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Influence of Type of Management and Climatic Conditions on Productive Behavior, Oenological Potential, and Soil Characteristics of a 'Cabernet Sauvignon' Vineyard

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Abstract: (1) Background: Degradation of soils and erosion have been described for most of the soils presented along the Maule Valley. Organic and integrated management promotes agroecosystem health, improving soil biological activity. Due to this, the aim of this research was to study the effect of organic, integrated, and conventional management on the productive, oenological and soil variables of a vineyard cultivated under semiarid conditions during 5 consecutive seasons; (2) Methods: Yield, grape and wine oenological, and soil physicochemical parameters were evaluated. Bioclimatic indices were calculated in the studied seasons; (3) Results: Conventional management allowed to improve yield and the number of bunches per vine compared to organic management. However, this latter enhanced mineral nitrogen and potassium content in soil. Based on bioclimatic indices, heat accumulation improved number of bunches per plant and most of the soil physicochemical parameters; (4) Conclusions: Organic management improved the accumulation of some microelements in soils at the expense of yield. Organic matter decreased along the study was carried out. Season was the conditioning factor of the variability of most of the studied parameters, while the interaction between season and type of management affected soluble solids, probable alcohol and pH in grapes, and total polyphenol index and pH in wines.

Keywords: berry composition; Cabernet Sauvignon; conventional; integrated; organic; yield parameters

1. Introduction

Rainfed of the Maule Valley (Chile) has been characterized by a cereal, livestock, and viticulture agricultural history, all widely extractive activities [1]. Respect to the edaphic conditions, the soils from the rainfed areas of the Maule Valley presents low levels of organic matter (less than 2%) and low macro and micro nutrients content, mainly of boron [2]. Due to the extensive activities performed along this area, the soils present serious problems of erosion, and 80% exhibit the condition of non-arable, addition, rainfall does not amount to 600 mm·year^{-1}, and is concentrated from autumn to winter (May to August) [1]. Based on the aforementioned, together with the change in the use of agricultural land towards forestry activity, has led to small landowners to sell land and migrate to the city, generating important socio-cultural impacts [3].

Conventional viticulture disposes of agrochemicals such as inorganic fertilizers and synthetical chemical pesticides to the farming management, whereas these aforesaid products are banned in organic viticulture and only organic fertilizers and a certain non-synthetic pesticides are allowed in the agricultural management [4,5]. In organic viticulture, diseases control is mainly carried out using copper or sulfur treatment, while weed management is performed by tillage or grass-cutting [4,6,7]. Due to the high ability to adapt to the environment and its hardly manageable, weeds could affect productivity by competing with the vines [8]. The use of wheat and rye as cover crops may decrease weed growth, biomass, and density, without negative impacts on the vines [9,10]. In this way, the utilization of cover crops in the vineyards cultivated in rainfed conditions and in Mediterranean regions is not straightforward since water is the limiting factor and there is a severe competition for this resource [11]. Lower pruning weights and shoot length, fewer lateral shoots, and higher canopy openness have been observed in cover cropped vineyards [9,12]. However, long-term cover cropping using clover, ryegrass, and fescue is restricted in areas where water availability is limited [13]. It has been reported that, in these conditions, grapevines can be adapted, and a compensatory growth of their root system was observed, partly preventing the direct competition for resources between them and the cover crops [14]. In this scenario, the use of cover crops may avoid the dramatic reductions of stomatal conductance which occur in mid-summer and also allows to decrease yield and slightly increase grape quality [11]. These authors suggested that summer senescent and self-seeding herbaceous cover crops help to decrease soil erosion, which could improve organic matter and micro and macro nutrients content in soil.

Climate conditions had a strong influence on grape productivity delaying ripening and conditioning grape quality [15,16]. Certain bioclimatic indices have been developed in order to differentiate, describe and delimit distinct wine-growing sites. The Heliothermal Index (HI) uses daily temperatures during the period of the day in which grape metabolism is more active and includes a correction for length of the day in the case of higher latitude sites [17]. The Winkler Index (WI) was developed on the basis of the growing degree days, summed over the season on average, which allows to classify climates and to identify the grape varieties that can be fit to those regions [18]. The Biologically Effective Degree-Day Index (BEDD) allows to classify cold sites with low or late maturity potential, and hot sites with high or earlier maturity potential [19]. Night thermal conditions are associated to the accumulation of secondary metabolisms and can be estimated using the Cold Night Index (CI) [20]. In addition, bioclimatic indices associated with thermal accumulation such as mean thermal amplitude (MTA), average mean temperature of the warmest month (MTWM) and maximum average temperature of the warmest month (MATWM) can provide valuable information to characterize and compare different mesoclimates [21].

Based on the aforementioned, the aim of this work was to study the effect of organic, integrated and conventional management on the productive behavior, grape and wine oenological parameters, and soil physicochemical composition of a Cabernet Sauvignon vineyard located in Cauquenes, Maule Valley (Chile) during 5 consecutive seasons.

2. Materials and Methods

2.1. Study Site and Plant Material

The field trial was performed during 5 consecutive seasons (2003–2004, 2004–2005, 2005–2006, 2006–2007, and 2007–2008) in an experimental vineyard located into a rainfed area of Cauquenes, Maule Valley, Chile (35°58′ S, 72°17′ W; 177 meters above sea level). This area presents a sub humid Mediterranean climate. Cabernet Sauvignon (*Vitis vinifera* L.) ungrafted grapevines were planted in 1995 with a row orientation of east–west, trained to a double crossarms arrangements trellis system and pruned to a Guyot system, leaving about 40 buds per vine. The soil is Alfisol of granitic origin, slightly deep, of loamy clay texture horizon Ap Sandy loam with apparent density of 1.17 and 33% porosity, horizon Bt1, Bt2, and Bt3 clay with apparent density of 1.79, 1.75 and 1.77 (USDA). Plant density was 1428 plants·ha^{-1} with grapevine spacing between rows and within the row of 3.50 m × 2.00 m. Total surface planted was 2.37 ha. The vineyard was equipped with a drip irrigation system using 8 L·h^{-1}

drippers, to assure plant water needs when water is available. The vines were differentially irrigated from October to March when the leaf water potential reached 1.0 to 1.2 MPa.

2.2. Types of Managements

Three treatments or types of managements were performed in the vineyard. Organic management was carried out according to the Organic Industry Standards and Certification Committee [22]. Briefly, between rows were cover with green manure (*Avena sativa* and *Vicia faba*) in a dosage of 120 and 80 kg·ha^{-1}, while within rows were cover with different crops such as (i) a mixture of clover, (ii) *Medicago polymorpha* L., and (iii) *Lollium perenne* at a dosage of of 7.0, 7.0 and 3.0 kg·ha^{-1}, respectively. At sowing, 600 kg·ha^{-1} of phosphate rock was applied. After pruning, vine-shoots were crushed and incorporated to the soil. Additionally, compost of self-development skins, stalk and wheat straw were added at a dosage of 10 t·ha^{-1} at 20 cm of depth which equivale to 85 kg N·ha^{-1} per year. *Brevipalpus chilensis* management was performed using a water-miscible mineral oil preparation at a dosage of 1.5% applied at beginning of budburst. Subsequently, *Typhlodromus pyri* were released as biological control agent to the vineyard against *B. chilensis* at a relation of 1 to 6. Powdery mildew (*Uncinula necator*) management was performed using 20 kg·ha^{-1} of sulfur (powder) when the climate conditions were optimum for development for the disease. This was monitored from shoot development until veraison.

Integrated management was carried out according to the procedures of the International Organization for Biological and Integrated Control [23]. In brief, at the end of winter, Roundup was applied within rows at a dosage of 2 L·ha^{-1}. Natural weeds were maintained between rows. Monitoring and application of miscible mineral oil at 2% was carried out to *B. chilensis* control. After pruning, vine-shoots were crushed and incorporated to the soil. Sulfur application were made every 20 days from budburst to veraison to avoid grapevine diseases.

Conventional management in the vineyard was performed according to the exposed by Sotomayor et al. [24]. Briefly, conventional tillage was used to soil management, which remained without vegetation. Roundup was applied within rows at a dosage of 3 L·ha^{-1}. To avoid grapevine diseases, sulfur powder was applied at a dose of 20 kg·ha^{-1} every 15 days until veraison and a water-miscible mineral oil at 2% of Cyhexatin was applied at the beginning of the season and every 15 days until veraison for the control of *Brevipalpus chilensis*.

In all the vineyards, fertilization corresponded to the application of 100 kg·ha^{-1} of Urea, 100 kg·ha^{-1} of Triple Superphosphate (P_2O_5), 75 kg·ha^{-1} of Potassium Miurate (K_2O_5), 50 kg·ha^{-1} of Calcite Borate and 20 kg·ha^{-1} of Zinc Sulfate.

A randomized block design was performed into the vineyard, accounting 4 blocks, 3 treatments, and 3 replications. The sampling units corresponded to 21 plants, which were previously marked for identification.

2.3. Climatic and Soil Information

Climatic information was recorded since 2003 by a weather stations provided by Agromet [25] located around of 5 km from the site. Bioclimatic indices such as Huglin's Heliothermal Index (HI), Cool Night Index (CI), average mean temperature of the warmest month (MTWM) and maximum average temperature of the warmest month (MATWM) were calculated according to those mentioned by Gutiérrez-Gamboa et al. [26]. Briefly, HI was calculated from September first to March 31 by each season. This period corresponds to the growing stage of the Cabernet Sauvignon grapevines cultivated in Maule Valley, Chile. CI was calculated for March, while MTWM and MATWM were calculated for January. Mean thermal amplitude (MTA) corresponds to the sum of the differences between maximum and minimum daily temperature for March and was calculated according to the exposed by Tonietto and Carbonneau [20]. The Winkler Index (WI) was calculated from September first to March 31 for each season according to the exposed by Winkler et al. [18]. A pit was made in order to study soil physicochemical properties in the vineyard. pH, organic matter, nitrogen (N), phosphorus

(P), potassium (K), and boron (B) content were analyzed according to the methodology exposed by Sadzawka et al. [27].

2.4. Climatic Description of the Seasons

Precipitations calculated during each growing season (September to March) varied from 59.4 to 147.6 mm (Season 5 (S5) and Season 2 (S2), respectively). Bioclimatic indices are one of the common ways to characterize different climates based on the heat accumulation, vine growth and maturation potential [21]. Results of bioclimatic indices are shown in Table 1. Cool night index (CI) is a thermal indicator of night time temperature conditions at the end of the ripening stage, which is associated to the accumulation of secondary metabolites [20,26,28]. CI ranged from 9.4 to 12.0 (S3 and S4, respectively), with an average of 10.7. Huglin's heliothermal index (HI) is another bioclimatic index based on heat accumulation, which considers daily average temperature and daily maximum temperature, adjusting for day length during the season [20,29]. HI ranged from 2327.2 to 2416.4 (S2 and S5, respectively), with an average of 2354.9. The Winkler Index (WI) is calculated as the daily average temperature above a physiological base value of 10 °C. This is the minimum temperature at which grapevine growth occurs, for each day along its ripening from budburst through harvest stage [20,29,30]. WI ranged from 1559.6 to 1610.3 (S3 and S4, respectively), with an average of 1581.4. Mean thermal amplitude (MTA) reflects the differences between the maximum and minimum temperature at the end of the ripening stage [20]. MTA ranged from 439.5 to 522.4 (S1 and S5, respectively), with an average of 477.1. Certain bioclimatic indices such as the average mean temperature of the warmest month (MTWM) and the maximum average temperature of warmest month (MATWM) could give additional information about climate [26,28,31]. MTWM ranged from 20.8 to 22.2 °C (S2 and S5, respectively), with an average of 21.3 °C, while MATWM varied from 29.0 to 30.5 °C (S2-S4 and S5, respectively), with an average of 29.6 °C. Based on the aforementioned bioclimatic indices it is possible to characterize this climate as temperate.

Table 1. Information about bioclimatic indices such as cool night index (CI), Huglin's Heliothermal Index (HI), mean thermal amplitude (MTA), Winkler Index (WI), average mean temperature of the warmest month (MTWM), and maximum average temperature of the warmest month (MATWM) calculated for each study season, precipitations from September to March (Pp: mm) and harvest date.

Season	CI	HI	WI	MTA	MTWM	MATWM	Pp	Harvest Date
2003–2004 (S1)	11.0	2355.0	1577.4	439.5	21.3	29.8	105.4	March 23
2004–2005 (S2)	11.2	2327.2	1566.7	452.1	20.8	29.0	147.6	March 29
2005–2006 (S3)	9.4	2348.2	1559.6	514.7	21.1	29.5	112.0	March 21
2006–2007 (S4)	12.0	2377.5	1610.3	456.6	21.0	29.0	74.0	March 20
2007–2008 (S5)	10.2	2416.4	1593.0	522.4	22.2	30.5	59.4	March 25
Mean	10.7	2364.9	1581.4	477.1	21.3	29.6	99.7	-
SD	0.99	33.9	20.5	38.5	0.54	0.65	34.5	-

2.5. Productive and Oenological Parameters

Grapes had a good sanitary condition so it was processed immediately after the evaluations carried out. Harvest was performed when grapes reached 23–24 ºBrix. Grapevine yield (kg·plant^{-1}) was measured using a precision balance (Sartorius, Gottingen, Germany). The number of bunches harvested by each grapevine was counted (N°bunches·plant^{-1}) and the weight of the bunches (g) was evaluated using the same precision balance with the aim to calculate the vineyard yield (kg·ha^{-1}). Weight of 100 berries (g) was also evaluated for to get an average (g berries^{-1}). Ravaz index was calculated according to the exposed by Shellie [32], using yield and pruning weight.

Soluble solids (°Brix), probable alcohol, total acidity (g·L^{-1} of sulfuric acid) and pH were measured according to the International Organization of Vine and Wine (OIV) methodologies [33]. Total polyphenols index was determined in wines based on the stated by Amerine et al. [34].

2.6. Statistical Analysis

A general linear model, using the statistical program Statgraphics Centurion XVI.I (Virginia, USA) was performed. The treatments (types of management) were considered as a fixed variable, while the season (associated with climatic conditions) was considered as a random variable in the general linear model. Differences between samples were compared using the Tukey test at 95% of probability level. Principal component analysis (PCA) was performed using each variable together with the bioclimatic indices calculated from field data for the site, through InfoStat software (www.infostat.com.ar).

3. Results and Discussion

3.1. Grapevine Productivity

The effect of type of management (organic, integrated and conventional) evaluated during 5 consecutive seasons on yield ($t \cdot ha^{-1}$), Ravaz index and yield components such as number of bunches per plant, weight of bunches (g), weight of berries (g), and number of berries per bunch is shown in Table 2. Weight of bunches, weight of berries, and number of berries per bunch were not affected by the types of managements, except for the number of bunches per plant, which varied from 34 to 42. This parameter together with yield was higher in the conventional than the organic management in the vineyard. Number of berries per bunch was more influenced by season than the type of management and their interaction (Figure S1). Yield ranged from 5.95 to 4.83 ($t \cdot ha^{-1}$). Ravaz index varied from 2.96 to 2.05 and was higher in the conventional than the organic management, and this parameter was more influenced by season than the type of management and their interaction (Figure S1). Ravaz index represents the reproductive to vegetative growth ratio [35]. Balanced vines present Ravaz index values from 3 to 10, with optimal values between 5 to 7 [36]. The Ravaz Index balanced to 3, indicating an excess of vigor at the expense of yield [35]. Based on this, the vines managed organically present greater vigor than conventional management and this could indicate that the productive potential of these vines could be higher. This growth can be detrimental to the regulation of the bud differentiation, allowing a worse cluster microclimate, negatively affecting number of bunches per plant [37]. However, the aforesaid differences were mainly associated to climate conditions reached in each season (Table 2). Different results are reported in literature however, most of them have reported that organic management negatively affected yield in grapevine. Malusà et al. [38] showed that yield in organic vineyards were lower than in the vineyards under conventional management. Döring et al. [39] reported that the grapevines growing under organic management showed significantly lower growth and yield in comparison to the integrated treatment, which was associated with differences in growth and cluster weight. Brunetto et al. [40] reported that in a first study season, grapevines under organic management showed higher yield than the conventional ones. However, no differences were found in yield in the second season Pou et al. [11] reported that a mixture of perennial grasses and legumes as cover crops increased Ravaz index compared to no tillage and traditional tillage, offering a better balance between vegetative and reproductive growth. However, the opposite was observed by these authors, when yield reduction in cover cropped vines was the highest and counteracted their lower pruning weight. Season influenced all the productivity parameters of the grapevines (Table 2). Yield and Ravaz index reached in the second season were higher than the found in the first and third seasons, while weight of bunches and number of berries per bunch reached in the second season were the highest. Additionally, this season reached the lowest number of bunches per plant. Based on this, it is possible that there was some compensation effect on yield component among the seasons, as has been discussed by Sadras et al. [41]. The third season presented a higher weight of berries than the fifth season.

To classify the different types of managements by season according to grapevine productivity, principal component analysis (PCA) was carried out using yield parameters obtained from organic (O), integrated (I), and conventional (C) managements, together with different bioclimatic indices, such as cool night index (CI), Huglin's Heliothermal Index (HI), mean thermal amplitude (MTA), Winkler Index (WI), average mean temperature of the warmest month (MTWM), and maximum average temperature of the warmest month (MATWM) performed in a Cabernet Sauvignon vineyard along five consecutive seasons (S). Principal component 1 (PC1) explained 40.2% of the variance and PC2 explained 23.8% of the variance, representing 64.0% of all variance (Figure 1). PC1 was strongly correlated with HI index, MTWM and MATWM, while PC2 was correlated with yield, Ravaz index and number of berries per bunch. Both components allowed to separate the different treatments by season. Second season was correlated with high amounts of weight of bunches and number of berries per bunch, while fifth season was correlated with most of the bioclimatic indices. Accumulated rainfall during the second season was the highest compared to the rest of the seasons. This might condition most of the productive measured parameters. Besides, HI and WI indices were positively correlated with number of bunches per plant and Ravaz index, while HI index was negatively correlated with weight of berries and weight of bunches. MATWM and MTWM were correlated negatively with weight of berries.

Based on this, bioclimatic indices associated with the accumulation of effective degree days, such as HI and WI were positively correlated with the number of bunches per plant, while bioclimatic indices associated with the synthesis of secondary metabolites as MATWM and MTWM were inversely correlated with the weight of berries per bunch. It is of wide knowledge that the number of bunches per grapevine is determined during the previous year. Light and temperature exposure have the greatest potential to regulate the differentiation of anlagen into either bunch or tendril primordia [42]. Based on this, high intensity of light and moderate temperatures on the bud after different viticultural managements favor the formation of cluster primordia [43,44]. The season factor influenced the number of bunches per plant more than the type of management. Number of bunches per plant was higher in the first, fourth, and fifth seasons than the in the rest of the study seasons, while the second season presented the lowest number. However in the only fourth season was presented a high heat accumulation based on WI, while the second season presented the lowest values of HI, MTWM, and MATWM. Therefore, data in relation to radiation can give more information to the obtained results. Respect to the weight of berries, it is probably that the low amount of this parameter reached in the warmer season is due to the dehydration of the berry, which was described by Bonada et al. [44]. None of the bioclimatic indices were related with yield, which was affected by the season.

Table 2. Effect of organic, integrated and conventional management on yield (t·ha^{-1}), Ravaz index, and yield components such as number of bunches per plant, weight bunches, weight of berries and number of berries per bunch in Cabernet Sauvignon grapevines evaluated during 5 consecutive seasons.

Factor	Yield (t·ha^{-1})	Ravaz Index	N°Bunches· Plant^{-1}	Weigh of Bunches (g)	Weight of Berries (g)	N°Berries· Bunch^{-1}
Type of management (M)						
Organic	4.8 a	2.1 a	33.7 a	81.1	0.98	83.8
Integrated	5.5 ab	2.4 ab	37.0 ab	82.2	0.98	84.1
Conventional	6.0 b	3.0 b	41.5 b	95.3	1.03	92.9
Season (S)						
S1	4.4 a	1.4 a	48 c	60.1 a	1.02 ab	58.7 a
S2	6.4 c	2.9 b	26 a	173.1 c	1.00 ab	174.2 c
S3	4.8 ab	1.5 a	32 b	83.3 b	1.12 b	75.3 ab
S4	5.7 bc	3.4 b	42 c	77.4 b	1.05 ab	72.5 ab
S5	5.9 bc	4.1 b	42 c	79.7 b	0.82 a	98.7 b
Significance (*p*-value)						
M	0.02	0.05	0.0076	0.054	0.62	0.54
S	0.004	0.0005	0.0001	0.00001	0.03	0.0004
M × S	0.6	0.007	0.57	0.22	0.06	0.01

M × S: Interaction between type of management (M) and season (S). For a given factor and significance $p \leq 0.05$, different letters within a column represent significant differences (Tukey's test, $p \leq 0.05$).

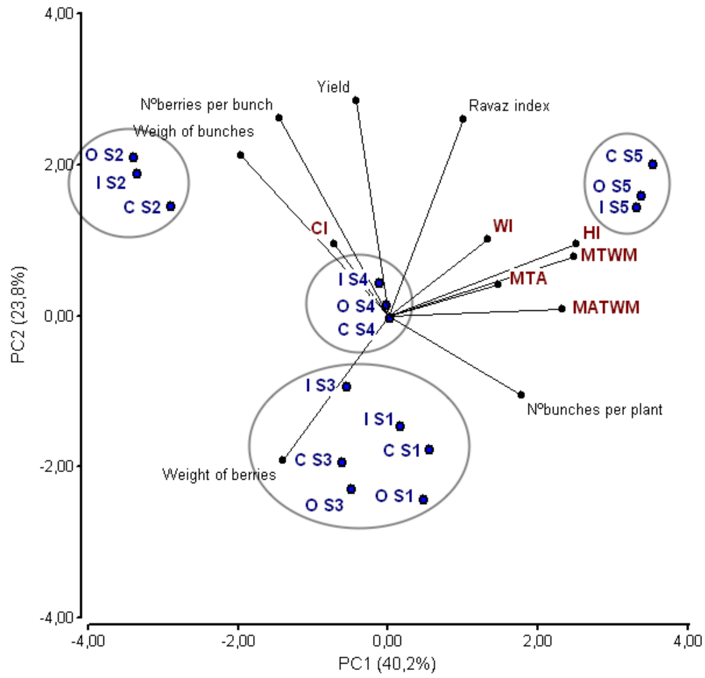

Figure 1. Principal component analysis (PCA) performed with grapevine productive parameter from a Cabernet Sauvignon vineyard planted in an organic (O), integrated (I), and conventional (C) managements, together with different bioclimatic indices such as cool night index (CI), Huglin's Heliothermal Index (HI), mean thermal amplitude (MTA), Winkler Index (WI), average mean temperature of the warmest month (MTWM), and maximum average temperature of the warmest month (MATWM) along five consecutive seasons (S).

3.2. Berry Composition

The effect of type of management (organic, integrated, and conventional) evaluated during 5 consecutive seasons on berry composition is shown in Table 3. None of the berry components were affected by the type of management, due to the treatments were harvested in the same stage of ripening. Little differences in berry composition have been reported by some authors in grapevines growing under changes on the types of managements. As was observed in Table 3, Döring et al. [39] reported that fruit quality parameters were not affected by the management system. These aforementioned results include the biodynamic system. Additionally, Tesic et al. [45] showed that only in the third study year, grapes from Chardonnay grapevines growing under organic management presented higher soluble solids and total acidity, together with a lower pH than the grapes from grapevines growing under conventional management. Soluble solids and probable alcohol were not affected by the season. However, total acidity, soluble solids to total acidity ratio, and pH were affected by the season factor. Total acidity ranged from 2.52 to 4.82 g$\cdot$L^{-1} of sulfuric acid. Total acidity content found in the fourth season presented the highest total acidity content, while the second season reached the lowest amount.

To classify the different types of managements by season according to berry composition, a PCA was carried out using grape physiochemical parameters from grapevines under organic (O), integrated (I) and conventional (C) managements, together with the different bioclimatic indices, such as CI, HI, MTA, WI, MTWM and MATWM performed in a Cabernet Sauvignon vineyard along five consecutive seasons (S). PC1 explained 38.4% of the variance and PC2 explained 28.0% of the variance, representing 66.4% of all variance (Figure 2). PC1 was strongly correlated with HI index and MTWM, while PC2 was only strongly correlated with CI. Both components allowed separation of the treatments by season. The second season was correlated with soluble solids to total acidity ratio (SS to TA ratio). Third season was positively correlated with probable alcohol, °Brix and pH, while was negatively correlated with the fourth season and WI index. As in Figure 1, fifth season was correlated with most of the bioclimatic indices. Besides, CI and WI indices were inversely correlated with pH, while WI index was correlated with total acidity. Based on these results, high temperatures during the month before harvest allowed to reach a low pH in grapes. High night temperatures tend to promote vegetative growth at the expense of productivity [46]. HI index was correlated with total acidity and inversely correlated with SS to TA ratio. Based on this, the bioclimatic indices associated with the heat accumulation or growing degree-days such as HI and WI were related with high values of total acidity. These results observed in Figure 2 were, somehow, unexpected since heat accumulation and low temperatures at the end of ripening stage is related to a delay in grape maturation associated with low pH and high total acidity. However, these bioclimatic indices are calculated based on the active growth temperature of the vine, considering corrections by maximum and minimum temperatures, day–night fluctuations, and latitude. According to Figure 2, bioclimatic indices associated to warm conditions such as MTA, MTWM, and MATWM were more related to high pH and °Brix. pH as soluble solids and probable alcohol were affected by the interaction between the type of management and season (Figure S2). In this way, the accumulated rainfall during the S1 and S3 growing season were higher than to those obtained in S4, which showed warmer temperature conditions. Additionally, the grapevines cultivated under organic management showed lower Ravaz index than the conventional ones, which was associated to a high vigor [11,35]. Therefore, vineyard productivity, which was influenced by climatic conditions and type of management, considerably affected berry composition in terms of soluble solids, probable alcohol and pH.

Table 3. Effect of organic, integrated, and conventional management on berry components in Cabernet Sauvignon grapevines evaluated during 5 consecutive seasons.

Factor	Soluble Solids (°Brix)	Probable Alcohol	Total Acidity [a]	$SS \cdot TA^{-1}$ [b]	pH
Type of management (M)					
Organic	24.9	14.2	3.85	6.31	3.47
Integrated	25.1	14.3	3.90	6.44	3.47
Conventional	25.2	14.4	4.00	6.48	3.49
Season (S)					
S1	25.1	14.3	3.99 b	6.29 b	3.40 a
S2	25.2	14.4	2.52 a	10.05 c	3.53 bc
S3	24.9	14.2	4.25 b	5.87 b	3.57 c
S4	24.8	14.2	4.82 c	5.15 a	3.45 ab
S5	25.2	14.4	4.13 b	6.10 b	3.47 abc
Significance (*p*-value)					
M	0.17	0.20	0.16	0.41	0.51
S	0.45	0.56	0.0001	0.0001	0.0016
M × S	0.0001	0.00001	0.07	0.087	0.0007

M × S: Interaction between type of management (M) and season (S). SS·TA: Soluble solids (SS) to total acidity (TA) ratio. [a] As $g \cdot L^{-1}$ of sulfuric acid. [b] Soluble solid to total acidity ratio. For a given factor and significance $p \leq 0.05$, different letters within a column represent significant differences (Tukey's test, $p \leq 0.05$).

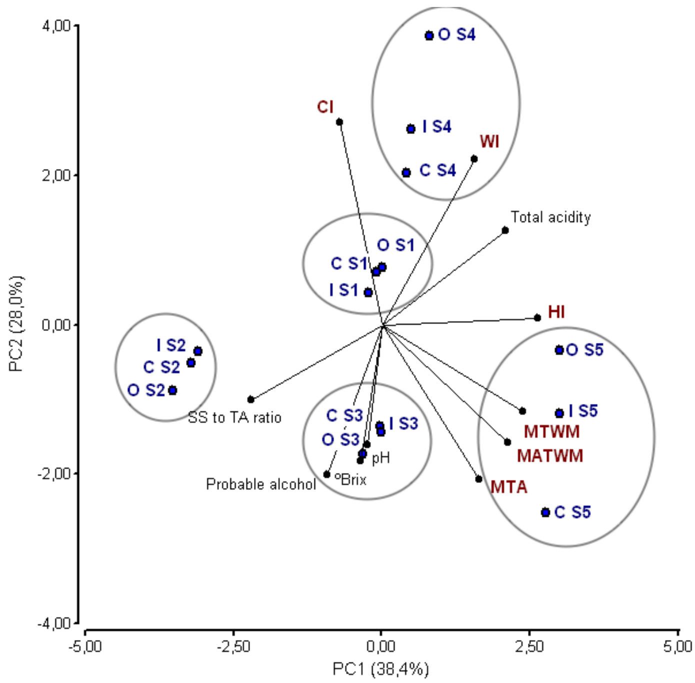

Figure 2. Principal component analysis (PCA) performed with berry composition from a Cabernet Sauvignon vineyard planted in an organic (O), integrated (I), and conventional (C) managements, together with different bioclimatic indices such as cool night index (CI), Huglin's Heliothermal Index (HI), mean thermal amplitude (MTA), Winkler Index (WI), average mean temperature of the warmest month (MTWM), and maximum average temperature of the warmest month (MATWM) along five consecutive seasons (S).

3.3. Wine Oenological Parameters

The effect of type of management (organic, integrated, and conventional) evaluated during 5 consecutive seasons on wine oenological parameters is shown in Table 4. Type of management did not affect the wine composition in terms of its alcohol degree and pH. However, the wines produced from grapevines planted in the integrated management presented higher total phenols than the organic wines. Provost and Pedneault [12] reviewed organic management vineyard and its impacts on wine quality. These authors suggested that organic management may increase the level of certain compounds in wines with little impacts on wine sensory perception. Martin and Rasmussen [47] indicated that organic managed grapevines suffer more levels of biotic stress than conventional grapevines and may probably produce higher rate of secondary metabolites, mainly phenolic compounds. These aforementioned results did not match with the shown in Table 4. Additionally, the wines from grapevines planted in the conventional management presented higher total acidity than the organic wines. Season had a considerable effect on wine oenological parameters. The wines elaborated in the first season presented the lowest content of total phenols and total acidity. The wines of the third and the fourth seasons reached lower alcoholic degree than the wines of the rest of the studied seasons. However, in all samples, this oenological parameter was high (>14% of alcoholic degree). The wines elaborated from the second season presented higher pH than the wines from the third and the fifth seasons.

To classify the different types of managements by season according to wine oenological parameters, a PCA was carried out using the measured physiochemical parameters in wines from grapevines under organic (O), integrated (I), and conventional (C) managements, together with the different bioclimatic indices, such as CI, HI, MTA, WI, MTWM, and MATWM performed in a Cabernet Sauvignon vineyard along five consecutive seasons (S). PC1 explained 42.8% of the variance and PC2 explained 30.3% of the variance, representing 73.1% of all variance (Figure 3). PC1 was strongly correlated with HI index and MTWM, while PC2 was strongly correlated with total phenolics and total acidity. Both components allowed to separate the treatments by season. Second and fourth seasons were correlated pH. Third season was positively correlated with total phenolics and total acidity. This season was inversely correlated with alcohol degree and the first season. Besides, all the bioclimatic indices except CI and WI were inversely correlated with pH. These results were unexpected since warm climate conditions and high temperatures at the end of ripening stage are mainly related to early ripening [26,28,31]. These authors showed that the sites that present warm climate conditions lead to wines with high alcohol degree and pH, together with low total acidity [26,28,31]. All the wine oenological parameters measured were influenced by the interaction season x type of management (Figure S3). Total polyphenol index and pH in wines were more influenced by the interaction between type of management and season, while alcohol degree and total acidity, including total polyphenol index, were also influenced by the season (Table 4). Canopy shade down regulate gene expression in the anthocyanin biosynthesis pathway [48]. Cluster shading decreased the accumulation of flavonols and skin proanthocyanidins with minimal differences in anthocyanins in pinot noir berries [49]. Organic management presented low values of Ravaz index, which is mainly associated with high vigor in vines (Table 2). Low vigor vines lead to higher wine anthocyanins, total phenols and color intensity than high vigor vines [50]. Moreover, S1 which reached the lowest total polyphenol index presented higher MATWM than the rest of the seasons with the exception of S5 (Table 1). The accumulation of flavanols and hydroxycinnamic acids was inversely related to MATWM in Carignan grapes [51].

Table 4. Effect of organic, integrated and conventional management on wine oenological parameters obtained from Cabernet Sauvignon grapevines evaluated during 5 consecutive seasons.

Factor	Total Polyphenol Index	Alcohol Degree (% v/v)	Total Acidity [a]	pH
Type of management (M)				
Organic	63.41 a	14.88	3.65 a	3.48
Integrated	80.94 b	15.28	3.82 ab	3.46
Conventional	73.68 ab	15.12	3.95 b	3.48
Season (S)				
S1	23.33 a	15.56 b	2.52 a	3.52 bc
S2	88.57 bc	15.36 b	4.25 c	3.56 c
S3	106.82 bc	14.26 a	4.82 d	3.44 ab
S4	106.8 c	14.54 a	4.13 c	3.47 abc
S5	78.34 b	15.66 b	3.48 b	3.38 a
Significance (*p*-value)				
M	0.027	0.068	0.0237	0.736
S	0.00001	0.0004	0.00001	0.002
M × S	0.00001	0.0105	0.011	0.00001

M × S: Interaction between type of management (M) and season (S). [a] As $g \cdot L^{-1}$ of sulfuric acid. For a given factor and significance $p \leq 0.05$, different letters within a column represent significant differences (Tukey's test, $p \leq 0.05$).

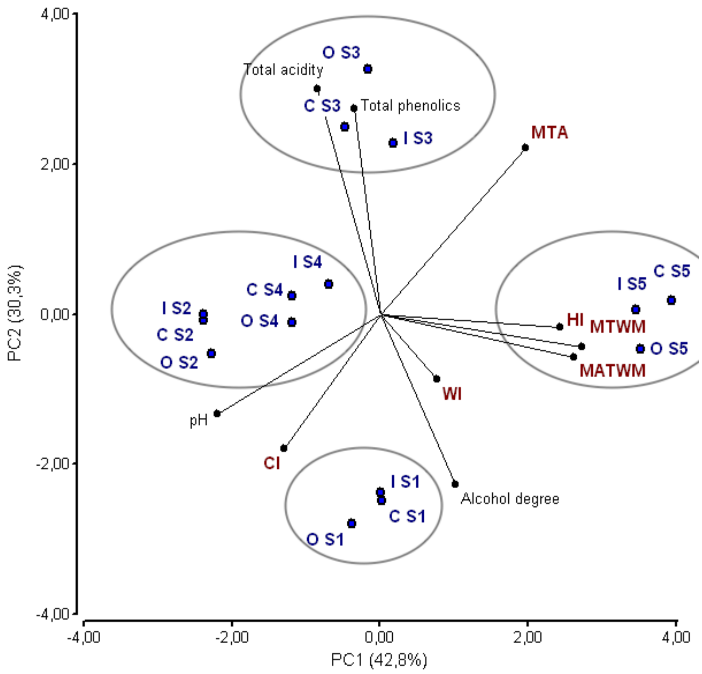

Figure 3. Principal component analysis (PCA) performed with wine oenological parameter obtained from Cabernet Sauvignon grapevines planted in an organic (O), integrated (I), and conventional (C) managements, together with different bioclimatic indices such as cool night index (CI), Huglin's Heliothermal Index (HI), mean thermal amplitude (MTA), Winkler Index (WI), average mean temperature of the warmest month (MTWM), and maximum average temperature of the warmest month (MATWM) along five consecutive seasons (S).

3.4. Soil Physicochemical Characteristics

The effect of type of management (organic, integrated, and conventional) evaluated during 5 seasons on soil physicochemical characteristics is shown in Table 5. Soils under the organic management showed the highest amount of N and K. N varied from 3.49 to 4.37, while K ranged from 165.7 to 185.3 (conventional and organic managements, respectively). The optimum mineral N content for grapevine development corresponds to the range of 15–25 ppm, while for K, the optimum level is 140 ppm [27]. Type of management did not affect pH, organic matter, P and B content in soils. pH ranged from 5.97 to 6.14 (integrated and conventional managements, respectively). These values are within the optimum development range of the grapevines [27]. However, there could be a tendency to increase the soil acidity, which is explained by the low content of organic matter reached [36]. Despite the aforementioned, organic matter was higher than to those exposed by Gutiérrez-Gamboa and Moreno-Simunovic [26] in rainfed vineyards from the Maule Valley.

These results differ to those reported by Fließbach et al. [52]. These authors showed that applying organic fertilization, the content of organic matter was improved compared to the traditional exploitation soils. Different results are reported in literature about the effect of type of management on soil chemical composition. In this way, Morlat and Chaussod [53] reported that long term additions of organic amendments improved soil water holding capacity and P and K content. In addition, Coll et al. [4] reported that organic management led to an increase in soil organic matter, P content, soil microbial biomass, plant feeding and fungal feeding nematode densities. These authors also reported that organic farming increased soil compaction, decreased endogenic earthworm density and not modified the soil micro food web evaluated by nematofauna analysis. Additionally, Steenwerth and Belina [54] reported that cover crops enhance soil organic matter, carbon dynamic and microbiological function in vineyards ecosystems. Type of management did not affect organic matter in soils, including the grapevines cultivated under organic management. It is probably that when organic matter is applied to a soil, it accumulates until reaching an equilibrium. This balance is achieved when the rate of mineralization (action of microorganisms) is equal to the rate of incorporation of organic matter, that is, the amount applied is equal to the amount that microorganisms use to develop their biological processes [55]. Tillage brings subsurface soil to the surface where it is then exposed to wet–dry and freeze–thaw cycles and subjected to raindrop impact [56]. This results in an increase in the susceptibility of aggregates to disruption [57]. Plowing changes soil physicochemical parameters, increasing the decomposition rates of litter [58]. The chemical and colloidal properties of soil organic matter can be studied only in the free state, that is, when it is separated from the inorganic compounds of the soil. Thus, the first task in research is to separate the organic matter from the inorganic matrix: from sand, silt and clay. In clay soils, the C content of macroaggregates was 1.65 times greater compared to microaggregates [59]. Due to the aforementioned, it is probably that there were no differences among the type of managements on organic matter on soils. Season was the most important factor of the variability of organic matter and its content tended to decrease over time according to the accumulated rainfall (Table 5). Temperature sensitivity values demonstrated a strong positive correlation with annual precipitation, so C decomposition in soils from zones with high precipitation exhibits increased temperature sensitivity [60]. Additionally, N contained in organic matter would cause an initial increase in pH, associated with the formation of NO_4^+ that consumes protons. The subsequent nitrification would result in a decrease in pH due to release of the protons to the soil solution. The decrease of the pH by formation of NO_3 would not achieve the original levels of acidity since a high concentration of NH_4^+ has a nitrification inhibiting effect [61].

P ranged from 6.83 to 7.89, while B varied from 1.23 to 1.38 (conventional and organic managements, respectively). With respect to the description by Sadzawka et al. [27], P should be higher than 8 ppm, and B between 1 and 2 ppm. According to the shown in Table 5, soils lack of mineral nitrogen. In this way, nitrogen accessibility by grapevines in rainfed conditions relies among other factors on the presence of sufficient soil water, which under Mediterranean climate conditions is mostly accumulated during winter and/or early spring rainfalls [28]. Season affected all the evaluated parameters with the exception of pH. During the fourth and fifth seasons the soil reached lower organic matter and N than in the rest of the study seasons. In the third season was showed the highest N and B content in soil. During the second seasons was showed the lowest P content, while in the fifth season was presented the lowest K content in soils.

To classify the different types of managements by season according to soil characteristics of the vineyard, a PCA was carried out using the measured parameters in soils from the vineyard under organic (O), integrated (I) and conventional (C) managements, together with the different bioclimatic indices, such as CI, HI, MTA, WI, MTWM, and MATWM performed along five consecutive seasons (S). PC1 explained 46.2% of the variance and PC2 explained 28.8% of the variance, representing 75.0% of all variance (Figure 4). PC1 was strongly correlated with organic matter, K, HI, MTWM, and MATWM, while PC2 was strongly correlated with B and CI. Both components allowed to separate the treatments by season. CI was negatively related with B. HI was negatively related with organic matter, N and K. MATWM was negatively related with K. MTA was positively related with B and negatively with K. MTWM was negatively related with N and K. WI was negatively related with organic matter, N and B. In this way, heat accumulation promotes low pH, organic matter, K and B in soil. Additionally, thermal amplitude was related with high B content in soil. It is probably that temperature affects decomposition organic matter of soil, affecting the rest of the measure parameters. The effects of temperature on soil organic matter decomposition have been reviewed by certain authors such as Kätterer et al. [62] and Conant et al. [63].

Table 5. Effect of organic, integrated and conventional management on soil physicochemical characteristics obtained from a Cabernet Sauvignon vineyard evaluated during 5 consecutive seasons.

Factor	pH	Organic Matter (%)	N (ppm)	P (ppm)	K (ppm)	B (ppm)
Type of management (M)						
Organic	6.07	1.51	4.37 b	7.29	185.3 b	1.38
Integrated	5.97	1.34	3.53 a	6.91	172.1 a	1.26
Conventional	6.14	1.45	3.49 a	6.83	165.7 a	1.23
Season (S)						
S1	6.07	1.73 b	4.62 b	6.60 ab	173.0 b	1.21 a
S2	6.39	2.07 b	4.54 b	6.39 a	194.1 c	1.09 a
S3	5.98	1.56 b	6.07 c	7.21 bc	180.1 bc	2.38 b
S4	6.05	1.06 a	2.83 a	7.43 bc	179.7 bc	0.91 a
S5	5.83	1.16 a	2.09 a	7.60 c	144.9 a	1.15 a
Significance (*p*-value)						
M	0.63	0.26	0.011	0.11	0.0008	0.25
S	0.22	0.0005	0.00001	0.0036	0.00001	0.00001
M × S	0.37	0.064	0.77	0.99	0.99	0.84

M × S: Interaction between type of management (M) and season (S). For a given factor and significance $p \leq 0.05$, different letters within a column represent significant differences (Tukey's test, $p \leq 0.05$).

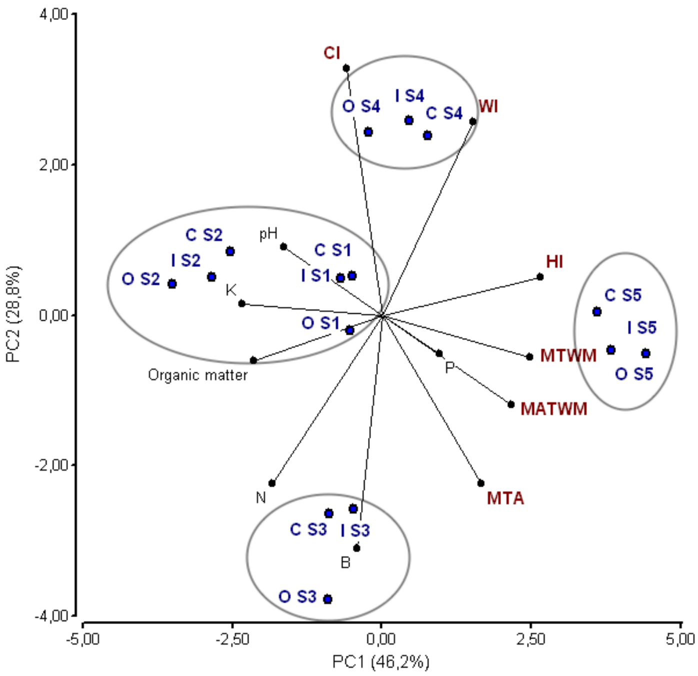

Figure 4. Principal component analysis (PCA) performed with soil physicochemical parameters obtained from Cabernet Sauvignon vineyard planted in an organic (O), integrated (I), and conventional (C) managements, together with different bioclimatic indices such as cool night index (CI), Huglin's Heliothermal Index (HI), mean thermal amplitude (MTA), Winkler Index (WI), average mean temperature of the warmest month (MTWM), and maximum average temperature of the warmest month (MATWM) along five consecutive seasons (S).

4. Conclusions

Type of management whether organic, conventional or integrated affected productive, wine oenological and soil physicochemical parameters. However, none of the grape oenological parameters measured were affected by the type of management. Conventional management showed higher yield, Ravaz index, number of bunches per vine and wine total acidity than the organic management.

However, organic management improved soil N and K content compared to conventional and integrated managements. Integrated management lead to higher total phenols than organic management. Season factor had mostly influenced productive parameters, grape oenological parameters with the exception of soluble solids, wine oenological parameters and soil chemical parameters except pH. Interaction between type of management and season influenced soluble solids, probable alcohol and pH in grapes, and total polyphenol index and pH in wines. Organic matter decreased along the study were carried out, being the season the most important factor of variability. Based on the bioclimatic indices, heat accumulation conditioned number of bunches per plant, leading to grapes and wines with low pH. In addition, heat accumulation also affected organic matter, pH and some micronutrients content in soils. In this way, thermal amplitude was positively related with B, which is a scarce microelement in rainfed soils from Maule Valley.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4395/9/2/64/s1, Figure S1: Significant interactions of analysis of variance for productive variables; Figure S2: Significant interactions of analysis of variance for berry components; Figure S3: Significant interactions of analysis of variance for wine oenological parameters.

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