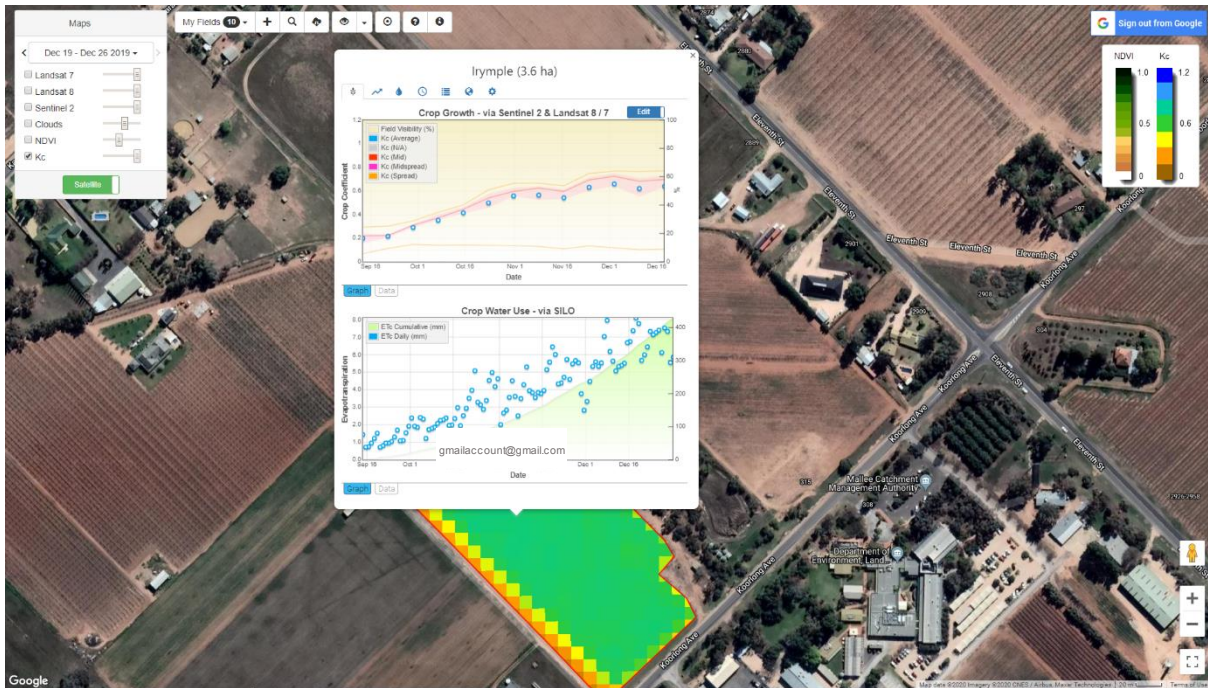




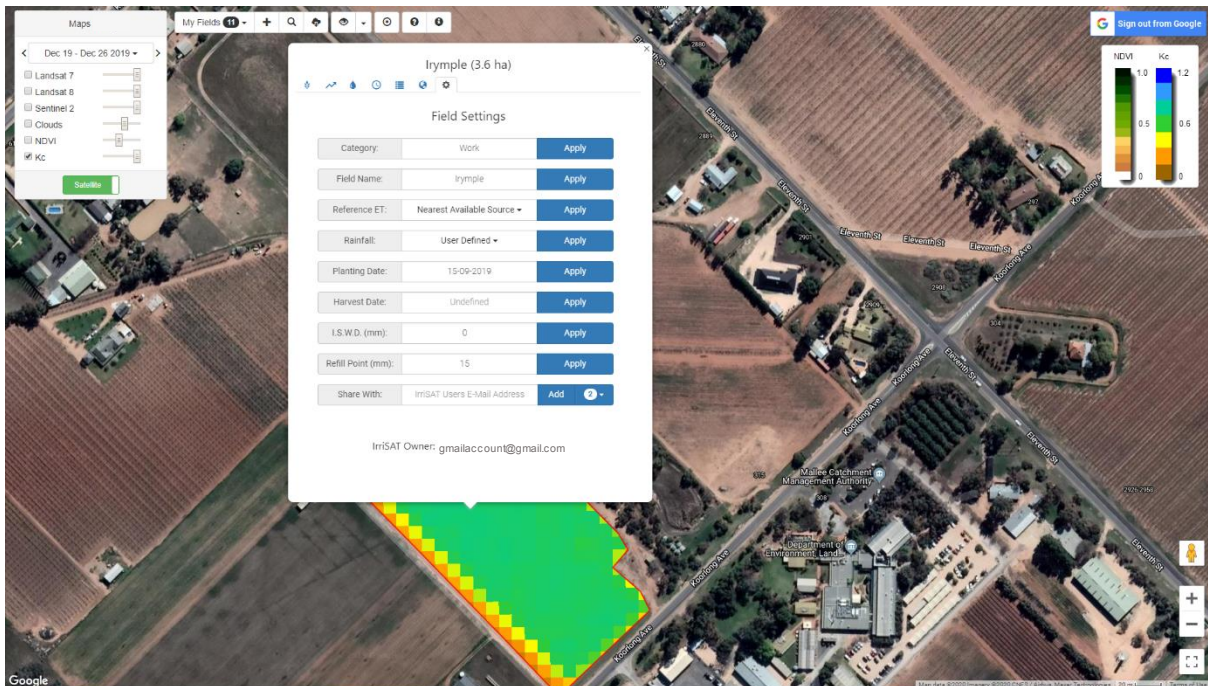
# SHARING AND EDITING FILES

## Sharing Files

**Step 1:** Click on the field you want to share.



**Step 2:** Navigate to the field settings by clicking on the cog icon.

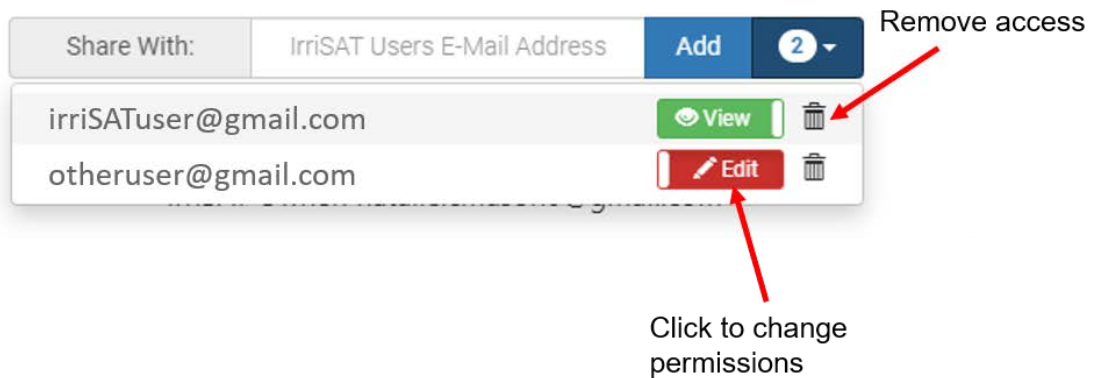


**Step 3:** In the “Share With” setting, type the email address of the IrriSAT user (NOTE: make sure it is the email used for their google account) and click add.



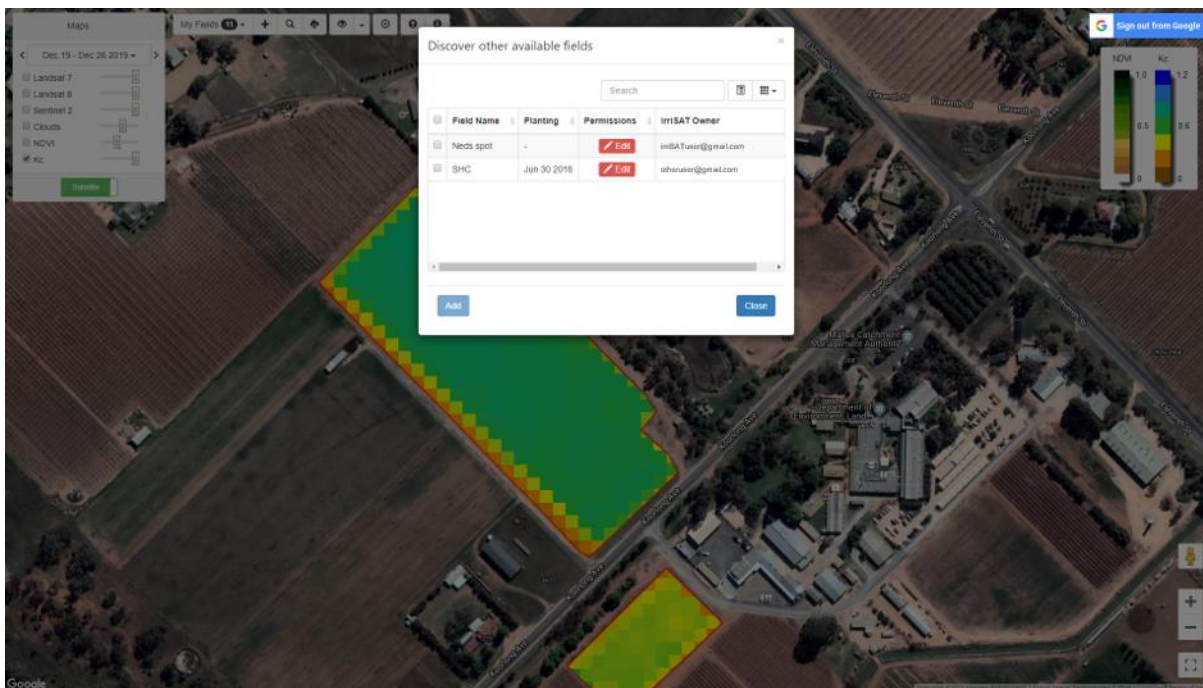
You will notice the number to the right of the add button indicates how many users you have shared the field with.

**Step 4:** Click on the number. A drop down will appear showing the emails of the users you have shared the field with. You can change permissions at any time which allow the users to view the field data or edit the field settings and data.



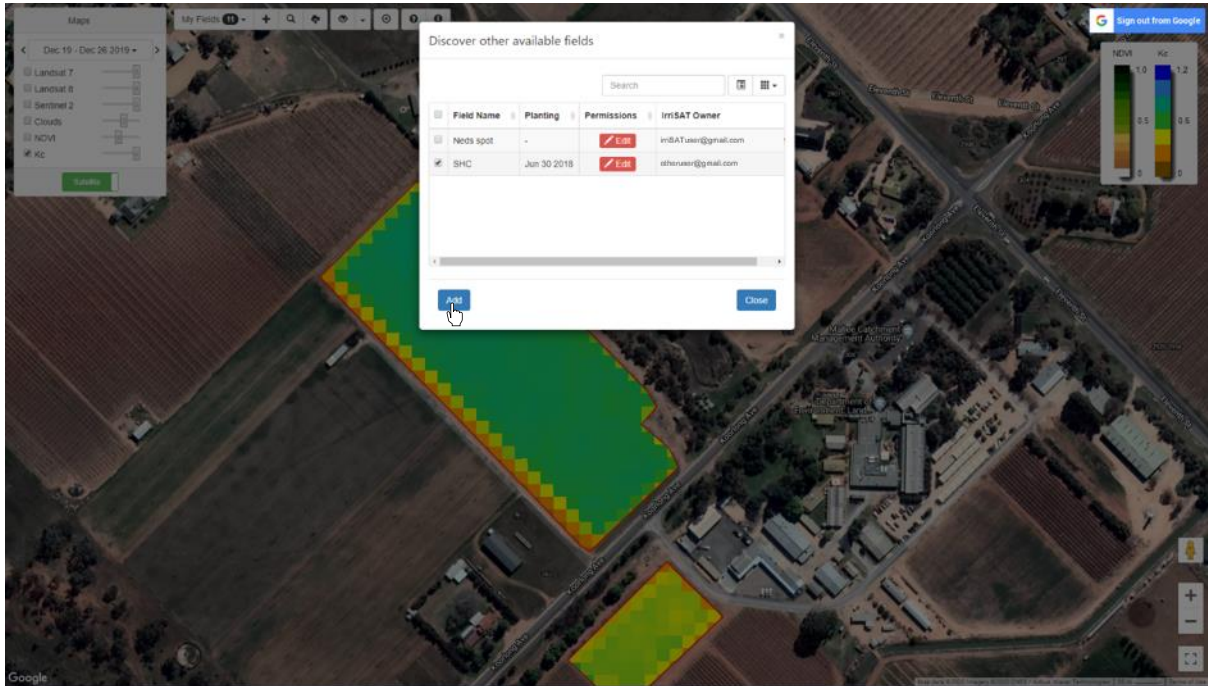
## Viewing Shared Files

**Step 1:** Click on the magnifying glass icon in the main toolbar. Fields that have been shared with you appear.





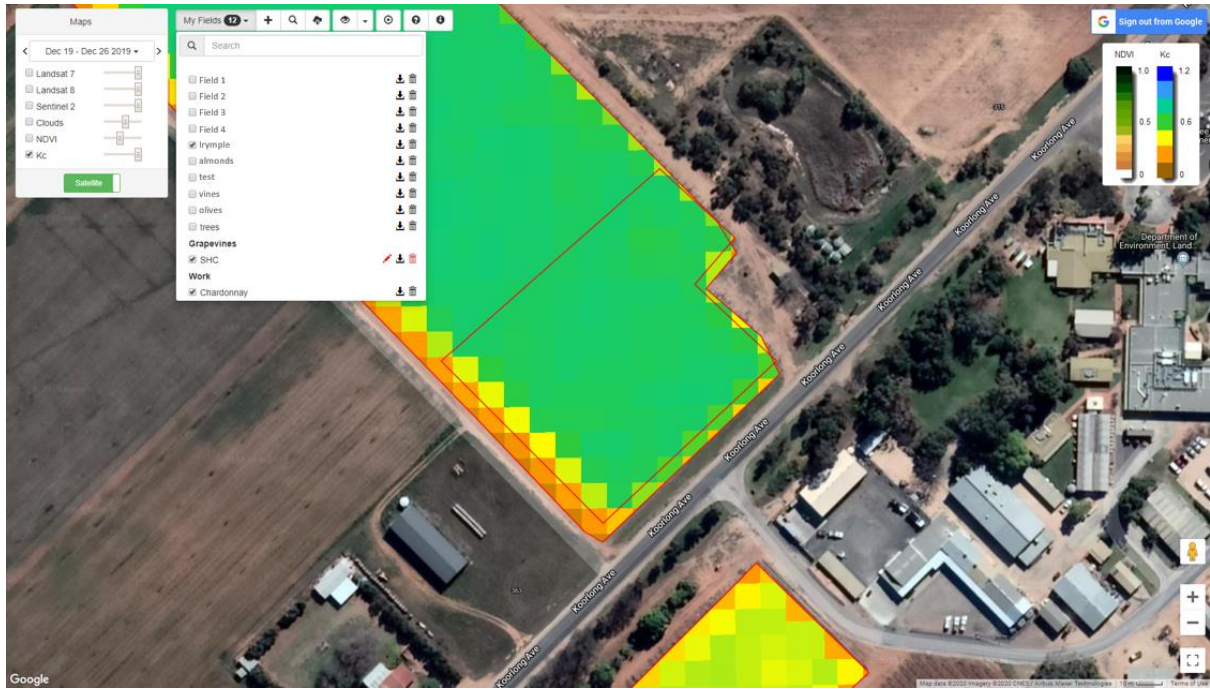
**Step 2:** Check the desired fields and select “add”.



**Step 3:** Click “My Fields” in the toolbar. The fields you have added will be listed here.



**Step 4:** Select the new field to jump to location .







September 2016

# IrriSAT

# Technical

# Reference



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## Executive Summary

IrriSAT is a decision support tool to assist irrigators with irrigation water management. The IrriSAT methodology aims to be as simple as possible (in order to limit the number of inputs and parameters required), yet sufficiently complex to accurately estimate irrigation requirements. The IrriSAT methodology described in this document can be summarised as follows:

- The water balance approach to irrigation scheduling keeps track of the soil water deficit by accounting for all water additions and subtractions from the soil root zone on a daily basis.
- The IrriSAT methodology uses a simplified approach whereby:  $\Delta S = P + I - ET_c$ . This approach assumes crop water consumption (or evapotranspiration) accounts for the biggest subtraction of water from the soil root zone while precipitation and irrigation provide the major additions.
- The soil in the root zone has an upper limit of storing water that can be used by crops. This upper limit is constrained to the field capacity.
- As the crop grows and extracts water from the soil to satisfy its water use requirement ( $ET_c$ ), the stored soil water is gradually depleted.
- $ET_c$  is estimated using field observations and nearby climate observations.
- Crop reference evapotranspiration ( $ET_o$ ) is estimated using the FAO Penman Monteith Tall-Crop (alfalfa) reference using observations obtained from weather stations.
- Crop coefficients ( $K_c$ ) are estimated by directly observing the crop growth on fields using remote sensing techniques. Strong relationships between NDVI and  $K_c$  can be used to achieve this.
- Tracking the water balance deficit in the root zone allows for a refill point to be defined which indicates when irrigation is required.
- Common metrics which can be used to measure the agronomic performance over a growing season include: the irrigation water use index (IWUI); crop water use index (CWUI); and gross production water use index (GPWUI).

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## List of Acronyms

CWUI	Crop Water Use Index
ET	Evapotranspiration
FAO	Food and Agricultural Organization
<i>fc</i>	Field Capacity
GPWUI	Gross Production Water Use Index
IWUI	Irrigation Water Use Index
MAX	Maximum
MIN	Minimum
NDVI	Normalized Difference Vegetation Index
NIR	Near-Infrared Spectrum
PM	Penman-Monteith
<i>pwp</i>	Permanent Wilting Point
RAW	Readily Available Water
R	Red Spectrum
SWD	Soil Water Deficit
TAW	Total Available Water
WUE	Water Use Efficiency

## List of Symbols

### Roman Symbols

$CR$	capillary rise [mm]
$C_n$	numerator constant [-]
$C_d$	denominator constant [-]
$DP$	deep percolation [mm]
$e_a$	actual vapor pressure [kPa]
$e_s$	saturation vapor pressure [kPa]
$E$	evaporation [mm]
$ET_0$	reference evapotranspiration [mm]
$ET_c$	crop evapotranspiration [mm]
$ET_{c,d}$	crop evapotranspiration for day d [mm]
$G$	soil heat flux density [ $\text{MJ m}^{-2} \text{day}^{-1}$ ]
$I$	irrigation [mm]
$I.S.W.D$	initial soil water deficit [mm]
$I_d$	irrigation for day d [mm]
$K_c$	crop coefficient [-]
$K_{c,i}$	the crop coefficient for a crop image pixel [-]
$K_{c,field}$	the arithmetic mean crop coefficient for a crop field [-]
$P$	rainfall [mm]
$P_d$	rainfall for day d [mm]
$R_n$	net radiation at the crop surface
$RO$	surface runoff [mm]
$SWD_d$	soil water deficit for day d [mm]
$SWD_{d-1}$	soil water deficit for the day prior to d [mm]
$T$	transpiration [mm]
$T_a$	air temperature at 2 m height [ $^{\circ}\text{C}$ ]
$U_2$	wind speed at 2 m height [ $\text{m s}^{-1}$ ]
$W_{in}$	water input to a system [mm]
$W_{out}$	water output from a system [mm]

### Greek Symbols

$\Delta$	slope vapor pressure curve [ $\text{kPa } ^{\circ}\text{C}^{-1}$ ]
$\Delta S$	change in soil water storage [mm]
$\Delta SF$	change in subsurface flow [mm]
$\Delta W$	change in soil water volume within a system [mm]
$\gamma$	psychometric constant [ $\text{kPa } ^{\circ}\text{C}^{-1}$ ]

## The Water Balance Model

In order to control the quantity and availability of soil moisture to a crop, a soil water balance is used to model the quantitative water dynamics within the soil. The water balance is a statement of the law of conservation of matter, stating that matter can neither be created nor destroyed but can only change from one state or location to another. All water added to, subtracted from, and stored within a given volume of soil during a given period of time can be defined as:

$$\Delta W = W_{in} - W_{out} \quad \text{eq (1)}$$

Where:

$\Delta W$	change in soil water volume within a system [mm]
$W_{in}$	water input to a system [mm]
$W_{out}$	water output from a system [mm]

Figure 1 (Allen et al 1998) provides a diagram of a full water balance for a unit of soil. Inputs to this water balance consist of water inputs to the soil (irrigation, rainfall, subsurface inflow and capillary rise) and outputs which remove water from the soil (evaporation, transpiration, runoff, subsurface outflow and deep percolation).

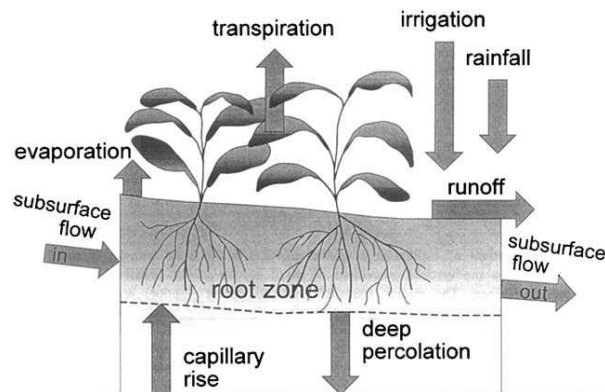


Figure 1: Conceptual full water balance model showing inputs and outputs, Allen et al. (1998)

The full water balance can be described at the soil root zone as:

$$\Delta S = P + I - T - E - RO - DP + CR \pm \Delta SF \quad \text{eq (2)}$$

Where:

$\Delta S$	change in soil water storage [mm]
$P$	rainfall [mm]
$I$	irrigation [mm]
$T$	transpiration [mm]
$E$	evaporation [mm]
$RO$	surface runoff [mm]
$DP$	deep percolation [mm]
$CR$	capillary rise [mm]
$\Delta SF$	change in subsurface flow [mm]



## Simplifying the Water Balance

The IrriSAT water balance model is a simple approach to tracking water deficit in the soil root zone. It further simplifies the water balance described in eq (2) by making the assumption that subsurface flow in and out are generally negligible (consistent with flat irrigated fields found extensively across the major irrigated areas). Additionally, capillary rise is assumed negligible, which would be the case with a water table deep below the soil surface and efficient irrigation practices. In certain irrigation situations these assumptions may not be met so it is important to understand the particular circumstance in terms of how this approach represents these situations. If for instance you have significant deep drainage or capillary rise it is possible to reduce/increase your indicated irrigation inputs to take these elements into consideration. However, in the majority of situations these components are generally small. The soil water storage in the root zone is then represented by the following equation:

$$\Delta S = P + I - ET_c \quad \text{eq (3)}$$

Where:

$\Delta S$	change in soil water storage [mm]
$P$	rainfall [mm]
$I$	irrigation [mm]
$ET_c$	crop evapotranspiration [mm]

These simplifications then leave the IrriSAT water balance deficit model as shown in Figure 2. With evapotranspiration ( $ET_c$ ) removing water from the soil root zone and irrigation and rainfall adding water to the soil root zone.

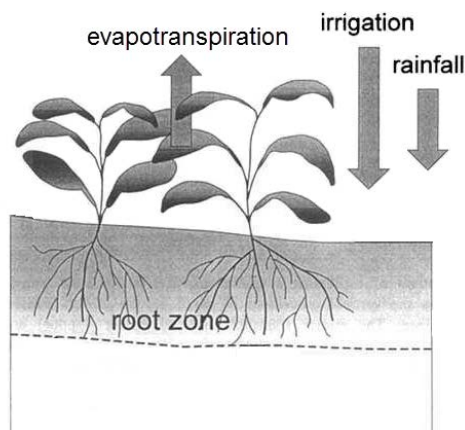


Figure 2: Conceptual IrriSAT water balance model showing inputs and outputs.

## Tracking soil water deficit through time

The soil water deficit (SWD) for any given day can then be represented by tracking the day to day water fluxes described in eq (3). This can be described as:

$$SWD_d = SWD_{d-1} + P_d + I_d - ET_{c,d} \quad \text{eq (4)}$$

Where:

$SWD_d$	soil water deficit for day d [mm]
$SWD_{d-1}$	soil water deficit for the day prior to d [mm]
$P_d$	rainfall for day d [mm]
$I_d$	irrigation for day d [mm]
$ET_{c,d}$	crop evapotranspiration for day d [mm]

## Initial conditions

To initialize the soil water balance in the root zone, an Initial Soil Water Deficit (I.S.W.D) needs to be given. In the absence of no user defined value it is assumed that heavy rainfall has taken place or an irrigation has been applied in order to fill the soil water to field capacity ( $fc$ ) and the default value is 0 mm at the planting date on which the water balance deficit starts. This value however can be overwritten if this initial condition assumption is not met i.e. soil is below field capacity and a user defined value entered. This could be the case if the field was pre irrigated and the planting date occurred days after the irrigation or the planting was undertaken on a dry soil profile.

$$SWD_0 = fc = 0, \text{ (or user defined)} \quad \text{eq (5)}$$

## Boundary constraints

Upper and lower constraints must also be applied to the soil water storage capacity in the soil root zone in order to represent the characteristics of the real world. (i.e. a bucket can no longer be filled once it is already full, and similarly a bucket can no longer be emptied once it is empty). These upper and lower constraints are referred to as the field capacity ( $fc$ ) and the permanent wilting point ( $pwp$ ) respectively and are discussed further in detail in the following section.

$$pwp \leq SWD_d \leq fc \quad \text{Whereby: } fc = 0, pwp < 0 \quad \text{eq (6)}$$

These constraints can then be applied to the daily soil water deficit as:

$$SWD_d = \text{MAX}(pwp, \text{MIN}(fc, SWD_d)) \quad \text{eq (7)}$$

The IrriSAT methodology assumes irrigation or rainfall gets applied to the soil root zone before reaching permanent wilting point, hence further simplifies eq (7) and the number of parameters needed as follows:

$$SWD_d = \text{MIN}(fc, SWD_d) \quad \text{eq (8)}$$

In order to maintain the mass balance defined in eq ( 1 ) it is assumed that if irrigation or rainfall are applied once the SWD reaches field capacity then this water is lost either through deep percolation below the root zone or through runoff. In IrriSAT this is termed 'lost water' - water that is not available for the crop to meet evapotranspiration requirements.

## Crop Water Use ( $ET_c$ )

Crop water requirements ( $ET_c$ ) can be estimated considering a climatic parameter called reference evapotranspiration ( $ET_o$ ), which represents the evapotranspiration from a standardize vegetated surface, and a crop factor called crop coefficient ( $K_c$ ) that relates  $ET_c$  to  $ET_o$  by the equation (Allen et al., 1998):

$$ET_c = ET_o K_c \quad \text{eq ( 9 )}$$

Where:

$ET_c$	crop evapotranspiration [mm]
$ET_o$	reference evapotranspiration [mm]
$K_c$	crop coefficient [-]

$ET_o$  is the rate that an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground evaporates water. As soil factors do not affect this reference surface, the only factors affecting  $ET_o$  are climatic parameters (radiation, air temperature, humidity and wind speed above all) which can be obtained from weather data. Different  $ET_c$  can result between crops even under the same environmental conditions due to differences in height, canopy architecture, ground cover, and development stage.  $K_c$  incorporates the non-weather factors such as canopy architecture, crop-soil resistance and row spacings that cause  $ET_c$  vary from  $ET_o$  into the equation.

Determining  $K_c$  by direct methods (lysimeters, energy balance, and soil water balance) for a specific crop in a single location is expensive and not easy to do and therefore generic  $K_c$  values are typically used, which often do not match the actual crop water use. This is due to the reasons such as differences in canopy management, row spacings, and agronomic management. Indirect methods, however, can be used for this purpose to provide site specific crop coefficients.  $K_c$  has been shown to be closely related to the canopy ground cover fraction (i.e. light interception) which can be estimated from remote sensing measurements of the Normalized Difference Vegetation Index (NDVI). Thus, the IrriSAT methodology integrates information from satellite sources (NDVI;  $K_c$ ) and from on-ground weather stations ( $ET_o$ ) to estimate site specific crop water requirements. This approach allows site specific  $K_c$  to be determined down to each individual pixel in a satellite image and hence crop water.

## Estimating reference evapotranspiration ( $ET_o$ )

Reference evapotranspiration is calculated as detailed in Allen et al. (2005) from climatic data obtained from a local weather station. This is estimated using the FAO Penman-Monteith approach as:

$$ET_o = \frac{0.408\Delta(R_n - G)\gamma \frac{C_n}{T_a + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + C_d U_2)} \quad \text{eq ( 10 )}$$



Where:

$ET_0$	reference evapotranspiration [mm]
$R_n$	net radiation at the crop surface
$G$	soil heat flux density [ $\text{MJ m}^{-2} \text{day}^{-1}$ ]
$T$	air temperature at 2m height [ $^{\circ}\text{C}$ ]
$U_2$	wind speed at 2 m height [ $\text{m s}^{-1}$ ]
$e_s$	saturation vapor pressure [kPa]
$e_a$	actual vapor pressure [kPa]
$e_s - e_a$	saturation vapor deficit [kPa]
$\Delta$	slope vapor pressure curve [ $\text{kPa } ^{\circ}\text{C}^{-1}$ ]
$\gamma$	psychometric constant [ $\text{kPa } ^{\circ}\text{C}^{-1}$ ]
$C_n$	numerator constant [-]
$C_d$	denominator constant [-]

The FAO Penman-Monteith (FAO PM) approach is physically based, and explicitly incorporates both physiological and aerodynamic parameters. Procedures have also been developed to estimate missing climatic parameters (Allen et al. 2005; Romero et al. 2009). This approach can also be used to reference two standardized crop heights which include: short-crop (grass ~12 cm high); and tall-crop (alfalfa ~ 50 cm high) by adjusting the  $C_n$  and  $C_d$  constants.

	$C_n$	$C_d$
<b>Short-Crop</b>	900	0.34
<b>Tall-Crop</b>	1600	0.38

Table 1: Short-Crop and Tall-Crop FAO PM Coefficients for daily calculations

Reference crop evapotranspiration is routinely measured and reported across the world from weather station networks and is also available on a grid based network for many countries.

### Estimating the crop coefficient ( $K_c$ )

The spectral distribution of the light reflected from plant canopies contains information that can be useful for monitoring canopy growth, transpiration, photosynthesis and for diagnosis of biotic and abiotic stresses. Leaf structure and its components such as chlorophyll or other pigments (carotenoids, anthocyanins, etc.) have an effect on the absorption of light. Leaves absorb most of the visible electromagnetic energy (less in the green region which is the reason why vegetation appears green to our eyes) but reflects a large part of the energy in the near-infrared spectrum, which makes its spectral reflectance different from that of soil or water (Figure 3). Green vegetation shows relatively low reflectance in visible wavelength and a suddenly increase at around red-edge (700 nm) while soil tends to show a steadily increasing reflectance with increasing wavelength (Jones 2014).

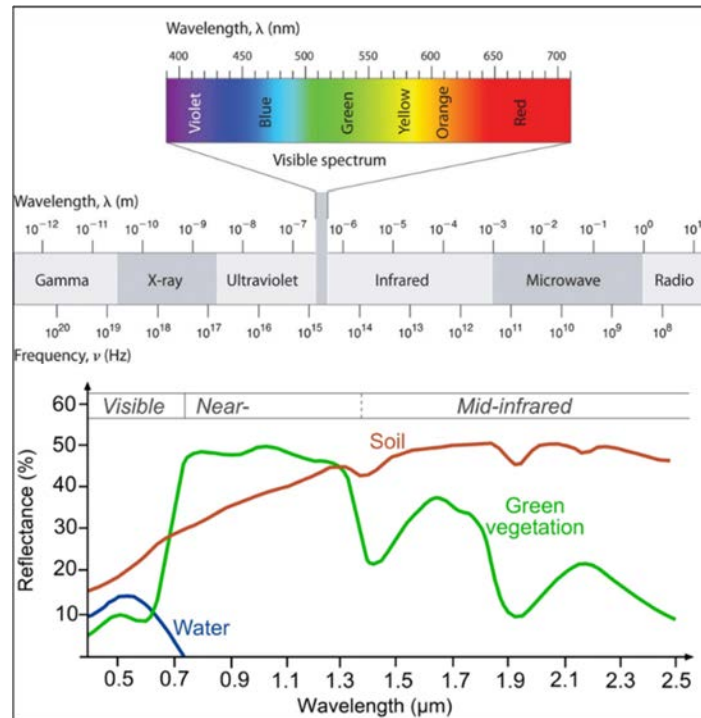


Figure 3: Wavelengths and frequency ranges of electromagnetic radiation (top) and; reflectance distribution of a green vegetation, soil and water surfaces in the visible, near-infrared and mid-infrared wavelengths.

Fully developed vegetation canopies tend to have less reflectance in the red spectrum (R) and higher reflectance in the near-infrared spectrum (NIR) as compared to developing canopies. This relationship is the base of the vegetation index known as NDVI, which is the mathematical combination of the R and NIR spectral bands as follows (Rouse et al., 1974):

$$NDVI = \frac{NIR - R}{NIR + R} \quad \text{eq (11)}$$

There are specific sensors available that enable measuring the reflectance of an object in the spectrum range of interest. Satellites such as the Landsat 7, 8 or Sentinel 2 are equipped with these sensors and are continuously recording data from the visible and infrared spectrum range, providing information that can be used to calculate and monitor the NDVI of a target crop during a whole season. Landsat 7 and Landsat 8 satellites provide images every 8-16 days with a spatial resolution of 30x30m. Sentinel 2 satellite images have a temporal and spatial resolutions of 5-10 days and 10x10m, respectively.

As mentioned above, NDVI has been strongly correlated with crop canopy cover for various crops in semi-arid areas and can be converted to  $K_c$  values by the empirical relationships such as (Trout and Johnson 2007):

$$K_c = 1.37 NDVI - 0.086 \quad \text{eq (12)}$$

After determining the crop coefficient for all pixels within an image the crop coefficient for a field can be determined by calculating the arithmetic mean of all pixels within its boundary:

$$K_{c,field} = \frac{1}{n} \sum_{i=1}^n K_{c,i} \quad \text{eq (13)}$$

Where:

$K_{c,field}$  the arithmetic mean crop coefficient for a crop field [-]  
 $K_{c,i}$  the crop coefficient for a crop image pixel [-]  
 $n$  the number of pixels within a field



## Irrigation Scheduling

In order to manage irrigation scheduling, an understanding of the basic soil states and regions between these states within the soil root zone need to be known (Wigginton et al). These are known as: saturation; field capacity; permanent wilting point; and readily available water, and are discussed in further detail throughout this section.

### Saturation

*Saturation* may occur after heavy rain, during surface irrigation, or following over-irrigation. This is when even the largest pores are filled with water. When the soil is saturated, there is no air for the plant roots. This will stress many plants and is often described as waterlogging.

### Field Capacity

Field capacity (full point) occurs after large soil pores (macropores) have drained due to gravity. Depending on the type of soil, this drainage may take from a few hours up to several days. When the large pores have drained, the soil is still wet, but not saturated. The soil is said to be at *field capacity*. Field capacity in most soils is at a soil-water tension of about  $-8$  kPa. The soil water deficit is 0 mm when the soil is at field capacity.

### Permanent Wilting Point

*Permanent Wilting Point* occurs when the soil reaches a point where the plant can no longer extract moisture because the water content in the soil is too low for the plants roots to enable extraction. Once the soil has passed this point, water is held by the soil so tightly preventing extraction and the plant will start to die. Soil at permanent wilting point is not necessarily "dry". When the water content of a soil is below the permanent wilting point, water is still present in the soil, but plant roots are unable to access it.

### Readily Available Water (RAW)

Only the water between field capacity and permanent wilting point is available to the plant. However, as the level of soil water approaches permanent wilting point, the plant has to work harder to obtain the water. To improve water-use efficiency, irrigators aim to maintain the soil water in the range that can be readily removed by the plant. This range is called the *Readily Available Water* (RAW).

Readily available water is expressed in millimetres per metre (mm/m) and indicates the depth of water (mm) held in every metre (m) of soil that can be readily removed by the plant. To achieve high production without causing waterlogging or excess drainage you need to know the RAW for each crop and field/block. Table 2 shows typical RAW values for various soil textures as well as various crop types.

Water Tension	To -20 kPa	To -40 kPa	To -60 kPa	To -100 kPa	To -1500 kPa
	<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>	<b>E</b>
	Water-sensitive crops such as vegetables and some tropical fruits should be irrigated.	Most fruit crops and table grapes, most tropical fruits.	Lucerne, most pasture, crops such as maize and soybeans, and grapes.	Annual pastures and hardy crops such as cotton, sorghum and winter crops.	TAW is the total water available in the soil. Plants stress well before this level is reached.
Soil texture	Readily Available Water (RAW) mm/m				Total Available Water (TAW) mm/m
<b>Sand</b>	35	35	35	40	60
<b>Sandy loam</b>	45	60	65	70	115
<b>Loam</b>	50	70	85	90	150
<b>Clay loam</b>	30	55	65	80	150
<b>Light clay</b>	25	45	55	70	150
<b>Medium to heavy clay</b>	25	45	55	65	140
<b>Self-mulching clay</b>	38	68	83	98	210

Table 2: Readily Available Water values for different soil textures and various crops

### When to irrigate? (refill point)

After the readily available water has been used, plant roots cannot extract water as easily from the soil and growth is affected. This point is referred to as the *refill point*. As its name suggests, refill point is the time to irrigate. The drier the soil, the more water it needs to return to field capacity.

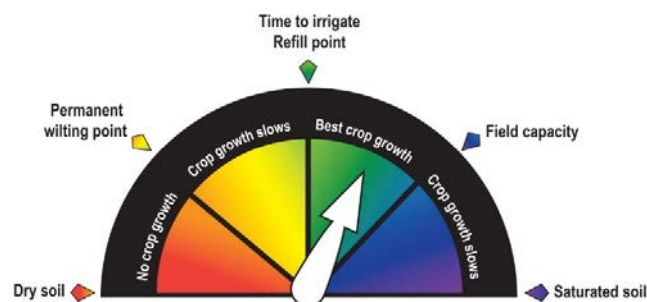


Figure 4: Soil Water 'Fuel Gauge'

Three factors should be taken into account when determining the refill point which are soil type, crop rooting depth and irrigation system. These factors may also change over time, hence the refill point may also change throughout the season.

### Soil Type

Soil type considerations for setting the refill point need to take into account the water holding capacity of the soil. For light sandy soils the amount of water held in the soil is small per meter depth of soil so deficits should be smaller. In heavier clay soils the amount of water held in the soil is greater hence larger deficits can be used.

### Rooting depth

A plant can only access water to its rooting depth and this knowledge needs to be combined with the soil type information above to set an allowable refill deficit. Rooting depth can be visually inspected.

### Irrigation system type

Lastly the type of irrigation system being used needs to be considered when setting the refill point. On sprinkler and pressurized irrigation systems there is a limit to how much water can be applied on a daily basis, hence setting large deficits will see the irrigation system unable to cope with applying set volumes. A drip irrigation system may be limited for instance to a maximum application rate of 10 mm/day hence setting a 50 mm deficit value will see problems in high  $ET_c$  periods as the system will struggle to replenish the root zone once a 50 mm deficit has been reached on a daily basis. Hence this is why pressurized irrigations systems are generally irrigated much more frequently than surface systems. i.e. daily at peak summer  $ET_c$  periods.

On surface irrigation systems application volumes are typically much higher (~ 50-100 mm) hence during high  $ET_c$  periods they still have the ability to rapidly replace large deficits, hence surface irrigation events maybe 5-10 days apart. Knowing these irrigation system limitations are important in guiding where to set the refill point to guide you with irrigation decisions.

So as a guiding principal consider these three factors above when setting the refill point. This value does not affect the water balance deficit but simply provides a point to indicate that the soil moisture profile has reached a value that is beginning to become stressful for the crop and irrigation is needed to maintain a comfortable root zone environment for plant growth.



## Agronomic Performance Indicators

Water use indexes measure the agronomic performance such as productivity or profitability as opposed to the water balance. The time period considered when calculating an agronomic or economic based water use index is generally over a season or year.

### Crop Water Use Index (CWUI)

The Crop Water Use Index (CWUI) or sometimes referred to as Water Use Efficiency (WUE) relates the total production returned to the amount total water consumed by the crop. It is a measure of a crop's capacity to convert water into plant biomass and can be described as:

$$\text{Crop } WUI_{field} = \frac{\text{Yield}}{\text{Total Evapotranspiration}} \quad \text{eq ( 14 )}$$

Where:

*Yield* a quantitative unit representing the production generated [i.e. kg or bale]  
*Total Evapotranspiration* the total evapotranspiration over the growing period [ML]

### Irrigation Water Use Index (IWUI)

The Irrigation Water Use Index (IWUI) relates the total production returned to only the amount of irrigation water used. It does not include rainfall and therefore is only useful for comparing nearby fields or farms within the same growing season. It should not be used to compare farms over significant distance or between seasons, where there can potentially be large differences in the amount of rainfall. The IWUI can be described as:

$$\text{Irrigation } WUI_{field} = \frac{\text{Yield}}{\text{Total Irrigation Applied}} \quad \text{eq ( 15 )}$$

Where:

*Yield* a quantitative unit representing the production generated [i.e. kg or bale]  
*Total Irrigation* the total irrigation amount applied over the growing period [ML]

### Gross Production Water Use Index (GPWUI)

The Gross Production Water Use Index (GPWUI) relates the total production returned to the amount of water used from all sources. It is generally used to compare between farms, regions and seasons and can be described as:

$$\text{Gross Production } WUI_{field} = \frac{\text{Yield}}{\text{Total Water Applied}} \quad \text{eq ( 16 )}$$

Where:

*Yield* a quantitative unit representing the production generated [i.e. kg or bale]  
*Total Water Applied* the total irrigation and rain applied over the growing period [ML]

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## APPENDIX B – KC VALUES FOR A RANGE OF IRRIGATED CROPS

Crop Kc values (FAO56)

Crop type	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Sum
Bare soil													
Bare Soil Loxon	0.36	0.26	0.29	0.18	0.08	0.1	0.07	0.14	0.09	0.19	0.24	0.36	2.35
Almonds (FAO56)		0.41	0.58	0.8	0.9	0.9	0.9	0.9	0.83	0.71			6.93
Almonds 10%sa		0.26	0.3	0.35	0.37	0.37	0.37	0.37	0.35	0.32			3.07
Almonds 30%sa		0.29	0.44	0.62	0.71	0.71	0.71	0.71	0.66	0.57			5.42
Almonds 40%sa		0.3	0.5	0.76	0.88	0.88	0.88	0.88	0.81	0.7			6.6
Almonds 50%sa		0.31	0.54	0.82	0.96	0.96	0.96	0.96	0.88	0.75			7.13
Almonds 70%sa		0.31	0.55	0.86	1	1	1	1	0.92	0.78			7.44
Almonds 90%sa		0.32	0.57	0.89	1.04	1.04	1.04	1.03	0.95	0.81			7.67
Apple (FAO56)			0.61	0.73	0.89	0.95	0.95	0.95	0.95	0.91	0.76		7.69
Apple 10%sa			0.28	0.32	0.38	0.4	0.4	0.4	0.4	0.38	0.35		3.31
Apple 30%sa			0.35	0.5	0.7	0.8	0.8	0.8	0.8	0.74	0.64		6.14
Apple 40%sa			0.38	0.6	0.87	1	1	1	1	0.92	0.79		7.56
Apple 50%sa			0.4	0.64	0.94	1.09	1.09	1.09	1.09	1.01	0.85		8.2
Apple 70%sa			0.41	0.66	0.99	1.14	1.14	1.14	1.14	1.05	0.89		8.56
Apple 90%sa			0.41	0.68	1.02	1.18	1.18	1.18	1.18	1.09	0.92		8.85
Artichoke 1stYR	1	1	0.97	0.5	0.59	0.92	1	1	1	1	1	1	10.98
Artichoke 2ndYR	1	0.97		0.54	0.93	1	1	1	1	1	1	1	10.43
Asparagus	0.53	0.5	0.5	0.5	0.75	0.95	0.95	0.95	0.95	0.95	0.95	0.91	9.38
Avocado	0.61	0.69	0.78	0.84	0.85	0.85	0.85	0.84	0.81	0.78	0.67	0.6	9.18
Banana	1	1	1.02	1.11	1.19	1.2	1.2	1.2	1.2	1.2	1.09	1	13.41
Banksia	0.69	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.71	0.73	0.74	0.72	8.48
Beans Dry						0.4	0.76	1.15	0.73				3.04
Beans Green			0.5	0.82	1.02								2.34
Beetroot							0.5	0.62	1.02	1.03			3.17
Blueberries			0.32	0.57	0.89	1.05	1.05	1.05	1.05	0.9	0.63		7.51
Boronia	1.04	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.07	1.1	1.11	1.08	12.8
Broad Bean	1.01	0.36								0.5	0.66	1.12	3.65
Broccoli	1.02								0.7	0.74	0.95	1.05	4.45
Brussel Sprout						0.7	0.7	0.77	0.94	1.05	1.04	0.97	6.17
Cabbage	0.99								0.7	0.78	1	1.05	4.53
Canola Irrigated	1.07	1.15	1.09	0.61						0.35	0.36	0.66	5.29
Canola Rainfed	0.93	1	0.95	0.56						0.35	0.36	0.6	4.76
Cantaloupe					0.5	0.62	0.82	0.8					2.74
Capsicum				0.6	0.77	1.03	1.05	1.05	1.05	0.97			6.53
Carrot Summer				0.72	0.98	1.05	1.01						3.76
Carrot Winter	1.05	1.01								0.7	0.83	1.04	4.63
Cauliflower	1.01								0.7	0.78	0.98	1.05	4.52
Celery								0.7	0.73	0.96	1.05	1.04	4.47
Cherry			0.61	0.73	0.88	0.95	0.95	0.95	0.95	0.9	0.8		7.7
Cherry RL Early cc			0.78	1.05	1.04	0.96	0.86	0.75	0.65	0.55	0.45		7.11
Cherry RL Early nc			0.55	0.8	0.8	0.75	0.68	0.62	0.56	0.5	0.43		5.68
Cherry RL Late cc			0.55	1	1.05	1.04	0.95	0.82	0.7	0.58	0.46		7.16



Crop type	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Sum
Cherry RL Late nc			0.34	0.76	0.8	0.8	0.74	0.66	0.59	0.51	0.44		5.62
Cherry RL Mid cc			0.55	1	1.05	0.99	0.88	0.77	0.67	0.56	0.46		6.93
Cherry RL Mid nc			0.34	0.76	0.8	0.76	0.7	0.63	0.57	0.5	0.43		5.48
Chickpeas	0.98	1	0.95	0.56							0.4	0.6	4.49
Chinese Cabbage									0.72	0.98	1.02		2.72
Citrus with cover (FAO56)	0.75	0.75	0.74	0.72	0.71	0.7	0.7	0.7	0.7	0.71	0.73	0.74	8.65
Citrus no cover (FAO56)	0.7	0.7	0.69	0.67	0.66	0.65	0.65	0.65	0.65	0.66	0.68	0.69	8.05
Citrus 10%sa	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	3.58
Citrus 30%sa	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	5.92
Citrus 40%sa	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	7.08
Citrus 50%sa	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	8.26
Citrus 70%sa	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	9.74
Citrus 90%sa	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	10.07
Clover Seed	0.4	0.6	0.98	1.15	1.05	0.67						0.4	5.25
Coffee	1.1	1.1	1.1	1.1	1.1	1.1	1.05	1.05	1.07	1.1	1.1	1.1	13.07
Cotton					0.35	0.6	1.05	1.15	1.11	0.85			5.1
Cowpeas/GreenGram							0.4	0.58	1.03	0.81			2.81
Cucumber						0.6	0.83	1	0.98	0.82			4.23
Date Palm	0.9	0.94	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.9	0.9	11.24
Egg Plant				0.6	0.76	1.02	1.05	1.02	0.93				5.38
Eucalyptus	1.2	1.2	1.2	1.2	1.2	1.18	0.98	0.98	1.08	1.2	1.2	1.2	13.82
Faba Bean	0.98	1.15	1.15	0.85	0.41						0.5	0.54	5.58
Garlic	1	1	1	1	0.86	0.73			0.7	0.81	0.98	1	9.08
Geraldton Wax	1.04	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.07	1.1	1.11	1.08	12.8
Jojobe	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	6
Lentil	0.92	1.1	1.1	0.82	0.41						0.4	0.44	5.2
Lettuce Spring	0.72	0.94	0.98										2.64
Lettuce Winter	0.98										0.72	0.94	2.64
Leucadendron	0.69	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.71	0.73	0.74	0.72	8.48
Linseed/Flax	1	1.1	1.1	1.09	0.77	0.38					0.35	0.49	6.28
Lucerne AvCutting (Hay)	0.9	0.91	0.94	0.95	0.95	0.95	0.95	0.95	0.95	0.93	0.9	0.9	11.18
Lucerne SeedProd(FAO56)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	6
Maize Grain			0.3	0.4	0.99	1.2	1.13	0.81	0.62				5.46
Millet			0.3	0.62	1	0.77	0.33						3.02
Olive	0.5	0.5	0.65	0.66	0.68	0.69	0.7	0.7	0.7	0.7	0.7	0.58	7.76
Olive RedcedYield	0.5	0.5	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.56	7.41
Onion Dry	1.04	1.05	1.05	1.05	0.92	0.79					0.7	0.82	7.41
Onion Green	0.99	1	1	1							0.7	0.8	5.49
Onion Seed	1.05	1.05	1.05	1.05	0.94	0.83			0.7	0.83	1.03	1.05	9.57
Open Water	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	12.6
Palm Tree	0.95	0.99	1	1	1	1	1	1	1	1	0.95	0.95	11.84
Parsnips	1.02								0.5	0.56	0.89	1.05	4.01
Pasture HighInput	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	12.6
Pasture LowInput	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	9
Pasture MedInput	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	10.2
Pea Dry	1.15	0.85									0.5	0.8	3.3
Pea Fresh	0.69	1.14	1.14									0.5	3.48
Pear			0.61	0.73	0.88	0.95	0.95	0.95	0.95	0.9	0.79		7.7

Crop type	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Sum
Pecan			0.56	0.68	0.83	0.9	0.9	0.9	0.9	0.83	0.7		7.2
Pimelea	0.69	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.71	0.73	0.74	0.72	8.48
Pineapples	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	6
Pistachios				0.42	0.7	1.03	1.1	1.07	0.69				5.01
Plum			0.56	0.68	0.83	0.9	0.9	0.9	0.9	0.83	0.71		7.2
Potato Summer							0.5	0.65	1.11	1.14	0.92		4.32
Potato Winter	0.5	0.59	1.06	1.15	1	0.76							5.06
Protea	0.69	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.71	0.73	0.74	0.72	8.48
Pumpkin				0.5	0.56	0.92	0.99	0.87					3.84
Radish Autumn Winter										0.7	0.87		1.57
Radish Spring Summer			0.73	0.89									1.61
Rambutan	0.6	0.67	0.79	0.92	1.05	1.1	1.1	1.1	1.1	0.73	0.5	0.5	10.16
Rhubarb	0.99	0.87	0.5	0.5	0.5	0.77	1	1	1	1	1	1	10.12
Rockmelons				0.5	0.68	0.85	0.83	0.67					3.53
Sesame						0.35	0.77	1.1	0.8				3.03
Silverbeet						0.59	1.02	0.99					2.59
Sorghum			0.3	0.45	0.94	0.99	0.72						3.4
Soybeans						0.4	0.88	1.15	1.15	0.98	0.6		5.16
Spinach	0.98									0.72	0.93	1	3.62
Spring Onion - Summer			0.7	0.74	0.97								2.41
Spring Onion - Winter	1									0.71	0.87	1	3.57
Stonefruit Apricot (FAO56)	0	0	0.56	0.68	0.83	0.9	0.9	0.9	0.9	0.83	0.71		7.2
Stonefruit Apricot 10%sa			0.27	0.3	0.34	0.36	0.36	0.36	0.36	0.34	0.31		3
Stonefruit Apricot 30%sa			0.33	0.44	0.6	0.67	0.67	0.67	0.67	0.62	0.54		5.22
Stonefruit Apricot 40%sa			0.35	0.52	0.73	0.83	0.83	0.83	0.83	0.76	0.65		6.33
Stonefruit Apricot 50%sa			0.38	0.59	0.86	0.99	0.99	0.99	0.99	0.91	0.76		7.44
Stonefruit Apricot 70%sa			0.41	0.68	1.02	1.19	1.19	1.19	1.19	1.09	0.9		8.85
Stonefruit Apricot 90%sa			0.41	0.7	1.06	1.23	1.23	1.23	1.23	1.12	0.93		9.15
Stonefruit Peach (FAO56)			0.56	0.68	0.83	0.9	0.9	0.9	0.9	0.83	0.71		7.2
Stonefruit Peach Reduced Yield			0.57	0.47	0.42	0.68	0.9	0.9	0.9	0.83	0.71		6.38
Stonefruit Riverland early			0.37	0.69	1.02	1.17	0.5	0.5	0.43	0.24			4.92
Stonefruit Riverland mid			0.37	0.69	0.86	0.9	1.01	1.25	0.97	0.24			6.29
Stonefruit Riverland late				0.66	0.86	0.89	1	1.25	1.09	0.51			6.26
Strawberry	0.85	0.85	0.85	0.79	0.75				0.4	0.44	0.68	0.85	6.45
Sunflower				0.35	0.45	1.02	1.15	0.76					3.74
Sweet Potato				0.54	1.01	1.15	1.12	0.83					4.64
Sweetcorn			0.3	0.62	1.14	1.12							3.18
TableGrape (FAO56)			0.3	0.42	0.75	0.85	0.85	0.84	0.59				4.6
Table Grape 10%sa		0.26	0.28	0.34	0.35	0.35	0.35	0.35	0.33	0.32			2.93
Table Grape 30%sa		0.27	0.38	0.62	0.65	0.65	0.65	0.64	0.59	0.55			5.01
Table Grape 40%sa		0.28	0.43	0.76	0.8	0.8	0.8	0.79	0.72	0.67			6.04
Table Grape 50%sa		0.29	0.48	0.9	0.95	0.95	0.95	0.93	0.85	0.78			7.08
Table Grape 70%sa		0.29	0.53	1.03	1.09	1.09	1.09	1.07	0.97	0.89			8.04
Table Grape 90%sa		0.3	0.55	1.1	1.17	1.17	1.17	1.14	1.03	0.95			8.57
Tea	0.95	0.98	1	1	1	1	1	1	1	1	0.95	0.95	11.83
Tomato			0.6	0.63	0.96	1.15	1.12	0.9					5.36

Crop type	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Sum
Turf SumActive			0.81	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85		7.61
Turf YrRound Active	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	11.4
Turnip									0.5	0.65	1.08	1	3.23
Walnuts			0.5	0.66	0.96	1.1	1.1	1.1	1.1	1.03	0.77		8.32
WaterMelons				0.44	0.87	0.98	0.83						3.12
Wheat/Barley	1	1.15	1.11	0.58							0.3	0.5	4.64
Winegrape (FAO56)			0.32	0.55	0.7	0.7	0.7	0.7	0.63	0.51			4.81
Winegrape Reduced Yield (SARDI)				0.29	0.39	0.43	0.43	0.43	0.39	0.24	0.16		2.76
Winegrape 10%sa			0.26	0.28	0.3	0.3	0.3	0.3	0.29	0.28			2.3
Winegrape 30%sa			0.28	0.41	0.49	0.49	0.49	0.49	0.47	0.42			3.56
Winegrape 40%sa			0.29	0.47	0.59	0.59	0.59	0.59	0.56	0.5			4.18
Winegrape 50%sa			0.3	0.54	0.69	0.69	0.69	0.69	0.65	0.57			4.82
Winegrape 70%sa			0.31	0.6	0.78	0.78	0.78	0.78	0.73	0.64			5.39
Winegrape 90%sa			0.32	0.63	0.83	0.83	0.83	0.83	0.78	0.68			5.72
Zucchini				0.5	0.56	0.88	0.88						2.82
South East Kc Values													
SE CANOLA - ZSEED MULTIPLICATION*			0.35	0.41	0.85	1.1	0.91						3.62
SE CANOLA (S)*	0.48	0.73	0.98	1.05	0.73	0.22					0.35	0.35	4.87
SE CARROT ZSEED	0.7	0.76	0.88	0.99	1.05	1			0.7	0.7	0.7	0.7	8.18
SE CEREALS*	0.44	0.72	1	1.15	0.78							0.3	4.39
SE CHINESE CABBAGE ZSEED		0.41	0.85	1.1	0.91								3.27
SE CLOVER ZSEED - ANNUAL	0.4	0.59	0.96	1.15	1.08	0.35						0.4	4.93
SE CLOVER ZSEED - PERRENNIAL	0.9	0.9	0.9	1.1	1.15	1.08	0.35		0.33	0.9	0.9	0.9	9.4
SE CLOVER ZSEED - PERSIAN	0.4	0.53	0.78	1.03	1.15	1.15	1					0.4	6.43
SE CLOVER ZSEED - RED	0.4	0.51	0.72	0.94	1.12	1.15	1.15	1				0.4	7.39
SE CLOVER ZSEED - SUBTERRANEAN	0.4	0.75	1.1	1.1	1.1	0.41					0.4	0.4	5.66
SE CORIANDER	0.7	0.79	0.96	1.05	1.05	0.5							5.05
SE FRUIT TREES*			0.3	0.62	0.78	0.93	0.95	0.95	0.95	0.93	0.82		7.22
SE GRASS ZSEED	0.75	0.75	0.95	1.15	0.39				0.66	0.75	0.75	0.75	6.9
SE LUCERNE FODDER	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.4	0.4	8.3
SE LUCERNE HAY*	0.4	0.63	0.85	0.85	0.85	0.85	0.85	0.85	0.63	0.4	0.75	0.75	8.65
SE LUCERNE SEED Prod	0.75	0.75	0.91	0.95	0.95	0.86	0.5	0.5	0.47	0.25	0.48	0.75	8.11
SE LUCERNE ZSEED*	0.75	0.75	0.9	0.95	0.95	0.84	0.5	0.5	0.43	0.24	0.46	0.75	8.01
SE LUPINS	0.4	0.55	0.85	1	0.84								3.64
SE MAIZE				0.3	0.53	0.98	1.2	1.2	0.99				5.19
SE MUSTARD		0.35	0.44	1.01	1.1								2.9
SE NATIVE FLOWERS*	0.4	0.4	0.4	0.48	0.64	0.63	0.64	0.64	0.56				4.79
SE NATIVE FOLIAGE*	0.57	0.56	0.38	0.2	0.25	0.34	0.43	0.51	0.56	0.57	0.58	0.58	5.53
SE OLIVE - FRESH*	0.65	0.65	0.69	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.69	0.65	8.23
SE OLIVE - OIL*	0.5	0.5	0.61	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.61	0.5	7.27
SE ONION				0.7	0.7	0.79	0.96	1.05	1.05	0.9			6.15
SE ONION SEED			0.7	0.7	0.79	0.96	1.05	0.93					5.13
SE PATURE	0.4	0.63	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85			7.83
SE PATURES - FINISHER	0.75	0.75	0.75	0.75	0.38								3.38
SE PASTURE - HALF	0.4	0.63	0.85	0.85	0.85	0.85							4.43



Crop type	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Sum
SE PASTURE - HIGH INPUT	0.4	0.73	1.05	1.05	1.05	1.05	1.05	1.05	1.05	0.95			9.43
SE PASTURE ROTATION GRAZING	0.4	0.64	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.75	0.75	9.34
SE PASTURE - STARTER								0.3	0.41	0.64			1.35
SE PEAS - FIELD	0.25	0.54	0.83	1.11	0.58								3.3
SE POTATOES - ZSEED					0.5	0.7	0.9	0.9					3
SE POTATOES (N)			0.5	0.83	1.15	1.15	1.15	0.48					5.25
SE POTATOES (S)				0.5	0.72	1.1	1.15	1.05					4.52
SE RADISH ZSEED		0.7	0.78	0.85	0.84	0.39							3.55
SE REFERENCE CROP*	1	1	1	1	1	1	1	1	1	1	1	1	12
SE STIRLING LUCERNE CAT. 2*	0.75	0.75	0.9	0.95	0.95								4.3
SE STIRLING LUCERNE CAT. 3*	0.75	0.75	0.9	0.95	0.95				0.75	0.75	0.75	0.75	7.3
SE STIRLING LUCERNE CAT. 4*						0.84	0.5	0.5					1.84
SE STIRLING LUCERNE CAT. 5*					0.71	0.84	0.5	0.5					2.55
SE STIRLING LUCERNE CAT. 6*						0.84	0.5	0.5	0.5	0.27	0.68	0.75	4.04
SE STIRLING LUCERNE CAT. 7*	0.75	0.75	0.9	0.95	0.95	0.84	0.5	0.5	0.13				6.27
SE STIRLING LUCERNE CAT. 8*	0.75	0.75	0.9	0.95	0.95	0.84	0.5	0.5	0.5	0.27	0.68	0.75	8.34
SE SUMMER FODDER (N)					0.3	0.5	0.7	0.7	0.7	0.7	0.5		4.1
SE SUNFLOWER				0.15	0.35	0.53	1.05	1.05	0.38				3.5
SE SWEETCORN					0.3	0.75	1.15	1.05					3.25
SE WINEGRAPE*			0.33	0.5	0.68	0.7	0.5	0.43	0.43	0.39	0.33		4.29

\*Specific SE crop calendars