# Water use efficiency of table and wine grapes in Western Cape, South Africa

## 1 Introduction

The Western Cape of South Africa is facing an increasing demand for water whilst water resources are scarce. As the water usage by the agricultural sector of Western Cape is significant (43% of the total water use) this sector needs to be actively involved in finding solutions to a looming water shortage crisis (Roux, 2006). The amount of water required by irrigated agriculture needs to be reduced, whilst the grape industry is maintained economically sustainable. Optimal use of the limited water resources is therefore essential. Information on the water use efficiency of different crops, farms and irrigation is required to suggest improvement in the water utilization. The application of remote sensing technologies makes it possible to estimate and evaluate water use efficiencies spatially and temporally.

This study aims at improving the understanding of the spatial and temporal variation of water use efficiency in grape cultivation in order to inform farmers how productively they are managing their available water resources.

## 2 Materials and methods

This study focuses on table and wine grape vineyards in the coastal regions of Western Cape (Paarl, Franschhoek, Stellenbosch and Somerset West) and on the table and wine grape vineyards in the Breede River Valley (Worcester and Hex Valley). The grape growing season normally extends from September to April. Annual rainfall is highly variable over the study areas, and ranges from 200 mm/year in some parts of the Breede River Valley to 1000 mm/year in the coastal areas.

The Surface Energy Balance Algorithm for Land (SEBAL) is used to estimate total evapotranspiration (ET), biomass production and water use efficiency (WUE) for table and wine grapes for three growing seasons: September 2004 to April 2005, September 2005 to April 2006, and September 2006 to April 2007. SEBAL requires the input of a number of biophysical parameters which can be derived from satellite images. Images of the Landsat 5-TM and Landsat 7-ETM satellites (path 175, rows 83 and 84) were used to derive information on albedo, NDVI and surface temperature.

**Table 1 List of acquired Landsat images and the period for which they will be used in the SEBAL modelling**

| ***Date*** | ***sensor*** | ***p175 r83*** | ***p175 r84*** | ***SEBAL period*** | ***Date*** | ***sensor*** | ***p175 r83*** | ***p175 r84*** | SEBAL period |
|---|---|---|---|---|---|---|---|---|---|
| 20/09/04 | 5TM | ● | ● | September 2004 | 20/12/05 | 7ETM | ● | ● | December 2005 |
| 22/10/04 | 5TM | ● | ● | October 2004 | 06/02/06 | 7ETM | ● | ● | January/February 2006 |
| 30/10/04 | 7ETM | ● | not available | October 2004 | 10/03/06 | 7ETM | ● | ● | March/April 2006 |
| 15/11/04 | 7ETM | ● | ● | November 2004 | 25/08/06 | 5TM | ● | ● | For grape classification only |
| 09/12/04 | 5TM | ● | ● | December 2004 | 12/10/06 | 5TM | ● | ● | September/October 2006 |
| 18/01/05 | 7ETM | ● | ● | January 2005 | 28/10/06 | 5TM | ● | ● | November 2006 |
| 27/02/05 | 5TM | ● | ● | February 2005 | 23/12/06 | 7ETM | ● | ● | December 2006 |
| 23/03/05 | 7ETM | ● | ● | March/April 2005 | 17/02/07 | 5TM | ● | ● | January/February 2007 |
| 09/10/05 | 5TM | ● | ● | September/October 2005 | 13/03/07 | 7ETM | not available | ● | March/April 2007 |
| 04/12/05 | 7ETM | ● | ● | November 2005 | 29/03/07 | 7ETM | ● | not available | March/April 2007 |

The MeteoLook algorithm (Voogt, 2006) interpolates and extrapolates climatic point data on the basis of physiographical properties. Meteorological data of a large number of weather stations was extrapolated using the MeteoLook algorithm. The spatial estimates of air temperature, relative humidity, wind speed and solar radiation served as input for SEBAL.

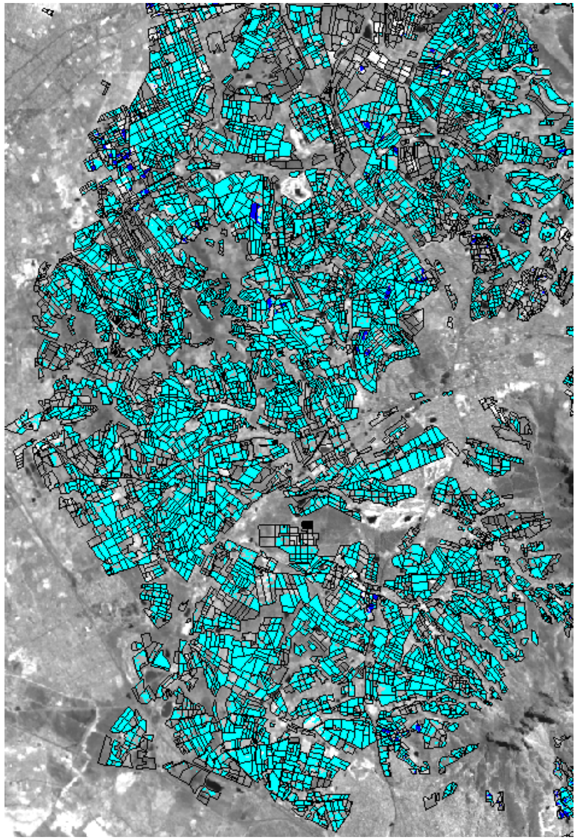

**Figure 1 Grape map (wine grapes in cyan, table grapes in blue)**

Land cover is another input of SEBAL, and also of importance in the analysis of the results. A land cover map was created on the basis of sequential unsupervised classification of Landsat 5-TM images and a polygon dataset including all agricultural fields in the Western Cape that was prepared by the Department of Agriculture. Besides land cover, vineyards were classified using the satellite imagery. A WaterWatch team visited the six study areas in December 2006 and 2007 to collect information on the exact location of the vineyards, the type of farming (table, wine or bush grapes) and the condition of the grapes (e.g. recently planted). The field survey resulted in a ground truth data set of ~3700 vineyards that was used to check the accuracy of the vineyard map. Overall accuracy of the vineyard classification was 82%. Table and wine grapes only cover 2.4% of the total land surface on the two satellite images with respectively 17,525 and 51,158 ha.

The Department of Agriculture has been measuring rainfall, irrigation application and soil moisture in 27-32 blocks in Hex Valley since 1991. Five table grape varieties are cultivated in the blocks, and grape production has been measured for each block. Wine grape yield, rainfall, irrigation application and soil moisture of 2005 was measured in 11 Colombar blocks in Worcester area. The water balance is calculated from the measurements on precipitation, irrigation and soil moisture.

The biomass production calculated by SEBAL can be defined as the total dry matter production by a plant (roots, stems, leaves and fruit). To translate the biomass production to yield, an empirical yield model was developed using the field measurements of yield in Hex Valley and Worcester. The Harvest Index (HI) indicates the part of biomass that is harvested. In this study the harvest index is an empirical function of water deficit in February and soil moisture content in November/December. The final grape yield depends on the biomass, the harvest index and the moisture content of the berries (fixed for table grapes, variable for wine grapes). The table grape model needed annual adjustment by using a single constant.

The spatial estimates of evapotranspiration and yield were used to calculate water use efficiency (WUE in kg/m$^3$). Water use efficiency (or water productivity) is defined as the marketable crop yield (Y in kg/ha) per unit of actual total evapotranspiration (ET in mm).

$$WUE = \frac{Y}{10 * ET}$$

## 3 Results

The three study years varied considerably from a hydrological point of view. The summer of 2004-5 was wet, with high rainfall in all areas. The summer of 2005-6 was the opposite, with very low rainfall. In 2006-7 the summer rainfall was still low in the Breede River Valley, but moderate in the coastal areas. In the coastal regions winter rainfall was relatively stable over the years. In most areas winter rainfall was (slightly) lower in 2004, although this effect was strongest in Worcester and Hex Valley. Winter rainfall in Worcester was low in 2005 and high in 2006, while in Hex Valley the exact opposite happens. Annual rainfall varied from over 800 mm in Franschhoek, Stellenbosch and Somerset West to less than 400 mm in Hex Valley and Worcester.

Irrigation supply in the season 2004-5 in Hex Valley was on average 559 mm, and increased to 725 and 729 mm in respectively 2005-6 and 2006-6. Irrigation supply in 2004-5 also started earlier than the two following years, most probably because of the dry preceeding winter. Soil moisture measurements indicate that on average 42 mm of soil moisture is consumed each year between October and March, which is low compared to the contribution of rainfall and irrigation.

Water consumption (actual evapotranspiration) estimated by SEBAL is validated using the water balance measurements of the Department of Agriculture in Hex Valley. The results of the validation are shown in Figure 3. SEBAL results are 11%, 7% and -16% higher in respectively 2004-5, 2005-6 and 2006-7. These differences can be attributed to both model and field measurements.

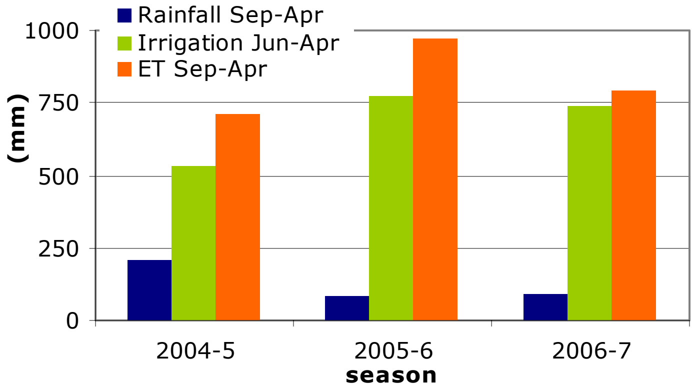


**Figure 2 Average rainfall, irrigation and water consumption in the Hex Valley blocks**

Figure 2 shows the average rainfall, irrigation and water consumption in the Hex Valley blocks. Low summer rainfall in 2005-6 and 2006-7 results in higher irrigation supply. In 2006-7 water consumption however does not increase equally with irrigation supply, which most probably is related to a better distribution of the rainfall over the season.

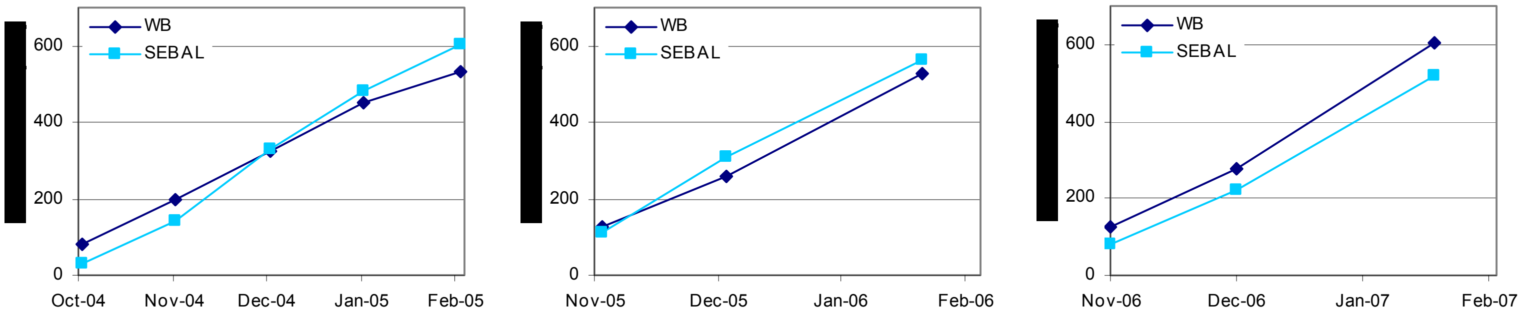


**Figure 3 Average period and accumulated evapotranspiration in the experimental blocks in Hex Valley during 2004-5, 2005-6 and 2006-7 calculated with SEBAL and with the soil water balance based on field experiments**

Figure 4 shows the frequency distributions of water consumption in table and wine grape vineyards in the three study seasons. Water consumption of table grapes is higher in 2005-6 and 2006-7, which might be related to higher cloud cover in 2004-5 and more available irrigation water in 2005-6 and 2006-7. The standard deviation of table grape water consumption was much lower in 2004-5. Water resources seemed to be more limiting in 2004-5, resulting in lower water consumption in all fields, thus a tendency to become more uniformly water stressed. Water consumption of wine grapes was more similar over the three years, with a small increase in 2006-7. For wine grape production it is more important to apply water stress than for table grape production, and water consumption does therefore not increase with increased water availability.

The standard deviation was for both table and wine grapes highest in 2005-6, which might be related to the temporal distribution of rainfall in that year. The red coloured part of the frequency distribution is very similar for all three years, which indicates there are farms with very strict water conservation practices.

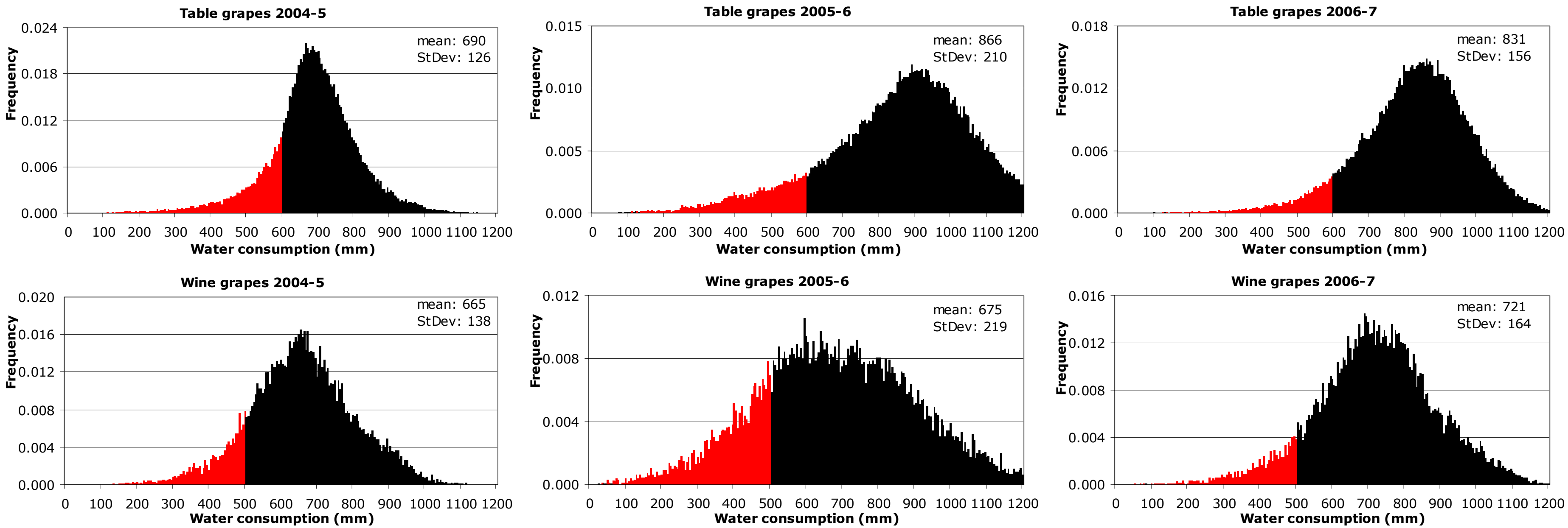


**Figure 4 Frequency distribution of water consumption in the season 2004-5, 2005-6 and 2006-7 for all pixels in classified as table grape in Hex River Valley, Worcester, Paarl (n= 76415) or as wine grapes in Worcester (n=19891)**

Figure 5 shows the results of the table and wine grape modeling. Average table grape yield increased in 2005-6 and 2006-7, which corresponds well with the water consumption figures. Wine grape yield also increases in the second and third study year, and variation in yield between fields was higher in 2005-6 and 2006-7. Wine grape yield was more uniform than table grape yield in all the three years.

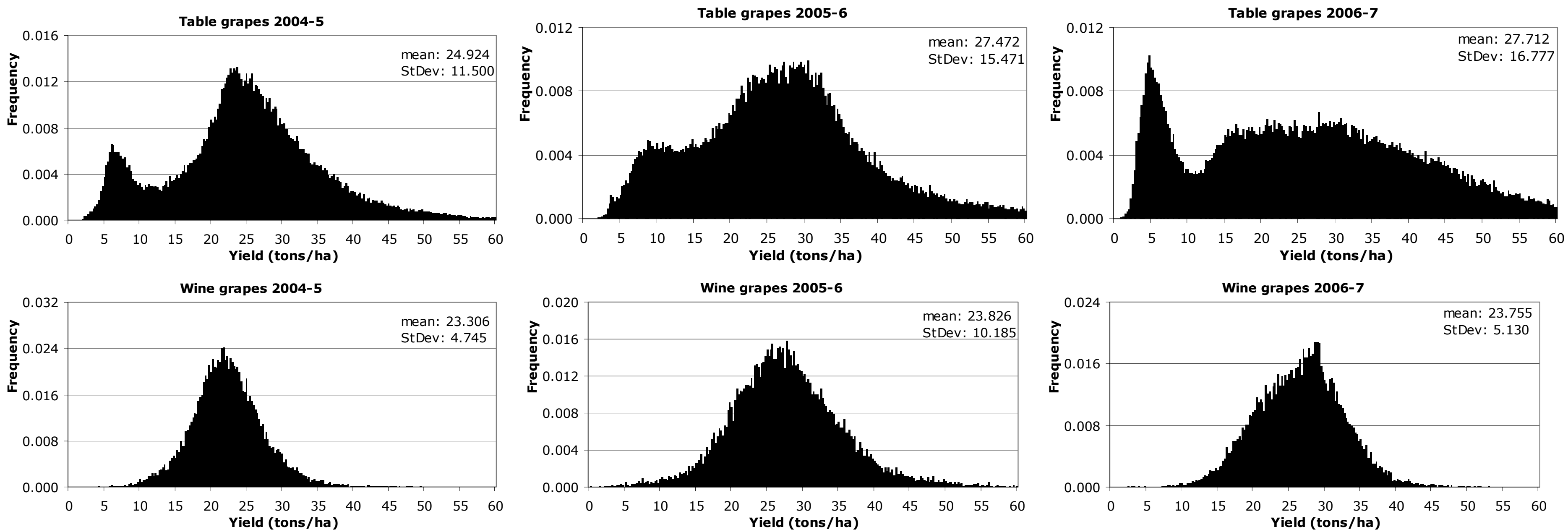


**Figure 5 Frequency distribution of yield in the season 2004-5, 2005-6 and 2006-7 for all pixels classified as table grape in Hex River Valley, Worcester and Paarl (n= 76415) or as wine grapes in Worcester (assumed to be of the Colombar variety) (n=19891)**

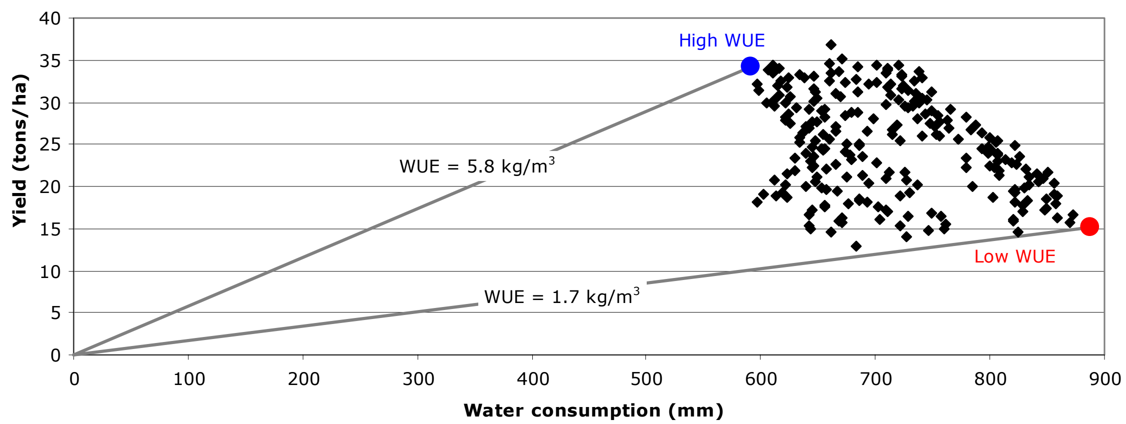


**Figure 6 The relation between water consumption and yield of table grapes in Hex Valley in 2004-5, and their effect on water use efficiency**

Figure 6 shows the relationship between water consumption and table grape yield in Hex Valley. It shows that table grapes consume between 600 and 900 mm during the season of 2004-5, and that the corresponding yields range from 10 to 35 tons/ha. Water use efficiency is highest when water consumption is low and yield is high.

Figure 7 shows the water use efficiency of table grape and Colombar wine grape vineyards in the study areas. Water use efficiency varies considerably over the years although the average remains rather conservative. In 2005-6 the water use efficiency of wine grapes was very high because of intended low water consumption and high yields. In 2006-7 the yield was similar, but water consumption increased, thus reducing the water use efficiency. Hence, control of water consumption is the key to increase water use efficiency.

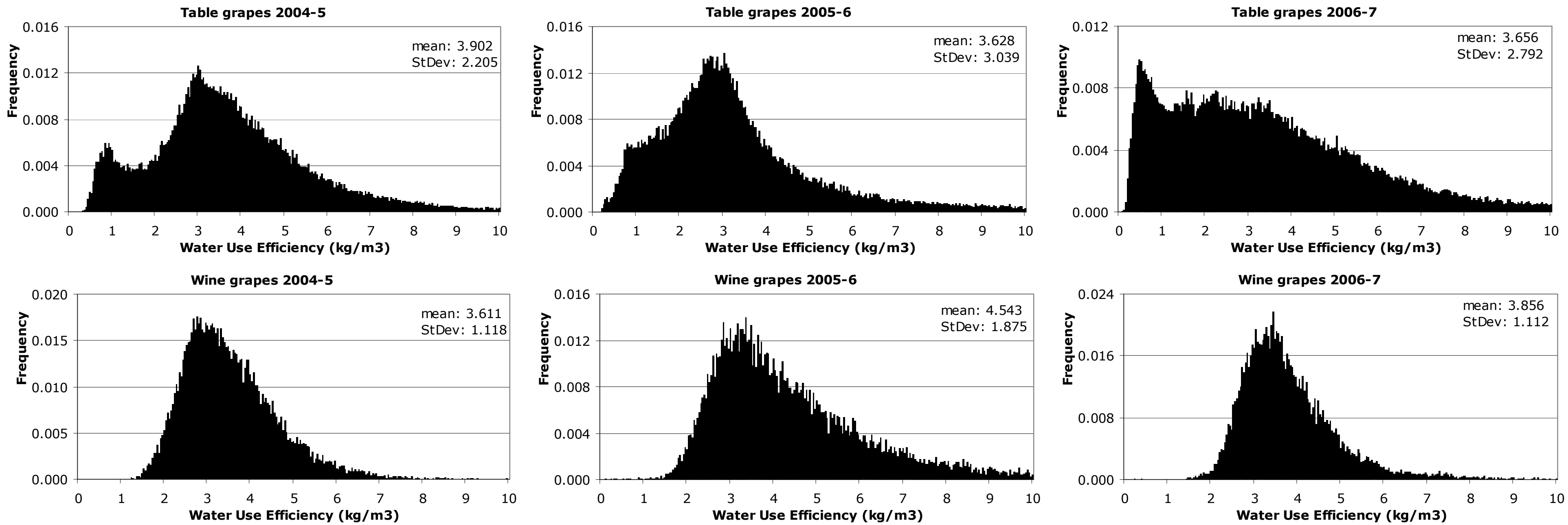


**Figure 7 Frequency distribution of water use efficiency in the season 2004-5, 2005-6 and 2006-7 for all pixels classified as table grape in Hex River Valley, Worcester and Paarl (n= 76415) or as wine grapes in Worcester (assumed to be of the Colombar variety) (n=19891)**

Figure 8 shows the results of the SEBAL and yield modeling for table grapes in Hex Valley. Water consumption increased in 2005-6 and 2006-7, while yield remained similar in 2004-5 and 2005-6, and only increased in 2006-7. For this reason water use efficiency was low in 2005-6, high in 2004-5 and even higher in 2006-7.

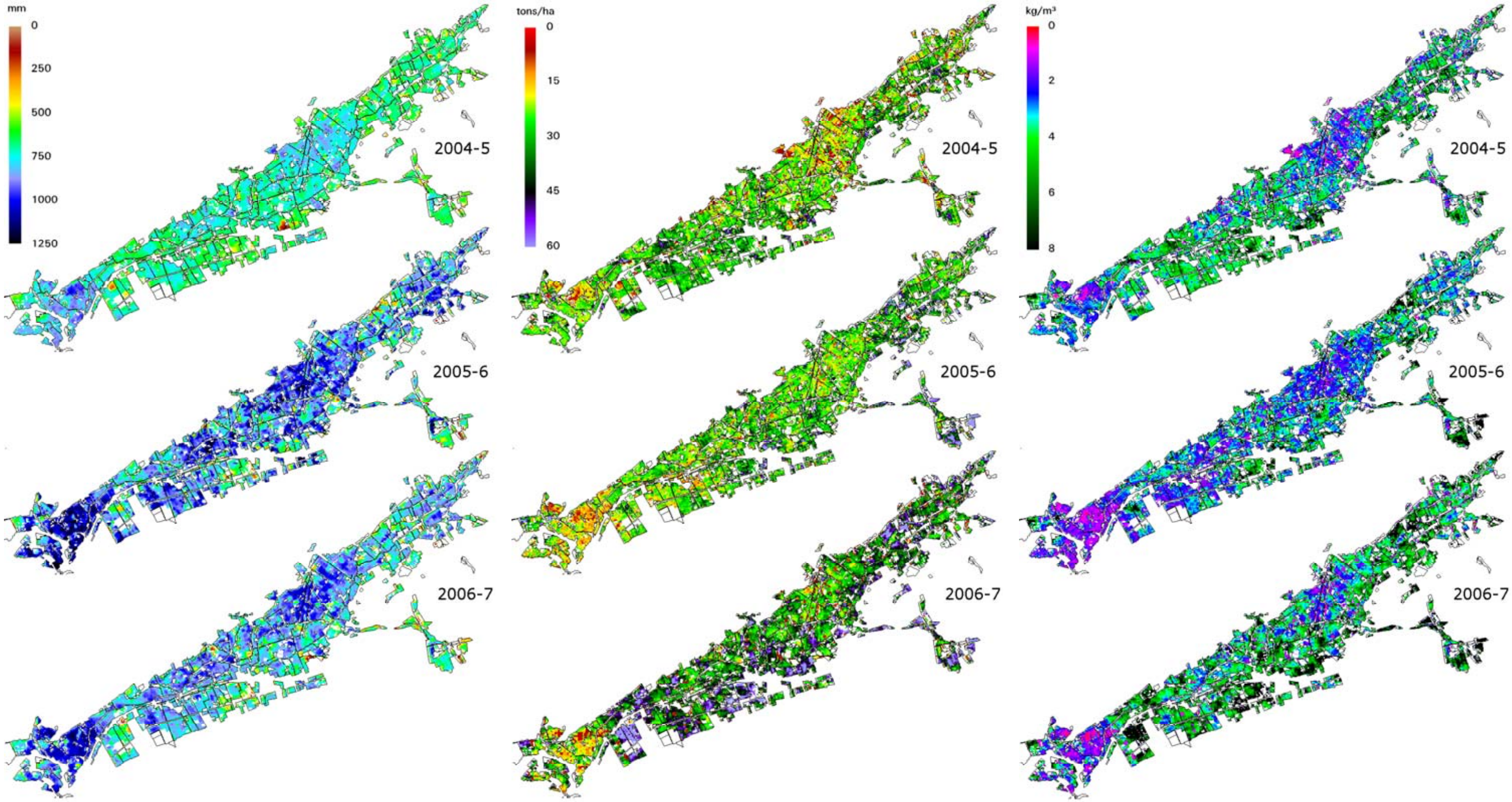


**Figure 8 Water consumption (left), yield (centre) and water use efficiency (right) of table grapes in Hex River Valley in 2004-5, 2005-6 and 2006-7**

## 5 Conclusions

The described methodology offers a strong tool for spatial and temporal evaluation of vineyard water use performance in the Western Cape. SEBAL accurately estimates total evapotranspiration of table and wine grapes. The modeling of table and wine grape yield is highly empirical, and still needs further development by including more wine grape cultivars. WUE of table and wine grapes was on average 3.7 kg/m$^3$ for table grapes and 4.0 kg/m$^3$ for wine grapes. The spatial variation in WUE in the grape producing areas (90% of the pixels in a 2.0 – 7.0 kg/m$^3$ range), suggests that WUE can be improved considerably. Vineyards with low and high WUE are identified.