Elimination of spatial variability using Variable Rate Drip Irrigation (VRDI) in vineyards

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Abstract.

Vineyards worldwide are subjected to spatial variability, which can be exhibited in both low and high yield areas meaning that the vineyard is not achieving his full yield potential. In addition, the grapes quality is not uniformed leading to different wine qualities from the same plot. The assumption is that a variability in available water for the plant due to soil variability leads to the observed yield variability. A variable rate drip irrigation (VRDI) concept was developed to reduce such variability. The VRDI system divides the vineyard into 30 x 30-meter irrigation zones, enabling individual irrigation of each zone according to a model based on normalized difference vegetation index (NDVI) maps. Before the VRDI installation, the natural variability of the plot was recorded by measuring LAI, SWP, and yield in a 1.2-hectare vineyard Syrah red grape in Israel during 2014. The first VDRI system was installed on the plot and operated in the 2016 and 2017 seasons. The VRDI system enabled to apply more water to areas were the vines vigor was low, and less water to vines with high vigor during 2014. Following the operation of VRDI system, the yield, leaf area index (LAI), canopy size, water potential, and primary juice chemical analysis results were very uniformed across the plot in comparison to previous years with applying uniform irrigation across the vineyard.

Keywords.

NDVI, drip irrigation, spatial variability, yield, stem water potential.

INTRODUCTION

Vineyard management is based on uniform application of irrigated water across an entire vineyard to ensure that each vine receives the same amount of water. In some parts of a vineyard, vines may be over-irrigated, while in other parts, they may suffer from water stress. This occurs due to differences in soil property and topography. When the soil is coarser, water-holding capacity is lower. Therefore, vines located in this type of soil are less vigorous than those in heavier soil, where water-holding capacity is higher. For vineyards with varied topography, yields from higher and lower spots can differ by up to 10-fold (Bramley and Lamb, 2003).

In light of these factors, certain areas in a field may require tailored irrigation scheduling in order to address uniform vine canopy size. Until now, no commercial drip irrigation system has successfully carried out differential irrigation across an entire vineyard. Several studies aiming to achieve differential irrigation have included sensor-triggered systems in greenhouses (Lichtenberg et al., 2013) and small-scale open field crop systems (Kamel et al., 2012). The most popular study of variable rate irrigation involved center pivot-irrigated crops (Patil and Al-Gaadi, 2012).

Differential drip irrigation studies based on canopy size, yield map and vine water potential have also been conducted in Australia (McClymont et al., 2012; Proffitt and Pearce, 2004) and Spain (Bellvert et al., 2012; Martínez, Casasnovas et al., 2009). In both studies, the vineyard was divided into management zones, and each zone was irrigated according to its needs. In the Australia study, variability reduction in vegetative growth and yield variability occurred, while in Spain there was no reduction in yield variability. Modifying the number of drippers per vine can result in different amounts of water applied, but it lacks the flexibility to schedule the irrigation differently for each vine, hence, a much-sophisticated system needs to be designed. The most advanced system of variable rate irrigation for vineyards was reported by Sanchez et al. (2014). They reported a decreased variability in both NDVI and yield in a VRI irrigated plot in comparison to a control of one irrigation block.

The aim of our study was to develop and implement a variable rate irrigation system and model in a vineyard by applying different amounts of water in different areas across the field, to reduce the spatial variability in both yield and quality.

MATERIALS AND METHODS

General

The research conducted in central Israel in a vineyard (31°52'7.14"N, 35° 1'28.38"E) located in a semi-arid climate with annual rainfall of about 500mm (only winter rain from October to April, no significant rain during the growing season). The Syrah variety vine grape (e.g. *Vitis vinifera)* was planted in 2006 in a 1.2-hectare plot with row spacing of 3 meters and vine spacing of 1.5 meters. Before installing the VRDI system, the vineyard was irrigated by a single on-surface dripper line located in the vine's row. The dripper's discharge rate was 1.6 liters/hour with spacing of 0.75 meters between drippers. The vineyard was irrigated once a week, always on the same day, and the average annual amount of irrigation water, until harvest, was about 90mm. irrigation scheduling was conducted by the farmer experience.

The vineyard's soil is clay-to-silty clay with a high calcium carbonate concentration (56%). The vineyard is located on a hillside with a west-east slope across the rows and a wave-like slope along the rows. The soil profile is at least 80cm deep.

Data collection

Vineyard data were collected before (2014) and after (2016 and 2017) the VRDI system was installed. routine measurements were made at six different locations across the plot: in the southern, center and northern areas, in two rows – A (east) and B (west) (Figure 3). During the growing season, routine measurements of mid-day stem water potential (SWP) (pressure bomb method, ARIMAD 3000S), leaf area index (LAI) (AccuPAR Ceptometer LP-80, Decagon devices) were conducted on five vines at each of the six locations. In addition, normalized difference vegetation index (NDVI) (Landsat, Sentinal 2) images were obtained each week for the entire plot. At the end of each season, five vines were harvested by hand from each of the six locations. The grapes from each vine were weighed, and the number of clusters was recorded. The harvested grapes were sent to the scientific winery operated by the Samaria and the Jordan Rift Regional R&D Center at Ariel University. The scientific winery prepared wine from each of the six samples, and conducted routine chemical analyses at the various wine-making stages. About one year after harvest, six Israeli wine specialists carried out wine tasting and ranking of the wines obtained from this experiment.

System installation

The VRDI system was installed in early 2015. The 1.2-hectare plot was divided into 12 irrigation zones (regardless to spatial variability pattern), each one 33 meters wide (11 rows) and 30 meters long (20 vines) (Figure 1). The 12 zones were divided into two strips, A and B, with six irrigation zones each: A1 to A6 and B1 to B6. Each irrigation zone can be independently irrigated by an electric valve, and all of the valves were controlled by a main controller. The valves, water meters and controller were installed within a 70cm x 90cm x 60cm (height) box. The box, as well as the sub-mains coming out of it, were buried in the soil so that only its lid could be accessed for maintenance. The irrigation laterals for each row were connected to the sub-mains according to zone number. All the dripper lines and laterals were placed at a depth of 10cm to avoid any mechanical damage to the system during the season.

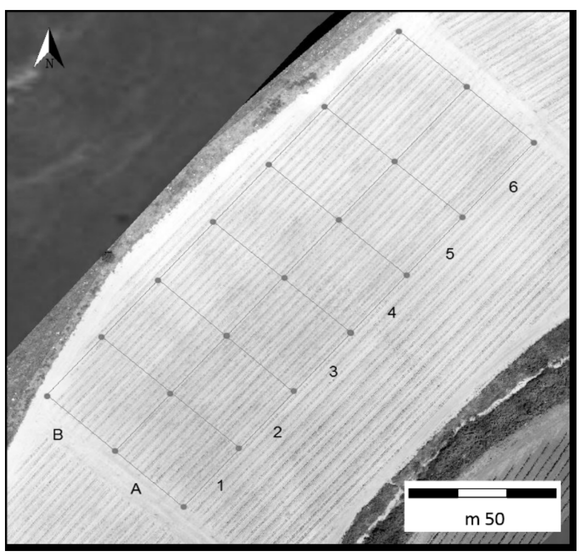

Fig. 1: VRDI system layout; 2 strips, 6 zones each (A1-A6; B1-B6); each zone is individually irrigated.

VRDI irrigation scheduling

VRDI irrigation scheduling in 2016-2017 was based on an NDVI value, stress factor and SWP for each zone. The zones that exhibited low vigor (A4-A6 and B4-B6) in 2014 were irrigated early in the season (beginning of April) at a high rate of up to 15mm per week. The zones that exhibited high vegetation in past years (A1-A3 and B1-B3) were irrigated late in the season (end of May) at a low water rate of 5mm per week. The weekly irrigation was calculated for each zone by equation (1):

$$ETc = ETo * Kc * IF \quad (1)$$

Where ETc is the crop water requirement, ETo is the reference ET obtained from a weather station, Kc is the crop coefficient and IF is the irrigation factor.

The irrigation factor (IF) was 0.4 from flowering to pea size barriers, and 0.15 to harvest. The irrigation factor limites the amount of water applied to achieve the desired SWP of the vines. The ETo was calculated by the Penman-Monteith equation with weather parameters obtained from a weather station located 300 meters from the vineyard. The Kc was calculated from the NDVI images according to the correlation found for vineyards (O'Connell et al., 2011):

$$\mathrm{Kc} = (\mathrm{NDVI\ value}) * 0.101 + 0.15 \quad (2)$$

Where Kc is the crop coefficient, NDVI value is the average of a pure NDVI pixels for a given irrigation pixel.

A compensated irrigation strategy was conducted to apply more water to the low vigor vines and less water for the high vigor vines. The irrigation scheduling described above was calculated for pixel A5 that has the desired canopy size and expected yield. This pixel was used as a reference pixel, where pixels with lower vigor received more water then the reference pixel and higher vigor pixels received less water then the reference pixel.

RESULTS

2014 results

The different measurements that conducted in 2014 on in the plot had indicated a clear trend along the rows from south to north. The observed trend was a reduction in vine canopy size that was reflected by the LAI values that were measured. The values of LAI that are shown in Figure. 2 were measured just before the harvest in August 2014, but the same trend was observed throughout the season in the plot.

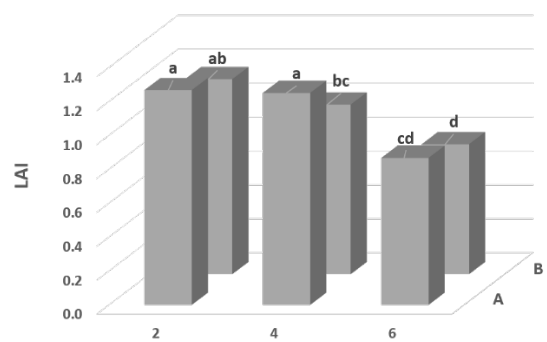

Fig. 2: Leaf area index (LAI) values measured in the 6 locations in the plot at the end of the season, just before the August 2014 harvest. Letters on the bars represent statistical significance.

The LAI values were consistent with the NDVI map obtained during the same period in August 2014 (Figure 3). A trend of reduced canopy size along the south-to-north rows can be clearly observed from the map. The map indicates variability intensity across the plot, and shows that the LAI values follow a logical trend rather than a random reading of uniformed zones.

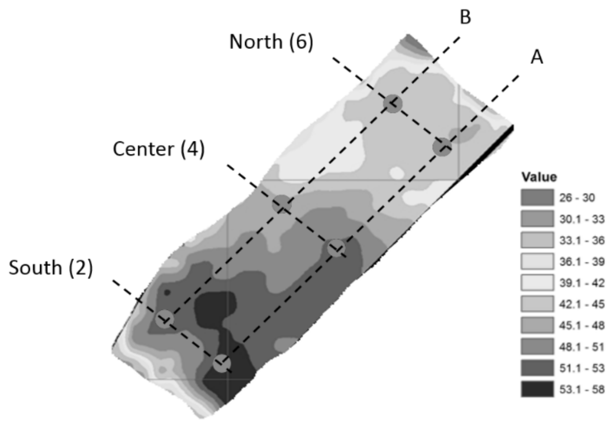

Fig. 3: NDVI map obtained in August 2014 just before harvest. The red dots are the measurement locations for LAI, SWP and yield. The numbers in brackets are the VRDI zone numbers for comparison and orientation.

We identified a yield variability trend of higher yields in the southern part of the plot and lower yields in the northern part (Figure 4). The yield for the different locations is in good agreement to the LAI measurements and the NDVI map.

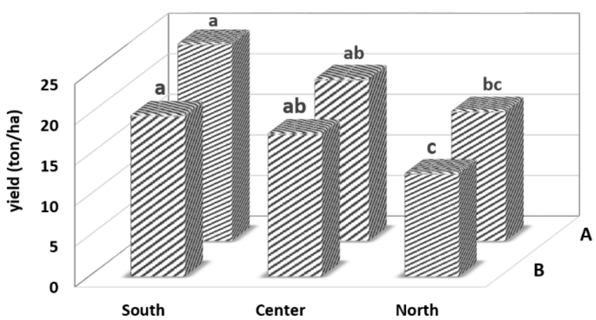

Fig. 4: Measured yields at 6 different locations during the 2014 season. Letters on the bars represent statistical significance.

Based on the 2014 survey, we can conclude that there is a variability pattern. The vines in the southern part of the plot were larger, less stressed and had higher yields. Meanwhile, less than 200 meters north in the same row and with the same irrigation scheduling, the vines were smaller, far more stressed, and had substantially lower yields. The 2014 harvest showed a gap of about 17% between the actual and full yield potential (defined as the high yield at the south part of the field), given the farmer's quality and yield constraints for that specific field and variety.

2016 results

2016 irrigation scheduling was based under the assumption that the northern zones of the plot (A4-A6 and B4-B6) had lower vigor in past years due to the lack of available water from winter rains. As such, irrigation was started earlier and with higher volumes of water in the season in these zones. The zones with higher vigor in 2014 (A1-A3 and B1-B3) were irrigated later in the season with lower volumes of water. During mid-season, when the canopy size of the vines in the different zones was similar (60% veraison stage) the volume of irrigated water had become similar for all zones until harvest, with the exception adjustments according to SWP measurements.

Figure 5 shows irrigation scheduling for the A strip (A1-A6) during the 2016 season, while the B strip irrigation underwent similar patterns.

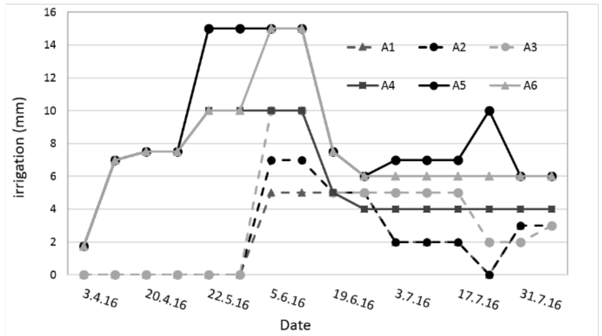

Fig. 5: Irrigation scheduling of A1 to A6 zones during the 2016 season. The irrigations for zones B1 to B6 are similar.

The LAI values measured in August 2016 show slight variabilities. However, the data shows that the trend of reduced LAI from south to north observed over the past years was not observed during the 2016 season (Figure 6). Although there is a statistical significant between the different zones, there is quite uniformity between north zone to south zones.

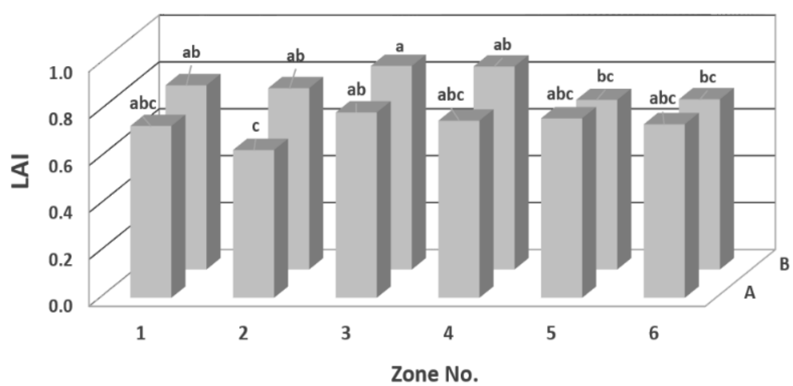

Fig. 6: LAI values measured across different irrigation zones during August 2016 season. Letters on the bars represent statistical significance.

The results of the 2016 harvest indicate that the previous pattern of south-to-north yield reduction (Figure 4) no longer existed as can be seen in Figure 7. After VRDI irrigation, the plot reached its potential yield throughout all the zones, while the yield nearly doubled in the northern zones in 2016 compared to 2014. Based on the results of the first year of VRDI system operation, we estimate that the 2016 season yield increased by about 17% compared to past years due to variable volumes of water applied to each zone.

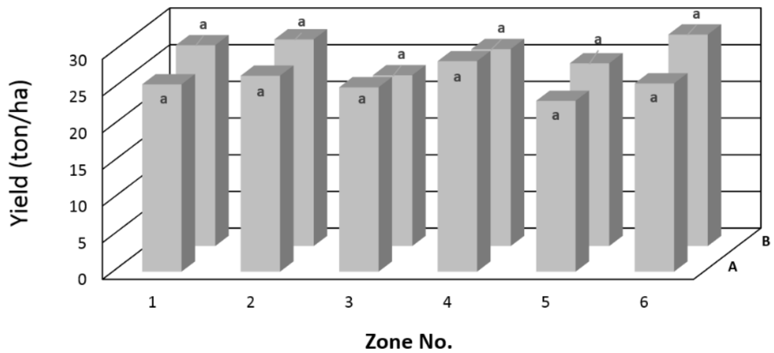

Fig. 7: 2016 season yield of grapes by zone as measured by the hand harvest of 5 vines in each zone. Letters on the bars represent statistical significance.

At the end of the 2016 season, the northern irrigation zones had received about 300% more water than the southern irrigation zones. About 20% less water was applied from the beginning of the 2016 season until harvest compared to past years when about 100mm of water was applied per season. The highest volume of water was applied to zone A5 (140mm), while the lowest volume (30mm) was applied to A1 (Figure 8).

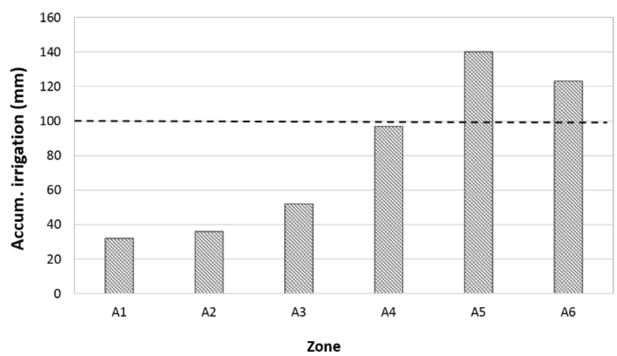

Fig. 8: Total volume of water applied in zones A1 to A6 during the 2016 season; dashed line represents the average annual volume of water applied in previous years.

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During the 2017 season the irrigation scheduling was done according to the model without interfering and without pre-irrigation for the low vigor pixels early in the season except for the first irrigation (Fig. 9).

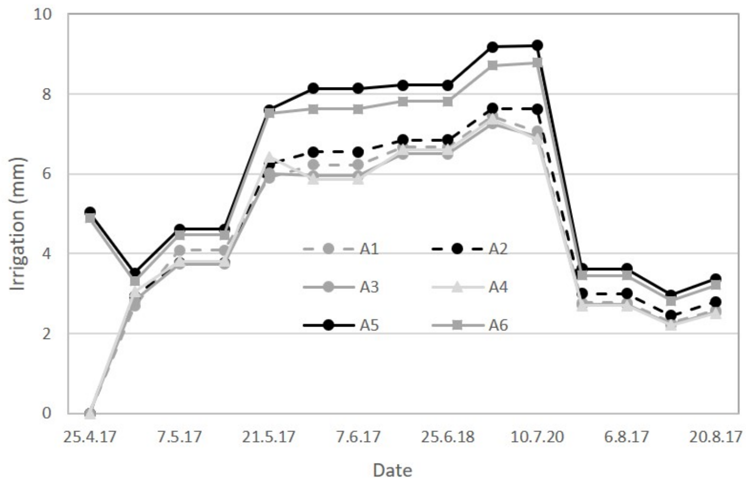

Fig. 9: Irrigation scheduling of A1 to A6 zones during the 2017 season. The irrigations for zones B1 to B6 are similar.

The LAI values for 2017 showed a slight trend of lower values at the north part of the plot (irrigation pixels A5, A6, B5 and B6). This trend is similar to the trend found in 2014 before the VRDI installation but the differences are not so severe as then. This trend could be explained by the different irrigation scheduling at the beginning of the season where there was no pre-irrigation for the low vigor pixels as conducted during the 2016 season.

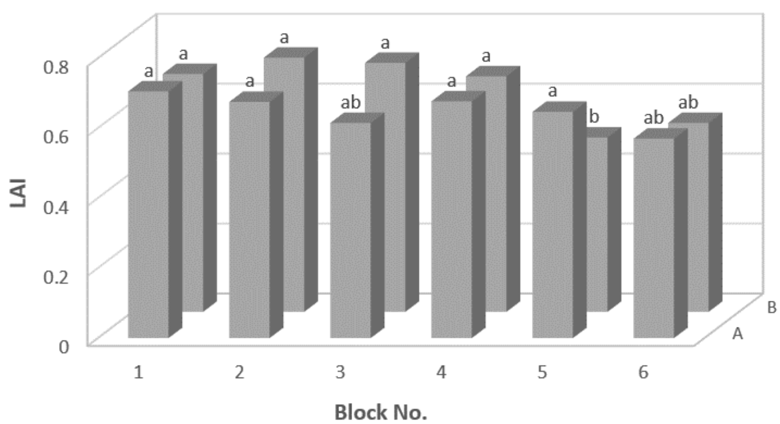

Fig. 10: LAI values measured across the different irrigation zones during August 2017 season. Letters on the bars represent statistical significance.

The yield results from 2017 indicates that the variable rate irrigation has managed to maintain similar yield across the plot in contrast to the trend found in the 2014 season yield (Fig. 4). The yield pattern found in 2017 was similar to the previous season indicating that the variable rate irrigation strategy has an impact on the growth and productivity of the vines at the different irrigation Blocks (pixels).

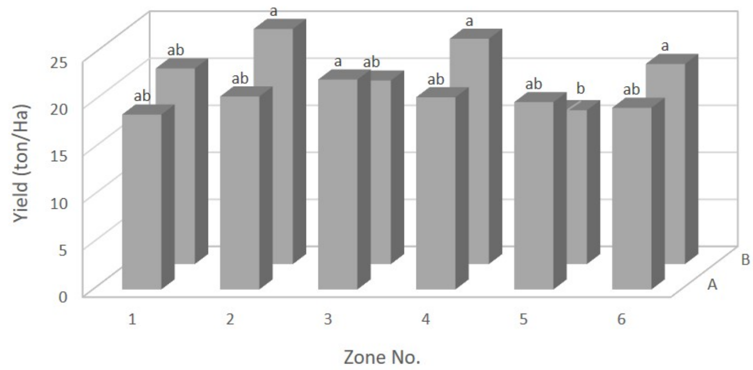

Fig. 11: 2017 season yield of grapes by zone as measured by the hand harvest of 5 vines in each zone. Letters on the bars represent statistical significance.

The accumulated irrigations (Fig. 12) shows that the northern irrigation pixels (A5, A6, B5 and B6) got about 30% more water than the southern pixels. This trend of increased irrigation for the northern pixels is similar to the 2016 season, but during 2017 the differences were much lower. In the 2017 season there were no pre-irrigations (except for one) while during 2016 there were few pre-irrigations with high rates of about 15 mm per irrigation which led to the high difference in accumulated irrigation between the south and the north. The irrigation model based on NDVI images is not able to recommend pre-irrigation, so it has to be taken care manually.

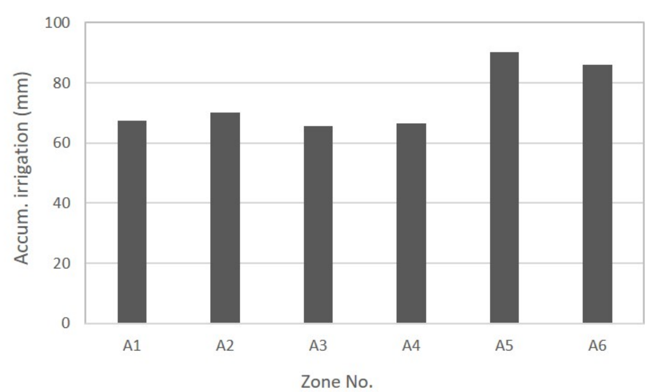

Fig. 12: Total volume of water applied in zones A1 to A6 during the 2017 season. The total irrigations for zones B1 to B6 where similar.

SUMMARY AND CONCLUSIONS

Prior to the deployment of VRDI in 2016, each part of the vineyard received the same volume of water regardless of need. With the VRDI system, irrigation – both in terms of time and volume – was changed for each zone. In one instance during the 2016 season, one zone received 300% more water than another even though the physical distance between the two was less than 120 meters along the row. Prior to the VRDI application, a pattern of lower canopy size, higher SWP, and lower yield along the plot's south-to-north rows. It is likely that the differentiated soil elevation or slope led to lower water-holding capacity in the northern part of the plot. Therefore, vines in those areas had less available water in the early stages of the growing season, leading to a smaller canopy size and lower yields. The VRDI system, meanwhile, enabled refilling of the soil with water in the northern zones early in the season. As such, they experienced similar initial conditions as in the southern zones, that is, a full soil profile filled with winter rainwater. Due to the variable allocation of water across the different irrigation zones, total yield in 2016 increased by 17% and water consumption fell by 20% compared to past years of single-zone irrigation. During the 2017 season the accumulated irrigation was higher for the southern irrigation pixels than for the 2016 season while the yield and the LAI were lower. That could be explained by lower water at the soil profile as a result of winter rain at the 2016-2017 winter. During the 2-15-2016 winter the vineyard area received 435 mm of rain from October 2015 to April 2016. For the same period in 2016-2107 winter the total rain summed in only 298 mm, where the last significant rain was at the middle of February 2017. This could explain why more water was needed to fill the soil profile during the 2017 season. As mentioned above, during the 2017 season there were no pre-irrigations done at the beginning of the season (except one) as conducted in 2016 season. This, in addition to the fewer rain, can explain why the LAI found in 2017 had a slight trend of lower values at the northern pixels in comparison the southern pixels. The yield was only slighted effected be the absence of the pre-irrigation since a part of the yield is being determined by the previous year growth. In order to achieve a good performance of the VRDI system, a pre-irrigation for the lower water holding capacity areas of the filed should be conducted, especially in dryer winters.

The VRDI system has exhibited very promising results in the 2-year operation, leading to reduced variability both in yield quantity and quality (data not shown). The system needs further development in order to achieve better irrigation scheduling using also the SWP values. Since SWP is a labor consuming method, an alternative for that such as thermal imaging should be incorporated into the model. The pre-irrigations at the beginning of the season should also be incorporated in the model in relation to the amount of winter rains.

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