RESPONSE OF SHIRAZ/101-14 MGT TO IN-ROW VINE SPACING

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Abstract:

Context and purpose of the study - Knowledge of vine reaction to plant spacing under high potential soil conditions is restricted. This study was done to determine effects of vine spacing (with fixed row spacing) of Shiraz/101-14 Mgt on a high potential soil on vine physiological reaction, growth, yield and grape composition. The study is targeting economic viability by considering establishment, yield, grape and wine quality, and expected longevity.

Material and methods – The project is carried out in the Breede River Valley, Robertson, South Africa. Shiraz(clone SH 9C)/101-14 Mgt vines were planted during 2008 to a VSP trellis with a fixed row spacing of 2.2 m and a row orientation of approx. NNE-SSW (30°). In-row vine spacing varies from 0.3–4.5 m with increments of 30 cm (from 15151–1010 vines/ha), totalling 15 treatments. Treatments were irrigated similarly per week (based on ET_0 values and standard seasonal crop factors). Grapes are harvested at two ripeness levels.

Results - After establishing the experiment vineyard in 2008, results have been generated over six seasons with complete pruning system (2-bud spurs, equally spaced) and cordon development. Canopies developed uniformly with cordon extension. General vegetative growth over treatments varied according to seasonal conditions. Except for individual leaf size, vegetative growth parameters (trunk circumference, shoot and cane mass) were mostly reduced for narrower spaced vines. Yield:cane mass ratios showed an increasing trend from narrow to wide vine spacing. Fertility, together with bunch mass, seemed to increase from narrow to wide spacings. Bunches of narrow spacing treatments seemed more compact. Physiological parameters revealed a complex interplay between vine structure expansion, microclimate, water relations, photosynthetic output, and carbon distribution. Grape composition followed trends of decreasing sugar levels (°B) and pH, and increasing titratable acidity (TA), from narrow to wide spacing. In line with physiological symptoms of stress and available leaf area per yield, sugar accumulation of wider spacings seemed delayed. A balance between oenological advancement, wine style and production returns per investment is critical. Total costs (as measured in this study), labour and yields showed very clear trends with an apparent optimal from 1.8–2.4 m vine spacing. Final sustainability would depend on the total cost of production, farm conditions, and labour skills.

Key words: Vine spacing, Physiology, Growth, Ripeness level, Grape composition, Sustainability

1. Introduction

To satisfy requirements regarding land/terroir utilisation and sustainability at farm level (especially yield, and associated wine quality), the distance between grapevine rows is normally restricted to the minimum. However, inter- and intra-row spacing of vines should still conform to current scientific-technological (practical) criteria regarding viticultural and physiological requirements to obtain best performance in terms of size and efficiency of the canopy, root system, and grapes. Considerable research has already been done on growth accommodation and related implications. Over the years, canopy management experiments demonstrated that vine vigour should be managed judiciously and proper canopy size and composition (referring to physical dimensions and leaf age) and canopy porosity/microclimate are essential for sustainable, product-focused grape and wine production (Smart *et al.*, 1990; Poni *et al.*, 1994; Hunter *et al.*, 2004, and references therein; Hunter *et al.*, 2016). Despite the fact that the spacing of rows and vines is an integral, major impacting factor in the quest for optimal grapevine functioning, balance and sustainability, it has received little focused attention in research efforts.

Previous experiments in South Africa contributed to the establishment of a commonly used principle by which vines are spaced wider with higher soil potential (Archer & Strauss, 1985, 1989, 1990; Hunter, 1998a, 1998b). These studies were done on a medium potential, depth-restricted soil under dryland and low intensity (supplementary) irrigation and both row and vine spacings were changed in the different treatments (comprising a range of 1000–20000 vines/ha). However, these studies did not answer to the repetitive global question as to what extent vine performance and related parameters are affected by vine spacing in terroirs with deep, high potential soil conditions. Under such conditions, growth balances may change when roots utilise the deeper soil layers whilst penetrating more vertically and/or more horizontally (with closer/wider spacing) (Archer & Strauss, 1985; Hunter, 1998b). Water relations, photosynthetic activity, shoot growth (and thus microclimate), yield, and the final grape and wine quality/style are expected to be affected under any of these circumstances.

The purpose of this study was to obtain the sole effect of vine spacing on physiological processes, shoot growth, microclimate, yield, and grape and wine quality/style under high potential soil conditions with minimum limitations to root penetration.

2. Material and methods

Experiment layout and measurements

Shiraz (clone SH 9C)/101-14 Mgt was planted during spring of 2008 with an approximate NNE-SSW (30°) row orientation at theRobertson experiment farm of ARC Infruitec-Nietvoorbij, located in the Breede River Valley, South Africa (GPS coordinates 33°49'29.87"S; 19°52'50.67"E). Vines were spaced from 0.3 m to 4.5 m with incremental increases of 30 cm from narrowest to widest, representing 15 treatments. Row spacing was fixed at 2.2 m. Vines were double cordon-trained on a VSP trellis with four sets of movable foliage wires. Each treatment was replicated four times on a total surface of about 2 ha. Irrigation was applied according to crop factors and averaged 25 mm/week from approximately pea berry size growth stage. To enhance complete cordon development of all treatments, vines were pruned to one-bud spurs for two winters (2010 and 2011) after planting in spring of 2008, where after two-bud spurs were pruned since the winter of 2012. Spurs were spaced similarly, irrespective of treatment, and the number of spurs only restricted by the length of the cordons. To restrict other cultural practice influences, vines were irrigated and fertilised similarly, avoiding excessive deficit or deficiency. Typical experiment appearance is shown in Fig. 1. The ambient and inter-canopy photosynthetic active radiation (PAR) (400–700 nm, mole/m^2/s) (in the bunch zone and upper third of the canopy at 10:30, expressed as % of ambient) was captured by means of a LI-COR LI-191 Line Quantum sensor. Photosynthetic activity (mole/m^2/s) was measured during mid-morning (10:30) using an open system LI-COR LI-6400 portable photosynthesis meter, whereas stem water potential (–kPa) measurements were done during mid-day using two equally calibrated Scholander pressure chambers. Measurements were done during the pre- and post-véraison growth periods on basal primary shoot leaves in the bunch zone. Shoots (including bunches) were sampled at two grape ripeness level stages per treatment replicate and used for determination of vegetative and reproductive growth characteristics. Cane mass was measured in winter.

Statistical design and methods

The experimental design is a randomised block design with 15 spacing treatments and four block replications. Data was subjected to ANOVA using the General Linear Models Procedure (PROC GLM) of SAS software (Version 9.4; SAS Institute Inc, Cary, USA) to determine polynomial trends. The data was then either subjected to the regression procedure (PROC REG) to fit linear and quadratic regressions or to the non-linear regression procedure (PROC NLIN). PROC NLIN was performed to fit more than one line to the data to determine the "joint-point" (also called segmented or broken stick regression) of lines (Hudson, 1966). Outliers were determined using the Shapiro-Wilk test on standardized residuals from the model to verify normality (Shapiro & Wilk, 1965). Outliers were replaced by predicted values of the model.

3. Results and discussion

Microclimate and Physiological parameters

Light microclimate in the canopy followed an increasing trend from narrow to wide spacings (Fig. 2). This is also evident from the representative photos in Fig. 1, showing the difference in canopy density between narrower and wider spaced vines, regardless of the uniform spur distribution across treatments. Mid-day stem water potential values (negative) followed an ostensible decreasing trend, i.e. increasing water stress, towards wider vine spacing (Fig. 3). Photosynthetic activity at the pre- and post-véraison stages showed very little movement with spacing, despite an apparent increase in PAR with wider spacing (Fig. 4). Considering the PAR and stem water potential trends, photosynthetic activity of the leaves seem to have reacted to the contrasting effects of both PAR and water potential. Although an ageing canopy towards harvest time would have been a secondary contributing factor, these two major, but generally opposite (Poni *et al*., 1994; Hunter *et al*., 2014), impacting factors seem to have had an equalizing effect on the photosynthetic activity of the leaves.

Based on previous research, it may be expected that the limitation on soil volume available to closer spaced vines may lead to development of higher density root systems (despite possible deeper penetration under conditions of this experiment) and thus higher localised water depletion per soil volume, especially under high ambient temperature conditions. Although lower leaf water potential values would be expected under such conditions compared to wider spacing, vines apparently reacted by closing stomata to reduce transpirational water loss. A denser canopy would have a further restrictive effect on leaf activity, whereas a more open canopy would naturally lead to higher leaf activity, unless it is too open, leaf senescence and photo-inhibition occur and water stress prevail (Hunter & Visser, 1989). The predicament of the vine also surfaced from the amount of water transpired per photosynthetic output, being stable during the active growth period, but having an increasing trend during the later stages of grape ripening from narrow to wide spacing (data not shown), despite apparently better exposed canopies of wider spaced vines (Fig. 2). This indicates progressively higher water use and/or water loss per unit of photosynthesis with wider vine spacing or vines were metabolically inhibited to utilise available water for a similar output. Although lower water potential of these vines may have had an effect on stomatal behaviour, a myriad of other physiological responses to vine structure expansion with wider spacing might have played a role, such as unequal development of aboveground and subterranean growth and thus disturbance in capacity of supply and demand bodies; distances of translocation may have deleteriously affected flow and volume *via* support channels; crop load per vine; higher water (irrigation) and nutrition (fertilisation) demands, etc.

Vegetative and reproductive parameters

Cane mass per vine and per surface area followed an increasing and decreasing trend, respectively, from narrowest to widest plant spacing (Fig. 5). The cane mass/vine trend corresponded with that found for shoot mass per shoot length and trunk circumference (Fig. 6). Spacing the vines equally farther apart induced an initial almost linear vegetative reaction, but this response faded from approx. 2.1 m and thus the *growth response* and *spacing increment* lines became increasingly dissimilar. Vine carbon allocation was therefore affected by distance between vines.

Yields of the last four years at two grape ripeness levels exhibited highest yield gain up to approximately 1.5 m spacing on a surface basis (Fig. 7). After this a slow increasing trend is observed that seem to stabilise around 2.1 m and beyond which available space for vine development seemed not to be in harmony with yield obtained per surface area. This is in spite of fertility and bunch mass showing increasing trends from narrow to wide spacing treatments and bunches of narrow spaced vines showing more compactness (data not shown). Substantial yield losses occurred from the first to second harvest; this is commonly found for Shiraz (Carlomagno *et al.*, 2018). Yield trends differed between ripeness levels and treatments with more open canopies seemed more prone to yield loss with progressive ripening. Yields per cordon space, expressed on a per hectare basis, indicate an initial fast decline from very narrow to approx. 2.4 m spacing, where after a slight further decrease occurred with wider spacing; this trend is reversed when yields per cordon space are expressed on a per vine basis (data not shown). Vegetative growth parameters indicate that individual primary and secondary leaves were larger with narrower vine spacing and that leaf size decreased from narrow to wide spacing (Fig. 8). This may be an explanation for differences in canopy appearance as shown/discussed earlier. The total leaf area/vine showed a general stepwise increase from narrowest to widest spacing (data not shown), but total leaf area/grape mass showed a general decreasing trend from narrow to wide spacing (Fig. 8). Yield/cane mass (Fig. 9) followed an increasing trend from narrow to wide spacings, similar to cane mass/vine (Fig. 5) and trunk circumference (Fig. 6); a stepwise increasing pattern and a plateau for the widest spacings are recognisable.

Grape composition

The grape composition over the last four years followed trends of decreasing sugar levels (°B) and pH, and increasing titratable acidity (TA), resulting in °B:TA also decreasing, from narrow to wide spacing (Fig. 10). Delayed/inhibited sugar accumulation with wider vine spacing is in line with trends found for water potential (Fig. 3), photosynthesis (Fig. 4) and water use efficiency (data not shown) that indicate that wider spaced vines experienced more stress. This is also clear from available leaf area/fresh grape mass that decreased from generally acceptable values of approx. 13 cm^2/g for narrow spaced vines to two thirds of that for wider spaced vines (> 2.7 m), bordering on overcropping (Fig. 8). This indicates differential irrigation/fertilisation demands per spacing group.

Costs and labour input during planting and training

The collective vine purchasing cost, total labour required for planting and young vine training, cumulative pruning and harvesting time, and cumulative yield for different vine spacing treatments over a period of 10 years shows very clear trends with an apparent optimal from 1.8 – 2.7 m vine spacing (Fig. 11). Figures on cost, labour and yields give a rough estimate of what may be expected when a specific vine spacing is selected. This would change from farm to farm, depending on farm conditions and level of training of the labour force. Furthermore, the gross difference may only be valid if all other costs are generalised and standardised; total cost of production needs to be considered, i.e. interest, tax, entrepreneurial remuneration, provision for renewal and cash expenditure. With reference to the latter, other cost components, such as direct costs, labour, mechanisation, fixed improvements and general overhead expenditure should be taken into account. Vine spacing selection requires overall sustainability consideration that includes both cost and market implications of the intended produce.

4. Conclusions

Carbon allocation differences among treatments were evident in leaf size, trunk circumference, shoot and cane mass, and yield. As spurs were allocated uniformly, canopy microclimate and visual canopy differences probably resulted from morphological size responses that generally decreased from narrow to wide plant spacing. The slower increase in sugar concentration along with trends found for water potential, photosynthesis, efficiency of water use and vegetative:reproductive growth relationships seem to indicate that the wider spaced vines experienced development-originating physiological restrictions and more stress. Results indicate a gradual transition from a higher vigour (and perhaps root-physiology/environment induced stress) to a lower vigour (and perhaps canopy-physiology/environment induced stress) condition, from narrow to wide vine spacing. This led to wider spaced vines having lower leaf:fruit ratios that caused disharmony between increasing spacing and yielding return as well as delayed grape sugar accumulation.

Both root system and canopy are involved in water potential and photosynthetic activity and the complex interplay between these two plant departments may often lead to a lack of (expected) differences. It is clear that vine spacing affects both aboveground and belowground departments of the vine and therefore induces an array of physiological trigger and homeostatic mechanisms. If these departments are not developing in a balanced way, the reaction of the grapevine to environmental and cultivation practices would be disturbed, often leading to erratic and unpredictable behaviour beyond the normal complexity experienced under field conditions.

5. Acknowledgements

Agricultural Research Council and SA Wine Industry (through Winetech) for funding. Our gratitude goes to Viticulture Department (L.F. Adams, A. Marais) and ARC Robertson Farm personnel for technical assistance.

6. Literature cited

ARCHER, E., STRAUSS, H.C., 1985. The effect of plant density on root distribution of three-year-old grafted 99 Richter grapevines. S. Afr. J. Enol. Vitic. 6, 25-30.

ARCHER, E., STRAUSS, H.C., 1989. The effect of plant spacing on the water status of soil and grapevines. S. Afr. J. Enol. Vitic. 10, 49-58.

ARCHER, E., STRAUSS, H.C., 1990. The effect of plant spacing on some physiological aspects of *Vitis vinifera* L. (cv. Pinot noir). S. Afr. J. Enol. Vitic. 11, 76-87.

CARLOMAGNO, A., NOVELLO, V., FERRANDINO, A., GENRE, A., LOVISOLO, C., HUNTER, J.J., 2018. Pre-harvest berry shrinkage in cv 'Shiraz' (*Vitis vinifera* L.): understanding sap flow by means of tracing. Sci Hortic. 233, 394-406.

VASCONCELOS, M.C., CASTAGNOLI, S., 2000. Leaf canopy structure and vine performance.Am. J. Enol. Vitic. 51, 390-396.

HUDSON, D., 1966. "Fitting segmented curves whose join points have to be estimated". J. Amer. Statistical Association 61, 1097-1129.

HUNTER, J.J., 1998a. Plant spacing implications for grafted grapevine I. Soil characteristics, root growth, dry matter partitioning, dry matter composition and soil utilisation. S. Afr. J. Enol. Vitic. 19, 25-34.

HUNTER, J.J., 1998b. Plant spacing implications for grafted grapevine II. Soil water, plant water relations, canopy physiology, vegetative and reproductive characteristics, grape composition, wine quality and labour requirements. S. Afr. J. Enol. Vitic. 19, 35-51.

HUNTER, J.J., ARCHER, E., VAN SCHALKWYK, D., STREVER, A.E., VOLSCHENK, C.G., 2016. Grapevine roots: interaction with natural factors and agronomic practices. Acta Hortic. 1136, ISHS 2016, DOI 10.17660/ActaHortic.2016.1136.10. Proc. I Int. Symp. on Grapevine Roots. pp. 63-80.

HUNTER, J.J., VISSER, J.H., 1989. The effect of partial defoliation, leaf position and developmental stage of the vine on leaf chlorophyll concentration in relation to the photosynthetic activity and light intensity in the canopy of *Vitis vinifera* L. cv. Cabernet Sauvignon. S. Afr. J. Enol. Vitic. 10, 67-73.

HUNTER, J.J., VOLSCHENK, C.G., MARAIS, J., FOUCHÉ, G.W., 2004. Composition of Sauvignon blanc grapes as affected by pre-véraison canopy manipulation and ripeness level. S. Afr. J. Enol. Vitic. 25, 13-18.

HUNTER, J.J., VOLSCHENK, C.G., NOVELLO, V., STREVER, A.E., FOUCHÉ, G.W., 2014. Integrative Effects of Vine Water Relations and Grape Ripeness Level of *Vitis vinifera* L. cv. Shiraz/Richter 99. I. Physiological Changes and Vegetative-Reproductive Growth Balances. S. Afr. J. Enol. Vitic. 35, 332 - 358.

PONI, S., INTRIERI, C., SILVESTRONI, O., 1994. Interactions of leaf age, fruiting, and exogenous cytokinins in Sangiovese grapevines under non-irrigated conditions. I. Gas exchange. Am. J. Enol. Vitic. 45, 71-78.

SHAPIRO, S.S., WILK, M.B., 1965. An Analysis of Variance Test for Normality (complete samples). Biometrika, 52, 591-611.

SMART, R.E., DICK, J.K., GRAVETT, I.M., FISHER, B.M., 1990. Canopy management to improve grape yield and wine quality - principles and practices. S. Afr. J. Enol. Vitic. 11, 3-17.

Figure 1: Canopy appearance affected by different plant spacing, Robertson, South Africa.

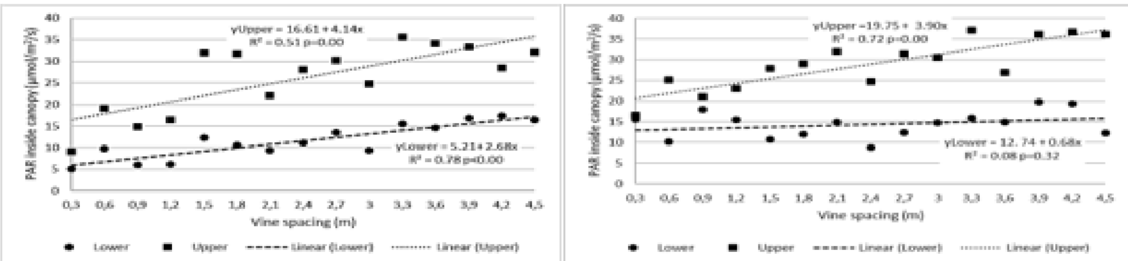


Figure 2: Photosynthetic active radiation (% of ambient) [pre-véraison (left) and post-véraison (right)] in the bunch zone and upper zone of the canopy of Shiraz/101-14 Mgt (means of 2014 - 2018 seasons).

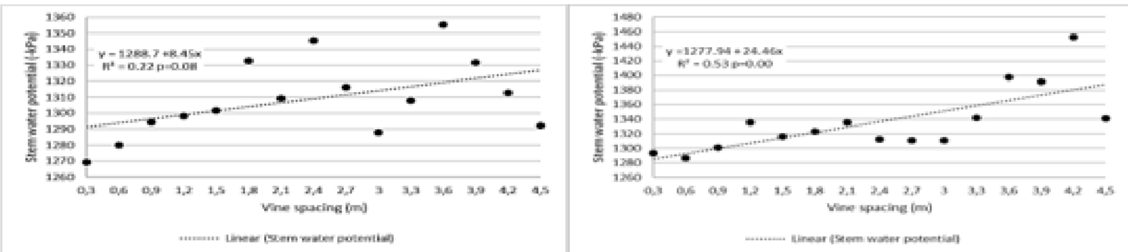


Figure 3: Stem water potential (pre- and post-véraison) of Shiraz/101-14 Mgt (means of 2014 - 2018 seasons).

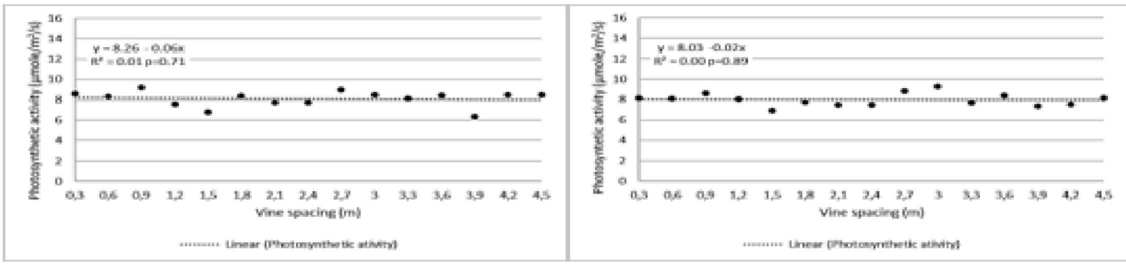
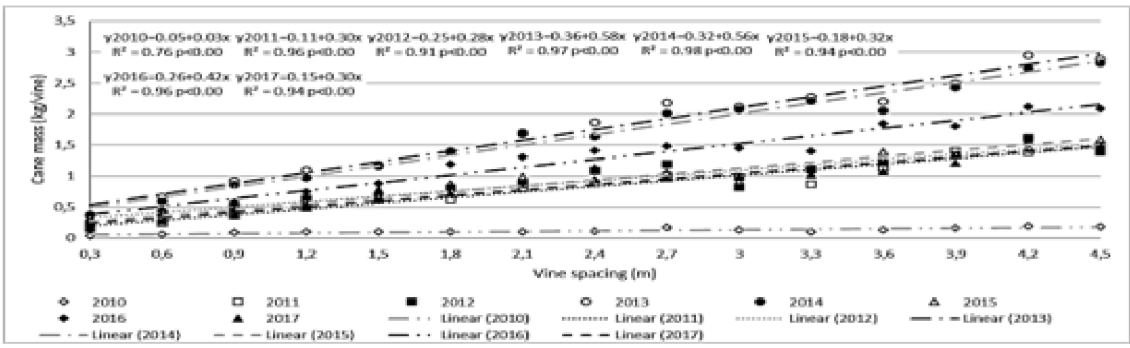


Figure 4: Photosynthetic activity (pre- and post-véraison) of Shiraz/101-14 Mgt (means of 2014 - 2018 seasons).



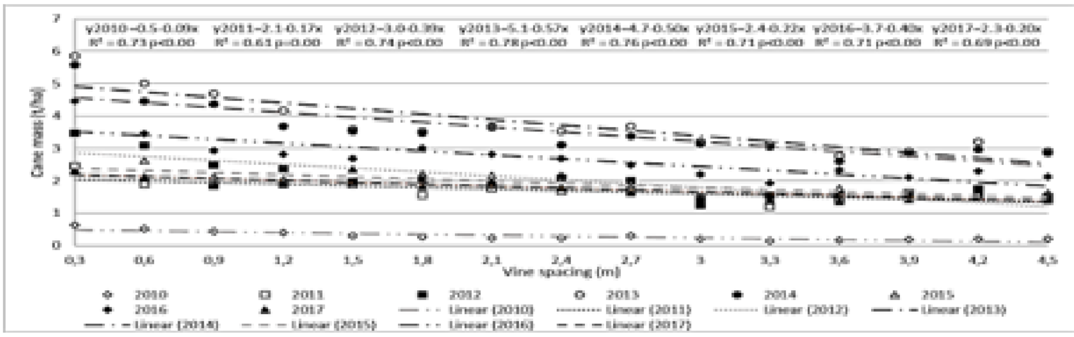


Figure 5. Cane mass (per vine, top; per ha, bottom) of Shiraz/101-14 Mgt (2010 – 2017 seasons).

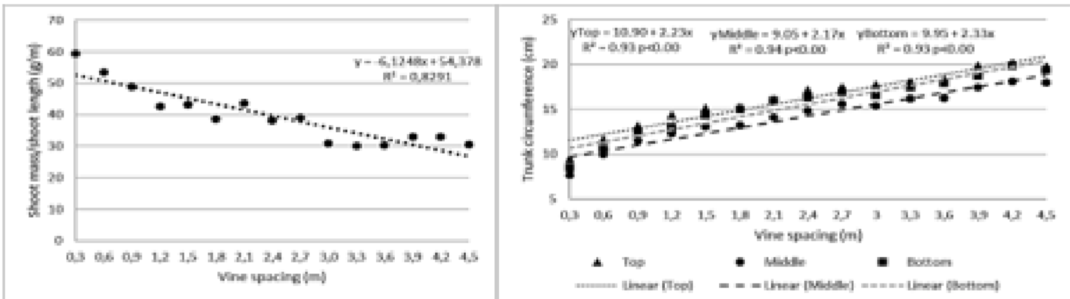


Figure 6. Shoot mass/shoot length (means 2012 – 2017 seasons) and trunk circumference (means of 2016 – 2017 seasons) of Shiraz/101-14 Mgt.

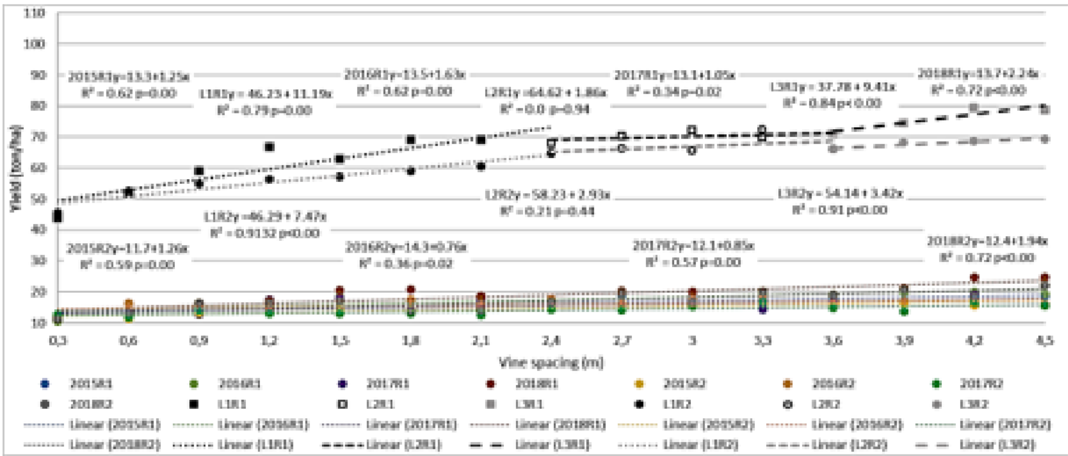


Figure 7. Yields of consecutive seasons (at two ripeness levels) of Shiraz/101-14 Mgt (2015 – 2018 seasons).

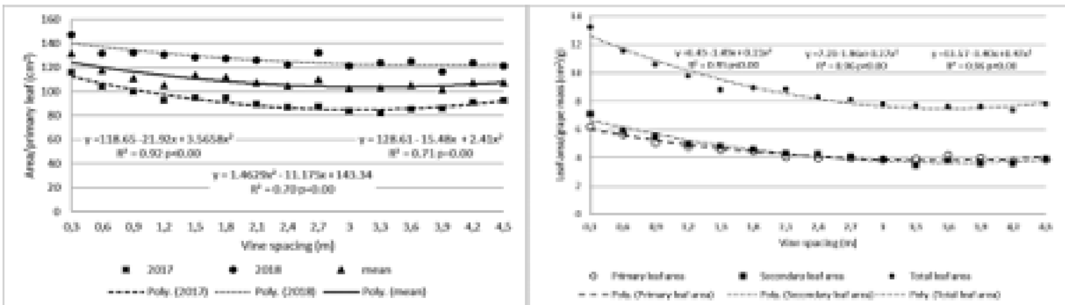


Figure 8. Area/primary leaf (2017 – 2018 seasons) and leaf area/grape mass (means of 2013 – 2018 seasons) of Shiraz/101-14 Mgt.

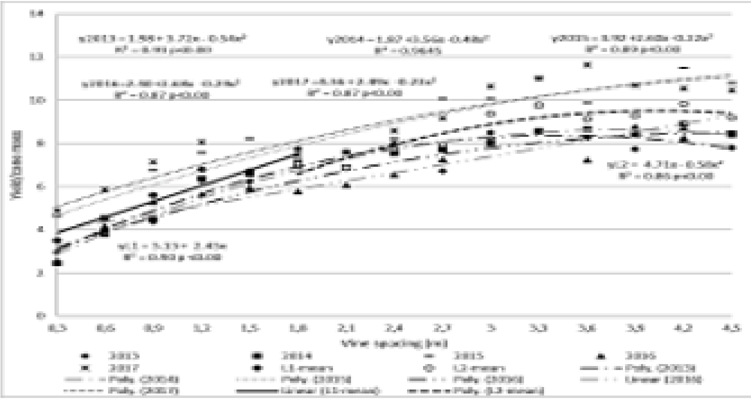


Figure 9. Yield/cane mass (either from single harvests or an average of two harvests, where applicable) of Shiraz/101-14 Mgt (2013 – 2017 seasons).

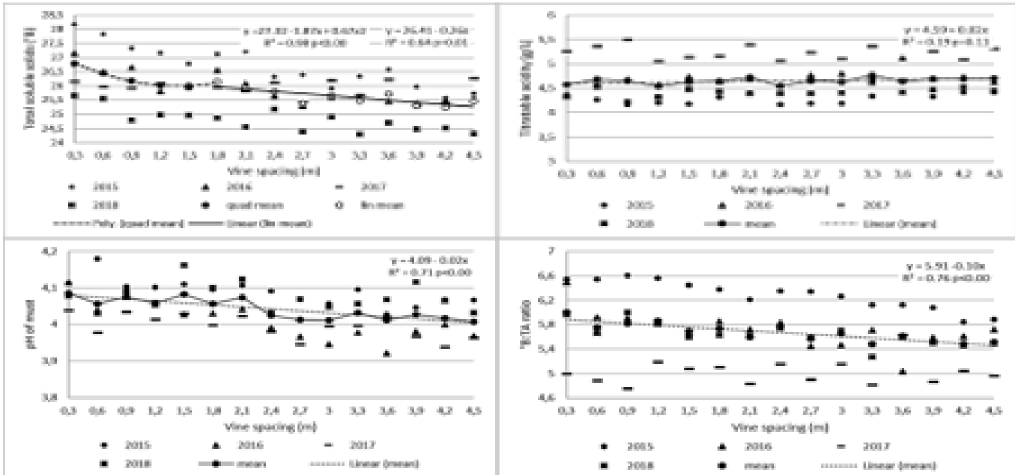


Figure 10. Grape composition (means of two ripeness levels) (Soluble solids: Top left; Titratable acidity: Top right; pH: Bottom left; °B:TA ratio: Bottom right) of Shiraz/101-14 Mgt (2015 – 2018 seasons).

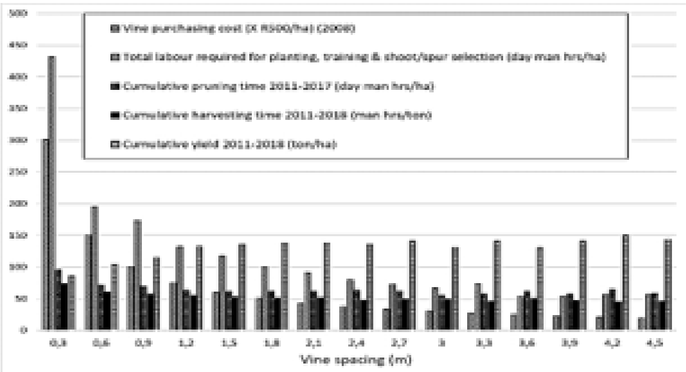


Figure 11: Collective figure showing grafted vine purchasing cost, total labour required for planting and young vine training, cumulative pruning and harvesting time, and cumulative yield for the different vine spacing treatments over a period of 10 years.