Controlling variability in vineyard with variable rate drip irrigation

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Abstract

Vineyards worldwide are spatially variable in canopy size and growth rate, a feature which is exhibited in both low-and high-yielding areas. A variable rate drip irrigation (VRDI) system was developed and operated over 2 years out of a 4-year experiment in a red wine vineyard. During the first year of the experiment, the vineyard was irrigated by the farmer and exhibited high variability in both yield and canopy size. Following 2 years' operation of the VRDI system, both canopy cover and yield were found to be homogeneous across the plot. At the 4th year, the vineyard was irrigated once again by the farmer which resulted in variability patterns similar to the first-year patterns.

Keywords: drip irrigation, spatial variability, yield, stem water potential

INTRODUCTION

Vineyard management is based on uniform application of irrigation water across an entire vineyard to ensure that each vine receives the same amount of water. However, 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 properties and topography. In coarser soil, water-holding capacity is lower. Therefore, vines located in this type of soil are often 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).Considering these factors, certain areas in a field may require tailored irrigation scheduling in order to attain 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 of these latter studies, the vineyard was divided into management zones, and each zone was irrigated according to its needs. In the Australian study, variability reduction in both vegetative growth and yield 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 irrigation differently for each vine; hence, a more sophisticated system needs to be designed. The most advanced system of variable rate irrigation for vineyards was reported by Sanchez et al., (2014), which resulted in decreased variability in both NDVI and yield in a VRI irrigated plot in comparison to a control of uniform irrigation.

The aim of the study was to implement a variable irrigation rate in vineyards by applying different amounts of water in different areas across the field, using Normalized differential vegetation index (NDVI) and water potential-based model, to reduce the spatial variability in both yield and quality.

MATERIALS AND METHODS

The research conducted in a vineyard in central Israel (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). A Syrah variety was planted in 2006 in a 1.2-haplot with row spacing of 3 m and vine spacing of 1.5 m. Before installing the VRDI system, the vineyard was irrigated by a single dripline per row located on the soil surface next to the trunk base. The dripper discharge rate was 1.6 l/h with spacing of 0.75 m between drippers. The vineyard was irrigated once a week, always on the same day. The average annual irrigation, from early season to harvest, was 90-100mm. The vineyard's soil is clay-to-silty clay with a high calcium carbonate concentration (56%). It is located on a hill side with a west-east slope across the rows and a wave-like slope along the rows. The soil profile is at least 80cm deep.

Experiment duration

The experiment was conducted over 4years (2014-2018), while 2014 was a 'control' year where variability was assessed, and the vineyard was irrigated from a single valve by the farmer. 2015 was a 'Shmita' year, which according to the Jewish tradition the vineyard should not be cultivated, and no grapes are allowed to be harvested. The wine growers are very strict with this tradition so no activity aside from preservation irrigation and system testing, was carried out in the vineyard this year. During 2016 and2017, the vineyard was irrigated with the VRDI system. In 2018, the VRDI system was shut down and the plot was irrigated once again by the farmer with the old irrigation system (2^{nd} control year).

System installation

The VRDI system was installed in 2015 and operated for a short time just for performance evaluation. The 1.2-ha plot was divided into 12 irrigation zones (e.g. irrigation zones); each zone was 33 m wide (11 rows) and 30 m long (20 vines)(Figure1). The 12 irrigation zones were set in two strips: A and B, with six irrigation zones each:A1 to A6 and B1 to B6. Each irrigation zone had the flexibility of independent irrigation in both quantity and timing. Each zone was controlled by one electric valve, and all the valves were controlled by a main controller. The valves, water meters and controller were installed within a 70cmx 90cm x 60cm (height) box. The box, as well as the sub-mains, were buried in the soil so that only the box lid could be accessed for maintenance. All the dripper lines and laterals were placed at a depth of 10cm along the vine rows to avoid any mechanical damage to the system during the season. The old irrigation system of one valve to the entire vineyard remained untouched and fully operational and was used for irrigating the vineyard in 2018.

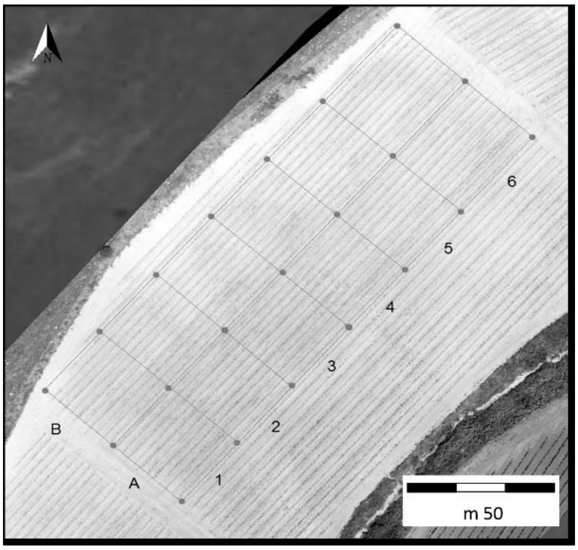

Figure1. VRDI system layout;2 strips, 6 zones each (A1-A6; B1-B6); each zone can be independently irrigated.

VRDI irrigation scheduling

The irrigation model developed for the VRDI system during 2016-2017was based on the NDVI value, stem water potential (SWP)of each zone, the stress factor required according to the phenological stage and weekly ETo measured from a nearby weather station. The model is based on one zone that serves as a reference, which all the other zones are irrigated to achieve same growth and yield patterns as that zone. The flexibility of the model is to choose any zone to be reference according to the desired outcome of yield. The irrigation for the reference zone was calculated by the crop coefficient approach by the FAO(Allen et al. 1998):

$$ETc = ETo \cdot Kc \qquad (1)$$

Where: ETc is the crop evapo transpiration (mm d^{-1}); Kc is the crop coefficient and ETo is the reference crop evapo transpiration (mm d^{-1}).
The Kc for the reference zone was calculated by the following correlation (O'Connell et al. 2011):

$$Kc\text{ref} = 1.01(NDVI\text{ref}) + 0.15 \qquad (2)$$

Where, Kc is the crop coefficient, NDVIref is the NDVI value of the selected reference zone
For each zone, the application of water was calculated according to the following model:

$$Irrigation(\text{i})(mm) = ETc \cdot \frac{NDVI(\text{ref})}{NDVI(\text{i})} \cdot \frac{SWP(\text{i})}{SWP(\text{ref})} \cdot SF \qquad (3)$$

Where: irrigation(i)is the irrigation applied (in mm) to zone(i); NDVI(i) is the NDVI value for zone(i); SWP(i) is the SWP (bar) for zone(i); SWP(ref) is the SWP of the reference zone and SF is a stress factor that was setfor 0.4 fromberry formation to the beginning of veraisonand 0.15 from veraisonto harvest.

A pre-season irrigation was conducted for the zones that exhibited low vigor (A4-A6 and B4-B6) in 2014.They 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 2014 (A1-A3 and B1-B3), were irrigated later in the season (end of May) according to the model mentioned above.

Data collection

During the growing seasons, routine measurements of mid-day stem water potential (SWP) (pressure bomb method, ARIMAD 3000S, ARTEC Testnology, Hertogenbosch, Netherlands), and leaf area index (LAI) (AccuPARCeptometer LP-80, Meter, Pullman, Washington, USA) were conducted on five vines in each irrigation zone. Normalized difference vegetation index (NDVI) was calculated throughout the season using data retrieved from Landsat 8 and Sentinel 2 A/B. The NDVI values for each zone were used for the irrigation scheduling model.
ET_0 was calculated from measurements by a nearby weather station.

At the end of each season, five vines were harvested by hand from each irrigation zone. 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 &Jordan Rift Regional R&D Center at Ariel University. The winery prepared wine from each sample and conducted routine chemical analyses at the various wine-making stages (data not shown).

RESULTS

The experiment was conducted for 4 years where in 2014 and 2018 the plot was irrigated by the old irrigation system (one valve for the entire plot)by the farmers' scheduling, while in 2016 and 2017 the plot was irrigated using the VRDI system (12 irrigation zones)according to the model described above. At the end of 2014, the canopy cover in the plot showed a trend of gradually decreasing LAI from south to north (i.e higher yield in zones A1 and B1 in the south than zones A6 and B6 in the north). Following the operation of the VRDI system, the trend of reduced LAI from south to north was eliminated and the plot had much less growth (Figure 2). During the operation of the VRDI system, the canopy size at the southern section of the plot was restricted due to the later irrigation commencement in late May to early June. In contrast, the north side showed higher canopy growth (in comparison to 2014) due to the early irrigation of only the northern section of the plot. Shut down of the VRDI system in 2018 and return to farmer irrigation resulted in a high LAI variability across the plot, in comparison to 2016-17 when the VRDI system was operated. The LAI variability pattern in 2018 was slightly different from the 2014 pattern, mainly in the southern zones that had lower LAI in 2018.

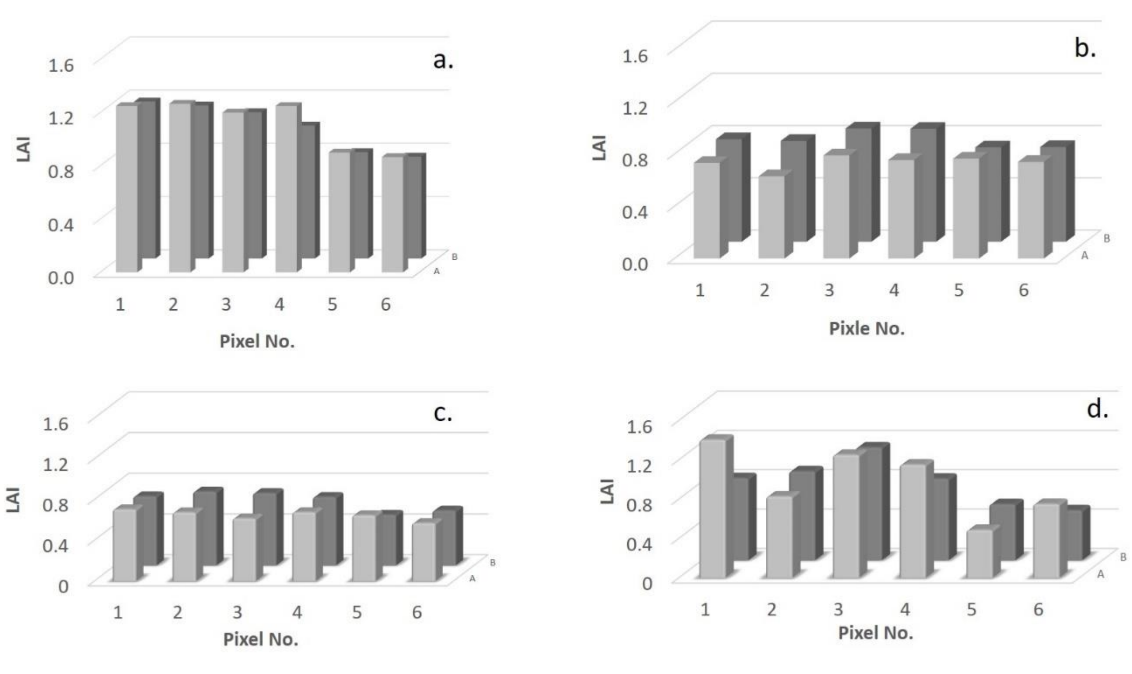

Figure 2. Leaf area index (LAI) in the different irrigation zones in August of each season, prior to harvest, where: (a)-2014, (b)-2016, (c)-2017 and (d)-2018. The lighter bars are for zones A1 to A6 and the darker bars are for zones B1 to B6.

Mid-day SWP measurement is a common practice to monitor the vines' stress to ensure the desired grape quality at harvest. In a variable plot, there is no option to manage the stress at multiple locations which results in a variability of berry size, sugar accumulation and total acid accumulation that ultimately affects wine quality. The SWP measurements conducted in 2014 showed that throughout the season, the vines in the north part of the plot were subjected to higher stress then those in the center and in the south part of the plot (Figure 3a). Furthermore, at the end of the season, the differences in SWP between the south and the north part of the plot were more than double. In contrast, in 2016-2017, while operating the VRDI system, there were no differences between the southern and northern zones (Figure 3b and 3c).In addition, throughout 2016-2017, the SWP across the plot were more similar than in 2014. That could be achieved by differential irrigation at each section of the plot according to the SWP values. In 2018, when the plot was once again irrigated with one valve by the farmer, the same trend of much stressed vines in the north, found in 2014, was observed as well as large differences in SWP values between the south and the north sections of the plot.

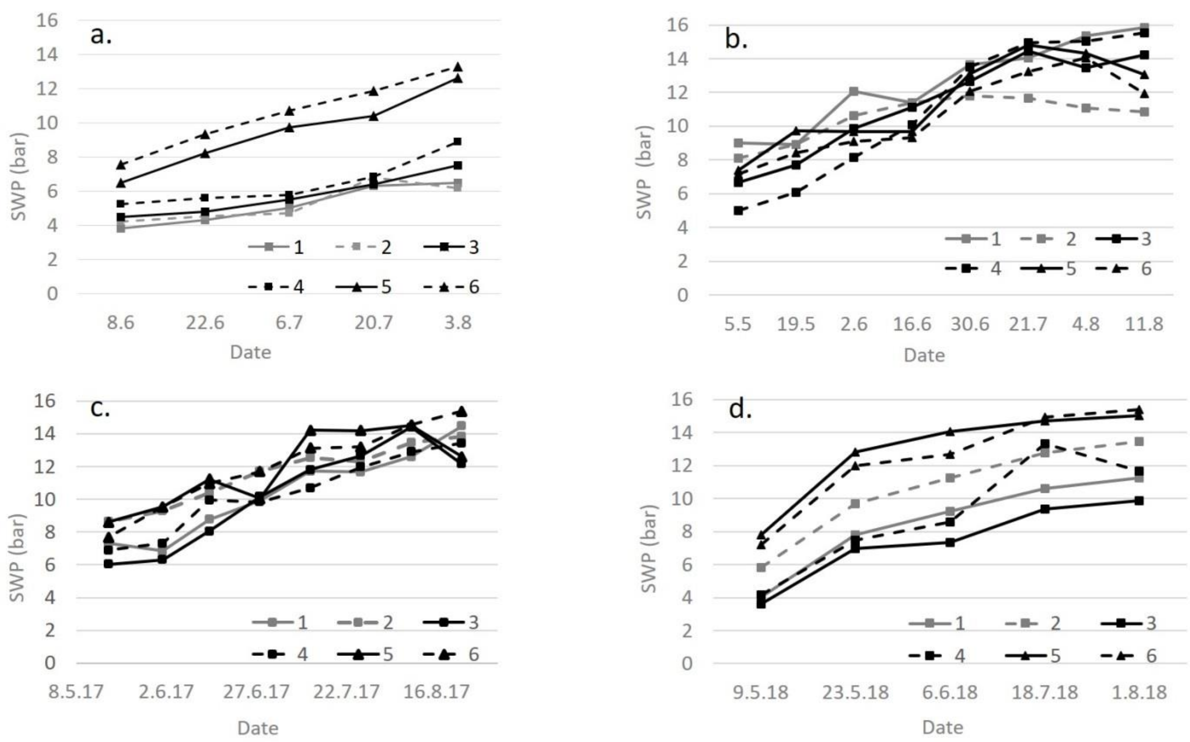

Figure 3. Mid-day stem water potential (SWP) at the different irrigation zones (1-6) of strip A (similar results for strip B)throughout the season, where: (a)-2014, (b)-2016, (c)-2017 and (d)-2018.

The yield measured during the 2014 harvest was found to have a trend of reduction across the plot from south to north. In the south part, the yield was about 20-24 t/ha while in the north part, only 150 m away, the yield was reduced to about 12-15 t/ha (Figure 4a).The yield variation across the plot that year was nearly 50%. This trend was similar to the trend in canopy size measured that year (Figure 2). In contrast, in 2016-2017 while operating the VRDI system, the previous trend in yield was not observed, although there were some variations between the zones. In 2016, the yield ranged from 24-28 t/ha and, in 2017, the yield ranged from 18-26 t/ha (Figure 4b, c).Yield variation during VRDI system operation was reduced to 15% and 25% for

2016 and 2017, respectively. When the VRDI system was shut down in 2018, the yield dropped drastically to 5-15 t/ha, where the same trend of higher yield at the south of the plot than in the north was observed again similarly to 2014 (Figure 4d).Yield variation during that year was 70% across the plot.

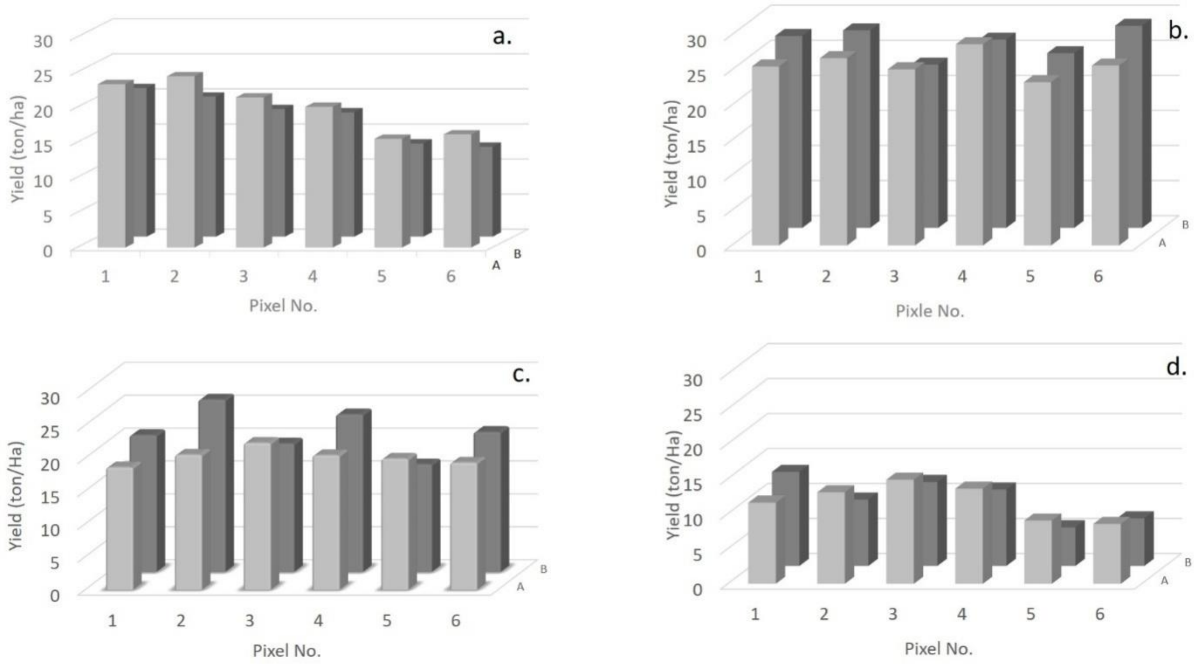

Figure 4.Yield (five vines were measured and the yield per ha was calculatedfor each zone) at the different irrigation zones where: (a)-2014, (b)-2016, (c)-2017 and (d)-2018. The lighter bars are for zones A1 to A6 and the darker bars are for zones B1 to B6.

The effect of the VRDI system on the uniformity of the canopy size can be also observed in the NDVI maps obtained throughout the seasons (Figure 5). The NDVI maps reveal the variability found in the plot in 2014 prior to the VRDI operation, a trend of larger canopy in the south and smaller canopy in the north, and a similar trend of the LAI during that period. The NDVI maps of the 2016-2017 seasons show less variability, which indicates more uniform canopy size due to the operation of the VRDI system (Figure 5b, c). The NDVI map pattern of 2018 shows similarity to the 2014 NDVI map and is derived from the same one-valve irrigation practice of the farmer.

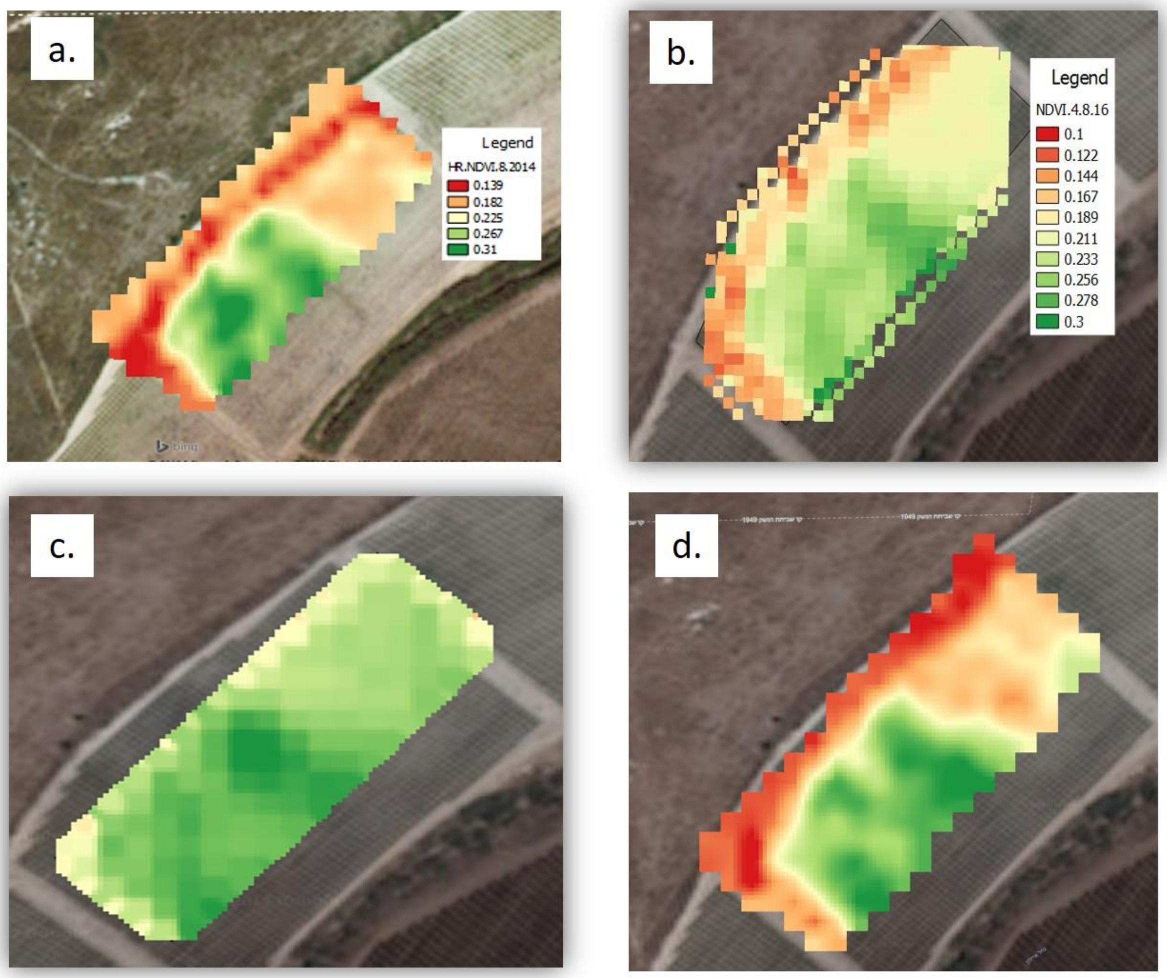

Figure 5. NDVI maps from the middle of August each year where: (a)-2014, (b)-2016, (c)-2017 and (d)-2018.

DISCCUSSION

The first year of the experiment (2014) was devoted to variability assessment of the vineyard while it was irrigated with a conventional drip irrigation system with one valve controlling the entire plot and irrigation scheduling according to the farmers' best practice. The variability pattern observed during that year was a gradient of decreasing canopy size and yield across the plot from south to north. This variability pattern is probably related to the topography of the plot and the water available to the vines at the early stages of growth. The main reason for the variability was assumed to be due to soil characteristics where, the southern section had much higher water storage than the northern part, which resulted in more intense vine growth and yield. During 2016-2017, the operation of the VRDI system allowed a pre-season irrigation of the northern zones to increase water storage in this section. The pre-season irrigation resulted in intense shoot growth at the north section and reduction of the variability Reduced irrigation in the southern zones resulted in restrained vine growth in those zones. Furthermore, the VRDI system allowed management of the water stress of each zone to maintain the stress curve as recommended for this variety of grapes. The shutdown of the system in 2018 caused an increase in plot variability to similar levels as observed in 2014.

COCLUSIONS

The vineyard plot in this experiment exhibited high variability in canopy size, water stress and yield. This variability is partly related to the water availability for the vines at each section of the plot and irrigating with only one valve per plot cannot address this variability. A differential irrigation of the plot can reduce the variability in vine growth and yield by controlling the available water for the vines in each zone. The operation of the VRDI system reduced the variability in NDVI and LAI along with increasing yield and reduction in applied water. The shutdown of the VRDI system resulted in increased variability. This experiment shows that the elimination of the variability with the VRDI system is not a 'one shot' treatment and the system needs to be continuously operated to preserve uniformity throughout the plot. The irrigation model can be further developed for other varieties of grapevines and other crops.

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