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RESEARCH ARTICLE

Influences of aspect and tillage on two winegrape cultivars on Mount Etna

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ABSTRACT
The effect of minimum tillage on two autochthonous *Vitis vinifera* L. varieties, namely Nerello mascalese and Carricante, established on the eastern and northern aspect slopes of the volcano Mount Etna in Sicily, was evaluated over two seasons. The objective was to determine whether conventional tillage and minimum tillage affect the vegetative growth, bud fertility, total leaf area, leaf nutritional status and fruit yield components. The ratio of bunches/retained buds was strongly influenced by aspect. Yield per vine was significantly different within cultivars and seasons depending on cultivar, tillage treatment and aspect. Due to its natural plasticity in marginal conditions, yields were consistently higher in Nerello mascalese. The yield reduction with minimal tillage was excessive in Carricante. As a consequence of the yield reduction in the second season, total soluble solids in particular were increased in Nerello mascalese. Linear discriminant analysis revealed the highest discrimination values for cultivar and the lowest ones for tillage.

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Bud fertility; linear discriminant analysis; slope; total leaf area; *Vitis vinifera* L; yield components

Introduction

Horticulture has been practised on the slopes of the volcano Mount Etna (Sicily, Italy) for a long time. The horticulture here is particularly interesting because the many sites are characterised by a diversity of aspects, orographies, soil properties and land uses. Grapevines are some of the oldest crops grown on this mountain and the vineyards are some of the most interesting in the world. For the most part, these are managed traditionally (for the Mediterranean region) using tillage, usually three times each season.

The relationship between vine properties and climate is well known. In particular, the exposure of leaf and fruit to the sun affects vine performance (Rotaru et al. 2010). Sànchez & Dokoozlian (2005) have shown direct correlations between light exposure, temperature and bud fertility, suggesting that these two variables—light and temperature—are the most important ones influencing induction and differentiation of the inflorescences.

Soil properties affect both the vegetative and reproductive growth of grapevines (Lee & Steenwerth 2013) as well as berry quality (Panten & Bramley 2011). In addition, soil

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management greatly influences the soil/grapevine interaction through its impact on the soil's physical, chemical and biological condition (Morlat & Jacquet 2003). Inevitably, therefore, soil management affects vine performance (Göblyös et al. 2009). The role of tillage practices (number, timing, depth, etc.) is thus a relevant focus for modern viticulture. Minimum or zero tillage and cover cropping is often advocated to improve soil fertility and reduce erosion, especially in marginal and steep areas (De Gryze et al. 2008). These practices should increase agro-ecological and economic sustainability. Conservation tillage has become an important tool in managing production systems throughout the world (Horwath et al. 2008). It increases infiltration of rainwater and soil water storage, reduces labour, fuel and equipment costs, improves soil tilth, cropping intensity, soil organic matter, and water and air quality (McLaughlin & Mineau 1995; Korkuta & Bahar 2013).

Zero tillage and cover cropping, however, can be disadvantageous for rain-fed vineyards in arid environments where competition for water between the cover crop and main crop (in this case winegrapes) can lead to severe water stress in the latter. In this case, it will have negative effects on growth, yield and berry quality, especially if the stress occurs in spring (Monteiro & Lopes 2007). Minimum tillage offers a valid alternative to conventional tillage to control weed growth, vine vigour and bud fertility. Fruit yield and its components also influence the levels of primary and secondary metabolites in the fruit (Ingels et al. 2005; Panten & Bramley 2011; Gouthu et al. 2012).

The grape yield depends on the vegetative/reproductive growth ratio, which is affected by trophic competition between growth sinks and the overall source–sink relationships of the plant (Pallas et al. 2010). In deciduous tree crops, reproductive behaviour depends on floral induction, initiation and differentiation (Wilkie et al. 2008). Grape buds differentiate over two seasons in which there are three distinct stages. The first two stages involve bud initiation and differentiation and are completed in the first season. The third stage occurs in the second season and involves the final phase of flower formation and development (Srinivasan & Mullins 1981). These early phases are important to winegrape growers because flower production depends on conditions during the previous season's floral period (Guilpart et al. 2014). A number of factors affect the balance between vegetative and reproductive growth; these include both endogenous (Guilpart et al. 2014) and exogenous factors linked to the weather (especially temperature and light) and to soil conditions (especially water and mineral availability). Despite grapevines exhibiting good performance in terms of plastic development in response to changes in trophic competition (Pallas et al. 2008), grapevines are also strongly modified by agronomic practices which tend to modify the inter-relationships between the various organs (Rives 2000).

This study is based on the hypothesis that different soil management techniques—and, namely, the adoption of minimum tillage—can affect bud fertility so that in the following season productivity could be reduced as a consequence of a limited number of bunches per vine. Consequently, some other qualitative parameters, including total soluble solids (TSS) content, are also likely to increase. These effects could vary under different conditions of aspect. The role of water stress on vegetative/productive equilibrium and on quality is well known under different canopy managements (Reynolds et al. 1996; Wheeler et al. 2005; Lopes et al. 2008, 2011; Tardaguila et al. 2010; Nicolosi et al. 2012; Vilanova et al. 2012; Ferlito et al. 2014). The aim of this research was to determine the effects of vineyard floor management of Mount Etna's vineyards (tilling *vs* minimum tilling of the inter-rows) in two areas with different soils and aspects. The focus was particularly on how soil management affects bud fertility, vegetative growth, nutritional status, fruit yield and its components in two varieties exhibiting different vegetative and reproductive behaviour.

Materials and methods

Site, plant material and experimental design

Two commercial *Vitis vinifera* L. vineyards were selected in the Mount Etna district, Sicily: one on the north facing slopes (north site [NS]) (37°50′N, 15°08′E, 557 m elevation) and one on the east facing slopes (east site [ES]) (37°41′N, 15°05′E, 680 m elevation). The sites were bordered on all sides by other vineyards and were established in 2002.

In each of the commercial vineyards, two autochthonous varieties—Nerello mascalese (NMA; black grapes) and Carricante (CRR; white grapes), both grafted on to 140 Ru—were planted at a density of 4,166 vines per hectare (spaced 1 m in the row and 2.4 m between rows). The row direction was east–west. Vines were trained using a unilateral cordon system at a height of 0.7 m with the top of the canopy at approximately 1.8 m. Vines were spur-pruned to six to eight nodes per vine (two nodes per spur and three to four spurs). The shoots were vertically positioned and were not hedged during the growing season. All agronomic practices were applied uniformly across treatments and in accordance with standard commercial practice in the area. Neither fertilisation nor irrigation were applied.

A factorial treatment combination was used to conduct the trial over two consecutive growing seasons from 15 January 2013 to 31 October 2014. The treatments (described below) were continued over three seasons being initiated on 15 January 2012. This enabled study of the response to management change.

Climate and soil

Daily temperature and rainfall data were either directly registered or provided by the Sicilian Agro-meteorological Information Service.

For each year, monthly minimum, mean and maximum air temperatures and rainfall registered in the experimental vineyards are given in Figure 1. The climate of the trial sites is characterised by wet winters, while summer is semi-arid mainly in the ES.

According to the USDA scheme (Klingebiel & Montgomery 1961), the vineyard soils are classified as loamy-sand and sandy-loam in the case of north facing slopes (NMA and CRR plantations, respectively) and sand in the case of east facing slopes. The organic matter, calcium (Ca), magnesium (Mg), potassium (K), iron (Fe) and manganese (Mn) contents of the soil were higher for the NS than for the ES, whereas the copper (Cu) content of the NS was lower. The soil pH was neutral for the NS and sub-alkaline for the ES (Table 1).

Vineyard floor management

Two soil management practices were compared (2013–2014): minimum tillage (MT) and conventional tillage (CT). The MT treatment included periodical mechanical weed control using a string-trimmer from January (winter) to the first few days of July (summer) with

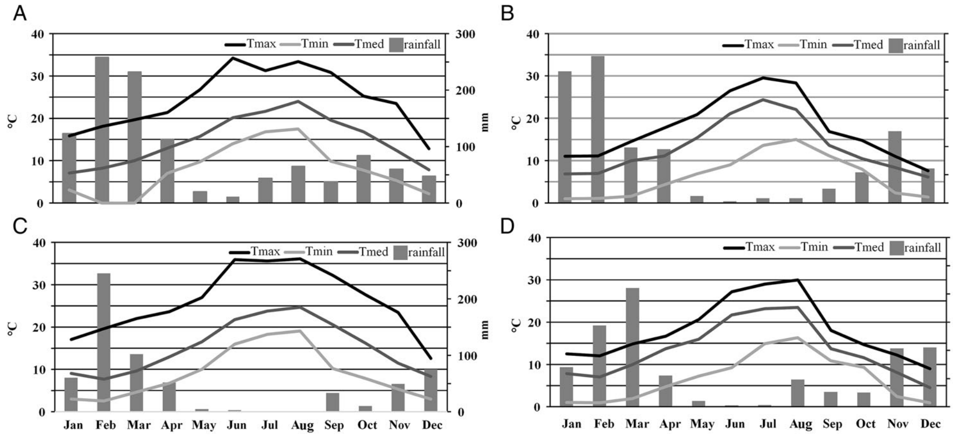

Figure 1. Monthly minimum, mean and maximum air temperatures and rainfall registered in the experimental vineyards. **A**, **C,** 2013 and 1014 east facing slopes, 37°41′N, 15°05′E, 680 m elevation; **B**, **D,** 2013 and 2014 north facing slopes, 37°50′N, 15°08′E, 557 m elevation.

only one mechanical tillage (15 cm deep) in mid-April (spring). Meanwhile, CT included a mechanical tillage in the last few days of January (25 cm deep), a second (15 cm deep) in the middle of April and a third during the first few days of July (10 cm deep).

Treatments

The treatments were applied to three independent plots consisting of seven rows containing 80 vines. All measurements were made on 20 index vines, selected for uniformity from the central five rows. The eight treatments were: (1) Nerello mascalese, north side,

Table 1. Main physical and chemical parameters of the first 0–30 cm of soil for each study area and cultivar.

		Value			
		North side		East side	
Parameter	Measure unit	Nerello mascalese	Carricante	Nerello mascalese	Carricante
Clay	(%)	3.45	12.15	3.95	2.85
Silt	(%)	16.35	10.90	8.50	8.35
Sand	(%)	80.20	76.95	87.55	88.80
$Nitrogen_{tot}$	(%)	0.32	0.34	0.27	0.08
Organic matter	(%)	3.2	3.4	1.1	0.8
Phosphorus P_2O_5	(ppm)	78	48	40	30
Potassium K_2O	(ppm)	245	288	194	180
Calcium $carbonate_{tot}$ ($CaCO_3$)	(ppm)	1	1	1	1
Electrical conductivity 1:5 25 °C	(mS cm^{-1})	0.04	0.04	0.03	0.04
pH		7.2	6.8	7.7	7.4
Cation exchange capacity (CEC)	(meq/100g)	8.58	9.29	2.72	3.03
Calcium (Ca^{++})	(ppm)	1512.5	1637.5	425	487.5
Magnesium (Mg^{++})	(ppm)	50	50	12.5	12.5
Sodium (Na^{+})	(ppm)	18	18	18	24
Potassium (K^{+})	(ppm)	204	240	162	150
Iron (Fe^{++})	(ppm)	122	143	93	101
Zinc (Zn^{++})	(ppm)	4.4	3.7	4	3.1
Manganese (Mn^{++})	(ppm)	15	17	11	10
Copper (Cu^{++})	(ppm)	11.6	10.1	27	20.3

minimum tillage (NMA-NS-MT); (2) Nerello mascalese, east side, minimum tillage (NMA-ES-MT); (3) Nerello mascalese, north side, conventional tillage (NMA-NS-CT); (4) Nerello mascalese, east side, conventional tillage (NMA-ES-CT); (5) Carricante, north side, minimum tillage (CRR-NS-MT); (6) Carricante, east side, minimum tillage (CRR-ES-MT); (7) Carricante, north side, conventional tillage (CRR-NS-CT); and (8) Carricante, east side, conventional tillage (CRR-ES-CT).

Vegetative behaviour, bud fruitfulness

In each growing season, for each treatment, when shoot length was about 40 cm (Biologische Bundesanstalt, Bundessortenamt and CHemical industry—BBCH: inflorescence 57) (Meier 2001), the number of shoots and bunches deriving from nodes on spurs, *bourillon* (the bud between the crown bud and the first main bud on spur), crown (the bud between the old wood and the *bourillon*) and latent buds was determined. The number of blind buds of main nodes was also registered. After this stage, the shoots derived from *bourillon*, crown and latent buds were hand-pruned and six to eight main shoots per vine, derived from the buds remaining after the winter pruning, were retained. The potential and observed bud fertility was assessed on these shoots. Bud potential fertility was calculated as bunches on main shoots (n)/total main shoots (n). The observed fertility was calculated as bunches on each shoot (n)/buds retained on the spurs (n).

For each index vine at harvest, leaf area was measured on each of two shoots and their laterals (area meter, model LI-3100, Licor). The total leaf area per shoot (main and lateral) and the number of shoots per vine were used to estimate the total leaf area per vine.

Vine nutritional status

Every year at BBCH 71 (Meier 2001) (mid-June for CRR, end-June for NMA), vine nutritional status was determined by analysis of 40 leaves (four subsamples) of the index plants collected from fruiting shoots. The analyses were carried out as described by Torrisi et al. (2013). Leaves were washed with distilled water, oven dried to constant weight at 65 °C for 24 h. A representative subsample was ground in a mill (IKA, Werke Staufen) and nitrogen (N) content (g kg^{-1} dw) was determined by micro-Kjeldahl digestion. Other leaf subsamples were dry-ashed in a muffle furnace at 550 °C for 12 h, dissolved in a 1% (v/v) solution of hyperpure HNO_3 69% (Panreac Quimica SAU) and analysed for phosphorus (P), K, Ca and Mg (g kg^{-1} dw), and for Fe, zinc (Zn) and Mn (mg kg^{-1} dw) by inductively coupled plasma spectrometry (ICP-OES Optima 2000DV, Perkin Elmer).

Crop yield and berry characteristics

In both years, the bunches were harvested at maturity in early October in the first week for the ES and in the second week for the NS. For yield assessment, all bunches per vine and per shoot were counted and weighed and the total fresh weight yields per vine and per shoot were recorded. Two bunches from each index vine (120 bunches) were randomly selected and dissected to determine bunch weight and mean berry weight.

A 100 berry sample of the index plants per experimental unit was chosen and divided into four subsamples to determine TSS (digital refractometer with temperature correction, model RX-5000, Atago), pH and titratable acidity (TA) expressed as g L^{-1} of tartaric acid equivalents, using an automatic titrater (Titrino model 798, Metrohm) with 5.0 mL juice samples being titrated against 0.1 M NaOH to pH 8.2.

Statistical analyses

Analyses of variance (ANOVA) were carried out using STATISTICA 6.0. For each cultivar, treatment and aspect, effects were assessed by testing the significance of each variable ($P \leq 0.05$). Mean separation was calculated using Tukey's HSD test. Cultivar and years were independently analysed. Significant variable effects on vegetative, reproductive and qualitative parameters were shown by a factorial analysis of variance ($P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$).

In order to predict membership in two or more mutually exclusive groups, selecting the variables most useful to differentiate the groups of samples and to obtain the classification function, a multivariate statistical analysis on vegetative and reproductive parameters was carried out through linear discriminant analysis (LDA) by using IBM SPSS Statistics version 21.0 (2012). The data set consisted of 480 cases, and 16 predictor variables were utilised to predict category membership.

Results

Vegetative and reproductive behaviour

As reported in Table 2, the shoot emission of NMA situated on ES was lower than that of NMA situated on NS during 2013, where MT was applied. During the 2014 season, this trend was stronger in MT and observed for CT as well. The vegetative activity of main shoots of Carricante was not influenced by treatment in either aspect. For this cultivar, however, MT applied on the NS resulted in a significantly smaller amount of *bourillon* and crown shoots during the first year, than those recorded for CT on the ES. In the following year, the amount of *bourillon* and crown shoots observed where MT was applied on the ES was significantly lower than those recorded for CT on the NS. These results are in line with the very low incidence of blind buds in both seasons in both varieties; in particular, the Nerello mascalese in all treatments showed a consistent reduction in 2014. The trend observed for main bunch number for NMA was similar to that recorded for main shoots, *bourillon* and crown shoots, as well as latent bud shoots. For CRR, however, the trend observed for main bunch number correlated with that of *bourillon* and crown shoots only during 2014.

Figure 2 shows the potential and observed fertility indices. The potential fertility of Nerello mascalese in 2013 was affected by aspect, being the highest values recorded in the NS area. Carricante showed a significant fertility reduction in 2013 for the ES-MT; in 2014, a fertility reduction was observed in the ES area, especially in the CT treatment. The observed fertility showed similar behaviour in 2013 in Nerello mascalese where the NS-MT area had the highest value. In Carricante, the fertility was reduced in the ES-MT in 2013 and in the ES-CT in 2014.

In both years, the total leaf area (TLA) per vine of the NMA-ES-MT was lowest; however, between years, a reduction was observed in 2014 only in the ES-CT (Table 3).

Table 2. Vegetative and reproductive behaviour in each of two cultivars under minimum and conventional tillage treatments. Measurements were made when all inflorescences were fully developed (Biologische Bundesanstalt, Bundessortenamt and CHemical industry: inflorescence 57). Mean values for each parameter indicated by different letters are significantly different ($P \leq 0.05$) based on Tukey's HSD test within cultivars and year.

	Main shoots (n)		*Bourillon* and crown shoots (n)		Blind buds of main nodes (n)		Main bunches (n)		*Bourillon* and crown inflorescences (n)		Latent bud shoots (n)		Latent bud inflorescences (n)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Nerello mascalese-north side-minimum tillage	6.77$_a$	6.93$_a$	1.87$_b$	2.03$_a$	1.17$_b$	0.23$_b$	8.70$_a$	6.50$_a$	1.03	0.20	2.43$_a$	2.73$_a$	0.27$_{ab}$	0.40
Nerello mascalese-east side-minimum tillage	5.30$_b$	6.07$_b$	1.83$_b$	1.87$_b$	2.23$_a$	0.83$_a$	4.90$_c$	6.06$_b$	0.93	0.33	0.87$_b$	0.70$_b$	0.07$_b$	0.13
Nerello mascalese-north side-conventional tillage	6.26$_{ab}$	7.47$_a$	2.50$_{ab}$	2.53$_a$	1.60$_{ab}$	0.17$_b$	7.77$_b$	7.23$_a$	1.50	0.27	2.77$_a$	2.67$_a$	0.57$_a$	0.33
Nerello mascalese-east side-conventional tillage	6.27$_{ab}$	5.97$_b$	2.73$_a$	1.17$_b$	1.03$_b$	0.13$_b$	6.30$_{bc}$	5.97$_b$	0.90	0.70	2.10$_a$	1.13$_b$	0.10$_b$	0.30
Carricante-north side- minimum tillage	6.97	6.37	1.20$_b$	0.75$_{ab}$	0.63	0.50	8.87$_a$	8.83$_a$	1.43	0.33	0.90	1.57$_a$	0.97$_a$	0.80$_a$
Carricante-east side-minimum tillage	6.87	6.10	1.80$_{ab}$	0.53$_b$	0.33	0.43	6.67$_b$	6.93$_b$	1.07	0.57	0.43	1.20$_{ab}$	0.20$_{bc}$	0.67$_{ab}$
Carricante-north side-conventional tillage	6.77	6.40	1.37$_{ab}$	1.00$_a$	0.43	0.39	7.53$_{ab}$	8.90$_a$	1.47	0.67	0.83	1.33$_{ab}$	0.70$_{ab}$	0.67$_{ab}$
Carricante-east side-conventional tillage	6.63	6.13	2.10$_a$	0.93$_{ab}$	0.77	0.42	9.13$_a$	6.33$_b$	1.93	0.57	0.50	0.80$_b$	0.07$_c$	0.13$_b$

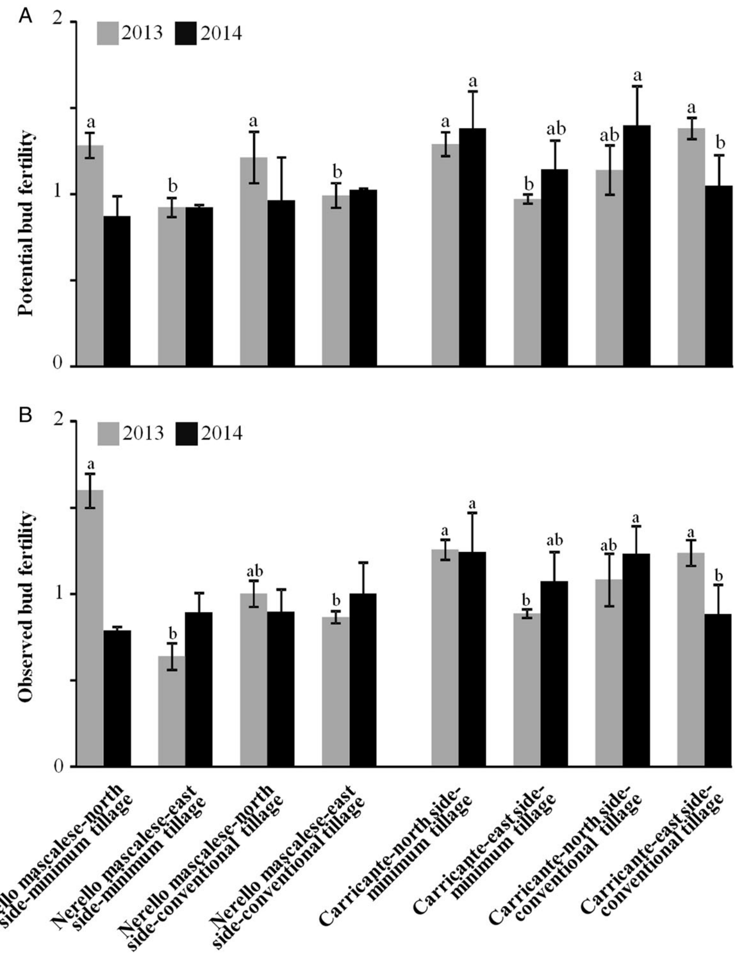

Figure 2. Potential (**A**) and observed (**B**) bud fertility registered in each of two cultivars under minimum and conventional tillage treatments. Measurements were made when all inflorescences were fully developed (Biologische Bundesanstalt, Bundessortenamt and CHemical industry: inflorescence 57). Mean values for each parameter indicated by different letters are significantly different ($P \leq 0.05$) (bars indicate one standard deviation) based on Tukey's HSD test within cultivars and years.

The highest TLA values were recorded for NMA-ES-CT and for NMA-NS-CT during 2013 and 2014, respectively. No significant differences were recorded in TLA/vine for Carricante. Regarding TLA per main shoot, significant differences were recorded in both years in NMA-ES-MT for which the lowest values were recorded. The TLA per lateral shoot for NMA was not influenced by tillage or aspect, whereas for CRR in the ES the TLA per lateral shoot was significantly lower than those in the NS.

Nutritional status

Leaf analyses showed that, except for the N content for NMA-NS-CT, the macronutrient concentration was very low for both aspects, both treatments and both seasons. The highest K contents were recorded for CRR-NS-CT in 2013 and for NMA-ES-CT in

Table 3. Total leaf area per vine, per shoot and per lateral shoot observed at harvest in each of two cultivars under minimum and conventional tillage treatments. Mean values for each parameter indicated by different letters are significantly different ($P \leq 0.05$) based on Tukey's HSD test within cultivars and year.

	Total leaf area/vine (m^2)		Total leaf area/main shoot (m^2)		Total leaf area/lateral shoot (m^2)	
	2013	2014	2013	2014	2013	2014
Nerello mascalese-north side-minimum tillage	5.40_a	5.59_a	0.79_a	0.80_a	0.22	0.21
Nerello mascalese-east side-minimum tillage	3.65_c	4.24_b	0.68_b	0.69_b	0.22	0.21
Nerello mascalese-north side-conventional tillage	4.95_b	5.96_a	0.79_a	0.79_a	0.21	0.21
Nerello mascalese-east side-conventional tillage	5.60_a	4.83_b	0.80_a	0.80_a	0.20	0.25
Carricante-north side-minimum tillage	5.04	5.02	0.72	0.78	0.27_a	0.26_a
Carricante-east side-minimum tillage	5.08	4.91	0.79	0.80	0.17_b	0.15_b
Carricante-north side-conventional tillage	5.40	5.10	0.79	0.79	0.23_a	0.20_a
Carricante-east side-conventional tillage	5.27	4.87	0.78	0.78	0.18_b	0.15_b

Table 4. Leaf nutritional status in each of two cultivars under minimum and conventional tillage treatments. Means values for each parameter indicated by different letters are significantly different ($P \leq 0.05$) based on Tukey's HSD test within cultivars and year.

	Nitrogen ($g\ kg^{-1}$ dw)		Phosphorus ($g\ kg^{-1}$ dw)		Potassium ($g\ kg^{-1}$ dw)		Calcium ($g\ kg^{-1}$ dw)		Magnesium ($g\ kg^{-1}$ dw)		Iron ($mg\ kg^{-1}$ dw)		Zinc ($mg\ kg^{-1}$ dw)		Manganese ($mg\ kg^{-1}$ dw)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Nerello mascalese-north side-minimum tillage	14.0_b	15.1	1.0	1.1	6.5	6.1_b	15.8_b	28.8	2.1_b	3.8	218_a	249_b	28_a	31	39_{ab}	27_c
Nerello mascalese-east side-minimum tillage	13.9_b	15.1	1.1	1.6	5.1	7.9_{ab}	14.9_b	28.1	3.0_{ab}	3.3	143_b	340_a	19_b	31	48_a	111_a
Nerello mascalese-north side-conventional tillage	21.7_a	14.0	1.0	1.0	7.0	7.1_{ab}	24.6_a	27.2	4.1_a	3.3	208_a	176_b	28_a	30	41_a	47_c
Nerello mascalese-east side-conventional tillage	14.0_b	15.4	1.2	1.1	6.5	10.3_a	15.8_b	24.9	2.1_b	2.8	163_{ab}	336_a	19_b	32	31_b	88_b
Carricante-north side-minimum tillage	14.0	14.4	1.1	1.1	5.9_b	5.2	16.9_{ab}	27.9_{ab}	3.5	4.4_a	182	388_a	23	49	33_{ab}	44_c
Carricante-east side-minimum tillage	18.8	12.6	1.2	1.2	8.9_a	5.7	19.8_a	27.3_{ab}	3.0	2.1_b	167	294_b	24	48	26_a	136_b
Carricante-north side-conventional tillage	16.8	15.4	1.1	1.1	10.0_a	5.2	15.6_b	32.1_a	2.7	4.2_a	162	361_a	24	39	37_{ab}	49_c
Carricante-east side-conventional tillage	14.8	11.9	1.1	1.3	5.8_b	6.1	20.8_a	25.1_b	3.1	2.1_b	166	335_a	27	59	43_a	210_a

2014. Higher contents of Ca, Mg and Fe were found in 2014 in all treatments, except for in NMA-NS-CT for Fe and Mg and in CRR-ES-MT and CRR-ES-CT for Mg. The amounts of Zn and Mn were extremely variable between years and aspects (Table 4).

Crop yield and berry characteristics

Due to its natural high vigour, NMA exhibited higher yields per vine than CRR during both years (Figure 3A). During the 2014 season, the yields per vine of the MT treatments of NMA were significantly lower than those of the CT treatments. The same significant trend was observed for CRR during 2014.

In 2013, vineyard yield decreased in Nerello mascalese MT compared with CT from 12.58 to 11.99 t/ha in the NS and from 12.54 to 11.56 t/ha in the ES. In the second season, the vineyard yield of Nerello mascalese decreased from 12.04 to 7.99 t/ha in the NS and from 9.70 to 6.45 t/ha in the ES. Meanwhile, in 2013, vineyard yield in Carricante MT compared with Carricante CT decreased from 6.83 to 6.33 t/ha in the NS and from 7.04 to 5.91 t/ha in the ES. In 2014, Carricante vineyard yield decreased from 5.9 to 4.12 t/ha in the NS and from 6.37 to 4.66 t/ha in the ES. Thus, in 2013, MT depressed the vineyard productivity in Nerello mascalese by about 4.6% (NS) and 7% (ES) and by about 33% in both aspects in 2014. Meanwhile, in Carricante, the vineyard yield reduction was about 7.3% (NS) and 13% (ES) in 2013 and about 30% (NS) and 27% (ES) in 2014.

For NMA, the yield per main shoot was affected by MT only on the NS (Figure 3C). In 2014, consistent with the trends observed for yield per vine, the yield per main shoot for

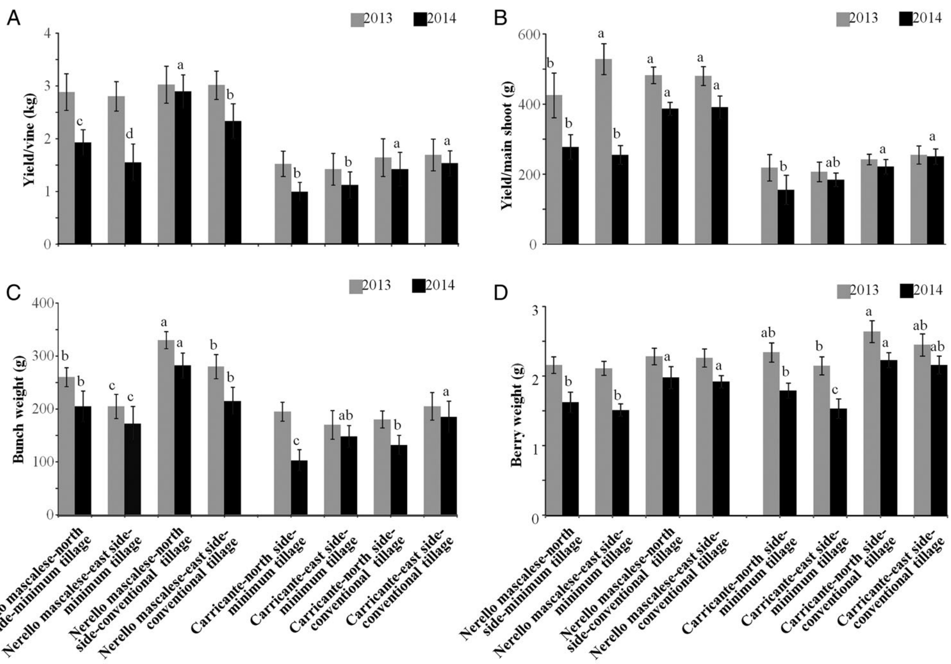

Figure 3. Yield/vine (**A**), yield/main shoot (**B**), bunch weight (**C**) and berry weight (**D**) in each of two cultivars under minimum and conventional tillage treatments. Means for each parameter indicated by different letters are significantly different ($P \leq 0.05$) (bars indicate one standard deviation) based on Tukey's HSD test within cultivars and years.

Table 5. Main qualitative parameters in each of two cultivars under minimum and conventional tillage treatments. Means for each parameter indicated by different letters are significantly different ($P \leq 0.05$) based on Tukey's HSD test within cultivars and year.

	Total soluble solids (°Brix)		pH		Titratable acidity (g/L)	
	2013	2014	2013	2014	2013	2014
Nerello mascalese-north side-minimum tillage	19.4	23.3_b	3.1	3.1	12.5_a	10.2_a
Nerello mascalese-east side-minimum tillage	18.6	22.6_b	3.2	3.1	9.7_c	8.6_c
Nerello mascalese-north side-conventional tillage	19.0	20.4_a	3.1	3.1	12.9_a	9.5_b
Nerello mascalese-east side-conventional tillage	18.3	20.2_a	3.1	3.2	10.8_b	8.8_c
Carricante-north side- minimum tillage	14.7_b	17.5_b	3.1	3.1	11.2_b	9.0_b
Carricante-east side- minimum tillage	15.6_{ab}	19.8_a	3.2	3.2	10.6^c	9.7^b
Carricante-north side-conventional tillage	14.8^b	16.4^b	3.2	3.1	12.4^a	10.7^a
Carricante-east side-conventional tillage	16.4^a	17.4^b	3.2	3.0	12.2^a	10.9^a

NMA was lower where MT was applied. The trend observed for CRR in 2014 was similar to that reported for NMA in 2013.

Bunch weight showed significant reductions in Nerello mascalese in the ES in both years for MT (Figure 3C). This result was confirmed in 2014 in which, in addition, a significant reduction in bunch weight was observed in all treatments. A reduction in bunch weights for each treatment occurred from 2013 to 2014.

Berry weights (Figure 3D) in Nerello mascalese showed no differences with MT in 2013 but a significant reduction in 2014 in both aspects. Carricante showed differences in both years. The highest reduction was observed in MT-ES.

The TSS showed significant differences only in 2014, with MT influencing TSS in both aspects. Between cultivars, Nerello mascalese had the higher TSS. Carricante had the highest TSS in the ES-CT in 2013 and in the ES-MT in 2014. The TSS was higher in both varieties in the second year. The TA in Nerello mascalese was significantly affected by treatment and aspect in 2013, in particular the ES-MT had the lowest values. In the NS no differences were observed among treatments. The TA in Carricante was reduced in the ES in both years and the treatment had a greater influence on acid degradation (Table 5).

Factorial and linear discriminant analysis

The main effects of year (Y), cultivar (C), aspect (A) and tillage (T) on vegetative, reproductive and qualitative parameters are given in Table 6. *Bourillon* and crown inflorescences, yield and its components and qualitative parameters were affected by the factor year ($P \leq 0.001$). The Y × C interaction affected the blind bud number, the yield/main shoot and the qualitative parameters. The Y × A interaction affected ($P \leq 0.001$) *bourillon* and crown inflorescences, berry weight and the qualitative parameters. The Y × T interaction influenced only qualitative parameters, while Y × C × A interaction affected only the berry weight. Both the Y × C × T and Y × A × T interaction influenced the observed fertility. The first interaction also influenced pH and TSS; the second, only TSS. Finally, Y × C × A × T affected only the TSS content. The main effects ($P \leq 0.001$) of the different variables are confirmed in the significant influence of cultivar on several fertility parameters, on yield components and on TSS and TA. The cultivar × aspect (C × A) interaction influenced the vegetative behaviour, TSS and TA. The cultivar × tillage

Table 6. Main effects and significant interactions of year, cultivar, aspect and tillage on vegetative, reproductive and qualitative parameters.

	Year (Y)	Cultivar (C)	Aspect (A)	Tillage (T)	Y × C	Y × A	C × A	Y × T	C × T	A × T	Y × C × A	Y × C × T	Y × A × T	C × A × T	Y × C × A × T
Main shoots (n)	ns	ns	*	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Bourillon and crown shoots (n)	*	***	ns	ns	**	ns	*	*	ns	ns	ns	ns	ns	ns	*
Blind buds of main nodes (n)	*	***	ns	ns	***	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Main bunches (n)	ns	ns	***	ns	ns	ns	ns	ns	ns	ns	ns	**	**	ns	ns
Bourillon and crown inflorescences (n)	***	ns	ns	***	ns	***	ns	**	ns	ns	ns	ns	ns	ns	ns
Latent bud shoots (n)	ns	ns	**	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns
Latent bud inflorescences (n)	ns	***	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Potential bud fertility	ns	***	***	**	ns	ns	ns	ns	ns	ns	ns	**	**	ns	ns
Observed bud fertility	ns	***	***	ns	ns	ns	**	ns	ns	ns	ns	***	***	ns	ns
Yield /vine (kg)	***	***	ns	***	**	**	ns	ns	ns	ns	ns	ns	ns	ns	ns
Yield/main shoots (g)	***	***	ns	***	***	ns	ns	**	ns	ns	**	ns	**	ns	ns
Bunch weight (g)	***	***	ns	***	ns	ns	***	ns	***	ns	ns	ns	ns	ns	ns
Berry weight (g)	***	ns	***	***	ns	***	ns	ns	**	**	***	ns	***	***	**
Total leaf area/vine (m^2)	ns	ns	***	***	ns	ns	***	ns	***	**	ns	ns	ns	**	ns
Total leaf area/main shoot (m^2)	ns	ns	ns	**	ns	ns	***	ns	ns	ns	ns	ns	ns	***	ns
Total leaf area/lateral shoot (m^2)	ns	ns	***	ns	ns	ns	***	ns	ns	***	ns	**	ns	ns	ns
Total soluble solids (°Brix)	***	***	***	***	***	***	***	***	***	ns	ns	ns	***	***	***
pH	ns	ns	**	ns	***	ns	ns	ns	ns	***	ns	***	ns	**	**
Titratable acidity (g/L)	***	***	***	***	***	***	***	***	***	***	ns	***	ns	**	ns

ns = not significantly different.
* = significantly different ($P \leq 0.05$).
** = significantly different ($P \leq 0.01$).
*** = significantly different ($P \leq 0.001$).

interaction (C × T) affected the bunch weight, the total leaf area/vine, TSS and TA. The aspect × tillage interaction (A × T) only affected total leaf area/lateral shoot and TA. The C × A × T interaction affected berry weight, total leaf area/main shoot and TSS. Aspect (A) affected *bourillon* and crown bunches, bud fertility, berry weight, vegetative behaviour, TSS and TA. Tillage (T) affected the *bourillon* and crown bunches, yield components and total leaf area/vine.

In this study, the information provided by the parameters analysed was used to predict the membership in each group of three categorical dependent variables consisting of two levels in each one: cultivar (NMA and CRR), aspect (NS and ES), tillage (CT and MT), through LDA.

As regards the dependent variable 'cultivar', 11 of the 16 original parameters showed capability in predicting the group membership (yield/main shoot, yield/vine, berry weight, latent bud shoots, potential bud fertility, *bourillon* and crown bunches, *bourillon* and crown shoots, total leaf area/lateral shoots, bunch weight, latent bud bunches, total leaf area/main shoot). As the dependent variable defines two groups, one statistically significant discriminant function was required to distinguish the groups. The magnitude of the eigenvalue, the high canonical correlation (0.845) and Wilks' Lambda associated significance with significant value (Sig. = 0.000), were indicative of the function's discriminating ability. Yield/main shoot, berry weight and yield/vine were the most discriminant variables showing the highest loading and thus the highest predictor capability in predicting the group membership. Moreover, based on the structure matrix, the predictor variables strongly associated with discriminant function 1 were yield/main shoot ($r = 0.594$), yield/vine ($r = 0.576$) and bunch weight ($r = 0.335$). A summary of the number and percentage of subjects classified correctly and incorrectly is given in Table 7. The results obtained by LDA testify that the parameters analysed allow a perfect discrimination of the two cultivars considered. In fact, 94% of the samples from the data set were correctly classified by using the classification function devised by the programme. Results were validated by the 'cross-validation' procedure (93.3% of cases correctly classified).

As for the dependent variable 'aspect', seven out of 16 variables were useful to predict category membership in one of two groups (latent bud shoot, berry weight, main bunches, total leaf area/lateral shoot, yield/main shoot, latent bud bunches, *bourillon* and crown

Table 7. Classification results[a,b] for the dependent variable 'cultivar'.

			Predicted group membership		
		Cultivar	Nerello mascalese	Carricante	Total
Original	Count	Nerello mascalese	215	25	240
		Carricante	4	236	240
	%	Nerello mascalese	89.6	10.4	100
		Carricante	1.7	98.3	100
Cross-validated[c]	Count	Nerello mascalese	214	26	240
		Carricante	6	234	240
	%	Nerello mascalese	89.2	10.8	100
		Carricante	2.5	97.5	100

[a]94.0% of original grouped cases correctly classified.
[b]93.3% of cross-validated grouped cases correctly classified.
[c]Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

Table 8. Classification results[a,b] for the dependent variable 'aspect'.

		Aspect	Predicted group membership: North site	East site	Total
Original	Count	North site	176	64	240
		East site	51	189	240
	%	North site	73.3	26.7	100
		East site	21.3	78.8	100
Cross-validated[c]	Count	North site	173	67	240
		East site	55	185	240
	%	North site	72.1	27.9	100
		East site	22.9	77.1	100

[a]76.0% of original grouped cases correctly classified.
[b]74.6% of cross-validated grouped cases correctly classified.
[c]Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

bunches). The magnitude of the eigenvalue, the high canonical correlation (0.560) and Wilks' Lambda associated significance with significant value (Sig. = 0.000), were indicative of the function's discriminating ability. For this variable, the parameters with the highest loading were latent bud shoots and berry weight. The predictor variables associated with discriminant function 1 were latent bud shoots ($r = 0.576$), berry weight ($r = 0.444$), latent bud bunches ($r = -0.420$), main bunches ($r = 0.371$) and total leaf area/lateral shoot ($r = -0.304$).

Table 8 reports that 76% of the samples from the data set were correctly classified by using the classification function devised by the programme. Results were validated by the 'cross-validation' procedure (74.6%). For the dependent variable 'tillage', four of the original variables were used to predict category membership in one of two groups: berry weight, bunch weight, yield/vine and observed fertility. The magnitude of the eigenvalue, the high canonical correlation (0.377) and Wilks' Lambda associated significance with significant value (Sig. = 0.000), were indicative of the function's discriminating ability. The standardised canonical discriminant function coefficients indicate that the only discriminating variable affecting the score was berry weight. Based on the structure matrix, the predictor variables strongly associated with discriminant function 1 were berry weight ($r = 0.734$), yield/vine ($r = 0.623$), bunch weight ($r = -0.610$) and yield/main shoot ($r = -0.422$). Only 62.9% of the samples were correctly classified by the discriminating function (Table 9) and 'cross-validation' procedure (61.9%).

Table 9. Classification results[a,b] for the dependent variable 'tillage'.

		Tillage	Predicted group membership: Conventional tillage	Minimum tillage	Total
Original	Count	Conventional tillage	158	82	240
		Minimum tillage	96	144	240
	%	Conventional tillage	65.8	34.2	100
		Minimum tillage	40	60	100
Cross-validated[c]	Count	Conventional tillage	156	84	240
		Minimum tillage	99	141	240
	%	Conventional tillage	65	35	100
		Minimum tillage	41.3	58.8	100

[a]62.9% of original grouped cases correctly classified.
[b]61.9% of cross-validated grouped cases correctly classified.
[c]Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

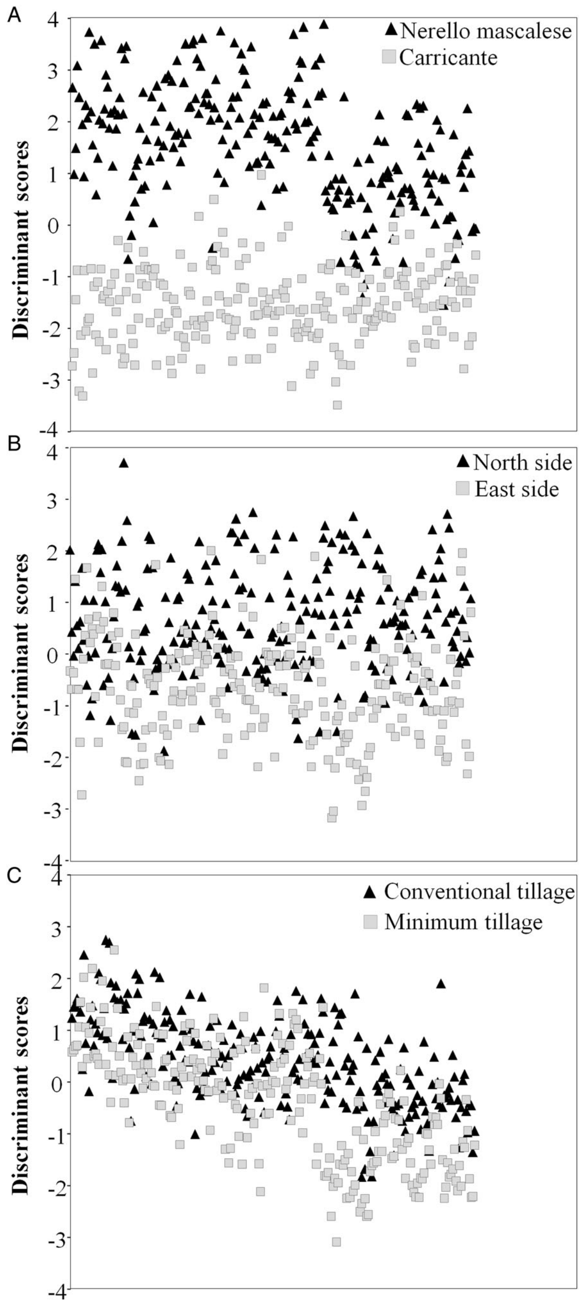

Figure 4. Plot of discriminant scores derived from the discriminant analysis for the dependent variables cultivar (**A**), aspect (**B**) and tillage (**C**).

In Figure 4 is also possible to view the graphical separation between the two cultivars (NMA and CRR), the two slopes (NS and ES) and the two vineyard soil management practices (CT and MT).

Discussion

This research explores the interactions between slopes of two different aspects, two soil management practices and two winegrape cultivars. The vine response was analysed in terms of 27 vegetative, reproductive, nutritive and qualitative variables, recorded at intervals during vegetative and reproductive growth and at harvest. The variables relate to a number of distinct growth processes including floral induction (bud fruitfulness), organogenesis (shoot and bunch initiation), morphogenesis (berry growth), biomass production and allocation (TLA, yield), and biochemical process (nutritional status).

The vineyards are located in an area that has a highly seasonal rainfall pattern and a dry period that corresponds with the phenological stages of late flowering, berry set, veraison and ripening. Here the soil and atmospheric water deficits—in combination with high air temperatures—exert complex effects on fruit yield and berry composition (Chaves et al. 2007). In the study area, these conditions are particularly limiting because of the soil's physical characteristics and also because of its low content of organic matter, especially on the east facing slopes.

The research considered both vegetative and reproductive bud development over a 2-year period as affected by environmental conditions and soil management. According to the results, the reduction in shoot growth in NMA-ES appears to be related to its higher thermal regimes. On the north facing slopes, the lower temperatures compensate for the increased water stress caused by MT; whereas on the eastern slopes, the combined effects of higher temperatures and the greater water stress resulting from MT caused a reduction in bud activity. The results obtained in the second year of the MT-ES treatment are probably due to the texture of the soil in this slope characterised by higher sand and lower silt percentage (Table 1). Under these conditions, it is possible that rapid drying and extreme temperatures may reduce root lifespans efficiency (Smart et al. 2006). On the whole, no correlation was evident between bunch reduction and blind bud number. In fact, the latter was very low in the second year.

To analyse grapevine performance, it is necessary to consider not only the weather and soil conditions of a particular season but also those at flowering in the previous year, and in particular the water and N stresses at that time (Matthews & Anderson 1989; Vasconcelos et al. 2009). In general, the number of bunch primordia per bud increase with increasing light intensity (Buttrose 1970). Although light and temperature are the major environmental determinants of yield and fruit quality—high temperatures (up to 30 °C) increase inflorescence production, whereas temperatures of 21 °C and below increase tendril production (Buttrose 1970; Wilkie et al. 2008)—Guilpard et al. (2014) report that decreases in leaf nitrogen and moderate water stress at flowering in the previous season can reduce bud fertility in the subsequent season by 36%–40%, although this response is cultivar dependent.

The TLA/vine reduction in NMA-ES-MT in both years, and also in CT in the second year, reduced the yield per vine. However, these treatments did not affect N and P leaf concentration, suggesting that the supply of these macronutrients in the soil was similar among treatments. The lowered concentration of leaf K is attributed to the drying of the upper soil layers during the summer (Pinamonti 1998).

In general, MT resulted in significantly lowered yields compared with CT. However, this effect was more evident in the second year (2014) in which the spring and summer temperatures were higher and the weather was drier than 2013. This observation seems to conflict with that of Monteiro & Lopes (2007), who reported that conservation tillage did not affect yield. On the other hand, Lopes et al. (2011) report that weeds (cover crops) increase competition for water and result in significant reductions in yield.

This reduced productivity in a vine that is sometimes excessively productive, such as Nerello mascalese, is interesting with regard to a standard that aligns with the requirements of a quality viticulture especially in a DOC (controlled designation of origin) wines producing area. In the less vigorous cultivar Carricante, this yield reduction is excessive. The 2014 performances should be understood in the light of the high seasonal variation in grapevine yield, which ranges from 15% to 35% (Chloupek et al. 2004; Keller & Mills 2004; Clingeleffer 2010). It is now well established that the main drivers of grapevine yield are bunch number per vine and berry number per bunch, which account for about 60% and 30% of seasonal yield variation, respectively, whereas berry weight variation accounts for only about 10% of seasonal yield variation (Dry 2000; Clingeleffer 2010); flowering and green berry stages seem to be important in the determination of berry size (Barbagallo et al. 2011). It is important to emphasise that the observed yield reductions are comparable to the levels of bunch thinning usually carried out in commercial vineyards. In particular, Keller et al. (2005) found that thinning (to achieve a target yield of 6.7 t/ha with Cabernet Sauvignon by reducing yields by 35%) and its timing had little or no influence on yields and its components in either the current or the subsequent season. Moreover, the effect of cluster thinning on wine composition is different between seasons due to the different crop load values between years (Intrigliolo & Castel 2011).

Nerello mascalese often produces very large and excessively compact bunches with consequent problems in ripening, colour uniformity and phytosanitary aspects; also, for this cultivar, a lengthening of the bunch, which is of particular interest in terms of improved quality, has been found (data not shown).

The absence of differences in TSS accumulation among the treatments for Nerello mascalese in 2013 is due to the high vigour of this cultivar that, despite quite severe soil water deficits during periods of high evapotranspirative demand, managed to maintain relatively high water potentials (Ferlito et al. 2014). The enhanced sugar accumulation in 2014 and in particular for the MT treatments is probably due to an extended vegetative–productive cycle in this year in which the weather was hotter. In line with Crippen & Morrison (1986), the higher TSS values observed in the ES were because sugar accumulation is greater in light-exposed fruit than in shaded fruit.

Differences among cultivars derive from their different vigour and source–sink equilibrium (Gaudillère et al. 2002; Castellarin et al. 2007; Chaves et al. 2010). Our TA observations in Nerello mascalese agree with those of Dos Santos et al. (2007) who showed a more drastic lowering of acid level under high levels of water stress. Nevertheless, our results show that MT does not have a negative effect on must quality.

The multivariate statistical approach through LDA allowed the discrimination with a cross-validated accuracy rate of 93.3% between the two winegrape cultivars Nerello mascalese and Carricante. This value testifies that the considered variables permit the classification of the two considered cultivars.

With regard to the aspects, the LDA allowed the discrimination with a cross-validated accuracy rate of 74.6% between the two different aspects—north and east facing slopes—suggesting that main shoot, latent bud shoot, berry weight, yield/main shoot, *bourillon* and crown bunches, latent bud bunches and total leaf area/lateral shoot were useful to classify the slope where the vines were cultivated.

In contrast, with regard to the two soil management practices—conventional tillage and minimum tillage—the values of the samples correctly classified by the discriminating function (62.9%) and of the cross-validated grouped cases correctly classified (61.9%) denote limitations on discriminating capability of the derivate function in the classification of this feature.

In conclusion, minimum tillage is an agronomic technique that may be useful for reducing excessive vegetative growth in grapevines, particularly in vigorous cultivars such as Nerello mascalese. For other cultivars, such as Carricante, which have more equilibrated vegetative–reproductive balances and lower productivity, minimum tillage may be more useful only for improving must quality, although the associated yield reduction may be considered a negative factor. In vineyards on Mount Etna, and in other viticulturally extreme areas, growers usually spend about 500 person hours per year per hectare in the vineyard. The greatest single effort (about 100 person hours) is required for weed control. This additional effort is not offset by economic gains associated with either fruit yield or fruit quality. Moreover, the high-vigour cultivars produce high yields but require a range of management practices to reduce yield such as bunch thinning, summer pruning of the canopy and defoliation in the vicinity of the bunches. All these interventions increase vineyard management costs.

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