Implications of Tall Fescue for Inter-Row Water Dynamics in a Vineyard

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ABSTRACT

Vineyards in the southeastern United States face challenges including poor internal soil drainage, high precipitation, and warm temperatures. This environment causes elevated humidity, creating ideal conditions for fungal diseases. Maintaining tall fescue (*Schedonorus arundinaceus* Shreb) and resident vegetation ground cover in vineyard inter-rows is a common cultural practice in the region, believed to benefit grape (*Vitis vinifera* L.) production by increasing competition for soil water and thereby favorably reducing vine vegetative growth. We hypothesized that, although inter-row fescue may reduce soil water availability, it may also increase humidity within the vineyard. Our objectives were to assess surface vapor flux from two inter-row treatments (bare soil and tall fescue) and to determine any corresponding effects on soil water content and humidity within the inter-row. Surface vapor flux, soil water content, and vapor pressure (30 cm height aboveground) were measured in inter-rows subjected to each treatment. Observed surface vapor flux for fescue inter-row exceeded that of bare soil by a daily average of 1.1 mm during the grape growing season. Despite fescue inter-row evapotranspiration (ET), soil water depletion was insufficient to produce stress in the vines. Fescue inter-row vapor pressure increased compared to bare soil inter-rows by an average of 2% ($P < 0.09$) during the growing season. Data suggest that fescue ET may increase inter-row humidity in warm, humid environments, while providing only modest influence on soil water availability. Additional work including increased plot size to accommodate fetch for microclimate measurements, and biological assessment of humidity implications for disease is warranted.

Management of ground surface conditions (e.g., cover crops, weeds, or residue) below a crop canopy can have important implications for the canopy microclimate (Stigter, 1984; Sauer and Norman, 1995). The hedgerow architecture of vineyards provides a unique environment where the grapevines interact with water and energy transport from the ground surface to the atmosphere (Weiss and Allen, 1976a,1976 b; Heilman et al., 1994), but widely-spaced rows also allow significant radiation to reach the ground surface, particularly in the inter-row. This radiation drives below-canopy ET from cover crops, weeds, and/or soil (Fandiño et al., 2012). Many studies have examined the influence of grapevine canopy architecture on canopy microclimate (Shaulis et al., 1966; Smart, 1985; Morsil et al., 1992; Heilman et al., 1996). However, few, if any, studies have examined how ground covers between the vine rows affect humidity below the canopy and in the inter-row.

Humidity is of particular concern in southeastern U.S. vineyards due to the presence of many fungal pathogens that thrive in warm, humid climates (Thomas et al., 1988; Willocquet and Clerjeau, 1998; Carroll and Wilcox, 2003). Inter-row humidity also increases the risk of fungal foliar diseases since some fungi such as *Botrytis cinerea* persist in dead tissue on the vineyard floor (Marois et al., 1992; Urbez-Torres, 2010). Fungal diseases can reduce carbon assimilation (Nail and Howell, 2004), which adversely affects crop growth and yield. Management practices have been adapted to reduce fungal diseases by means of training, pruning, and the application of fungicides (English et al., 1990; Lipps, 2010). The effects of ground surface cover management may also be important to limiting the incidence and severity of disease.

In addition to disease, excessive vegetative growth is also a common problem in vineyards of the southeastern United States. Excessive vegetative growth can lead to undesirable canopy architecture, reduce grape quality and contribute to poor wine quality (Smart et al., 1985; Dry and Loveys, 1998). Common regional practice is to establish tall fescue (hereafter referred to as fescue) or other grasses within the vineyard inter-row (Wolf, 2008). It is presumed that fescue may benefit grape production by competing for soil water, thereby decreasing

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Abbreviations: AE, available energy; DOY, day of year; ET, evapotranspiration; FC, field capacity; LE, latent heat flux; MBR, micro Bowen ratio; PWP, permanent wilting point.

vegetative growth and size (Celette et al., 2008; Hatch et al., 2011; Guerra and Steenwerth, 2012). However, increased water use and ET from grass may increase surface water vapor flux and contribute to elevated humidity.

The goal of this study was to examine the influence of a fescue cover crop on below-canopy water dynamics. We used novel micro Bowen ratio (MBR) energy balance measurement systems to determine ET in the inter-row (Holland et al., 2013) for fescue and bare surface conditions. While a bare surface may not provide a common vineyard management scenario in the southeastern United States due to practical considerations (inter-row equipment traffic, erosion), it provides a baseline to assess the effects of inter-row ET (fescue) vs. only evaporation (bare soil). We hypothesized that a fescue inter-row is more effective at transferring water from soil when compared to no ground cover (bare soil). This may limit water availability for grapevines, but increases humidity below the canopy, in the inter-row. Therefore, our objectives were to determine surface vapor flux from two treatments in the vineyard inter-row (bare soil and fescue) and to asses any corresponding effects on soil water content and inter-row humidity.

MATERIALS AND METHODS
Field Site and Ground Cover Treatments

A commercial vineyard, located near Dobson, NC (36°21′ N, 80°46′ W, 366 m elevation), served as the study site (Fig. 1). Located on gently rolling hills with a slope of 2 to 15%, the predominant soil type is the Fairview series (fine, kaolinitic, mesic Typic Kanhapludult) with a sandy clay loam surface texture (Soil Survey Staff, 2011). Vines at the test site were Chardonnay trained to bilateral cordons with shoots held upright in a single curtain with trellis catch wires. The vines were planted in 2001 in rows oriented north–south at a 2.7 m (row) by 1.8 m (vine) spacing. Width of the grassed inter-row, which contained weedy tall fescue, was 1.5 to 1.8 m and the width of the bare soil herbicide strip below the trellis was 0.9 to 1.2 m. Grapevine canopy width varied between 0.3 to 0.8 m, canopy height from the cordon varied between 0.3 to 1.4 m, and cordon height from the ground varied between 0.5 to 0.6 m during the grape growing season (March–October).

Two treatments: bare soil and fescue were maintained in the inter-row (Fig. 2). Six plots, three per treatment, were established in March 2011. Each plot measured 2.7 m (across inter-row) by 7.6 m (down inter-row, parallel to vine row). Plot width was constrained by vine row spacing. Plot length was chosen to provide significant fetch for inter-row surface energy balance measurements (discussed below). Plots were restricted in size to be co-located with consistent topography, soils, and vine characteristics. A non-selective, contact herbicide; glufosinate [(RS)-2-amino-4-(hydroxy(methyl)phosphonoyl) butanoic acid], was applied to eliminate vegetation in bare soil plots. With the exception of ground cover, plots received standard vineyard management (Wolf, 2008) per the host vineyard for the duration of the study (Fig. 1). Mowing in fescue plots matched that in the surrounding vineyard with a typical grass height of 7 cm.

Inter-row Energy Balance and Vapor Flux

Surface energy balance of the inter-row was estimated with MBR systems and supplementary data (described below) from April 2011 to April 2012. The MBR systems are a down-scaled version of traditional Bowen ratio systems, designed to measure sensible and latent heat fluxes of components within the footprint of a larger system (Ashktorab et al., 1989; Zeggaf et al., 2008). In the present study, MBR systems included gas intakes positioned at 1 and 6 cm height above grass or bare soil for measurement of air temperature (via thermistors, Beta-THERM USA, LLC, Shrewsbury, MA) and vapor pressure gradients (via LI-840A CO_2/H_2O gas analyzers, LI-COR, Lincoln, NE) to compute the Bowen ratio (Bowen, 1926). Fetch/height ratio was »15:1 across the inter-row and > 60:1 down the inter-row. A data logger (Model CR10X, Campbell Scientific, Logan, UT) recorded all measurements every 10 s, output averages every 5 min, and controlled each MBR system. Additional details on the MBR system construction, measurements, and testing are provided in Holland et al. (2013). Two MBR systems were placed in each treatment (grass and bare soil).

Supplemental data used to compute the surface energy balance included net radiation, soil water content, soil temperature, soil heat flux, and atmospheric pressure. Net radiation was measured using net radiometers (Model NR Lite2, Kipp and Zonen, Bohemia, NY) placed 23.5 cm above the surface in the middle of two plots, one per treatment. Soil heat flux plates (REBS, Seattle, WA) were installed at 6-cm depth, one per

Fig. 1. Vineyard study site located near Dobson, NC (36°21′ N, 80°46′ W). Inter-rows shown in the picture are standard management, commensurate with the fescue treatment in experimental plots (not shown). Photo taken July 2011.
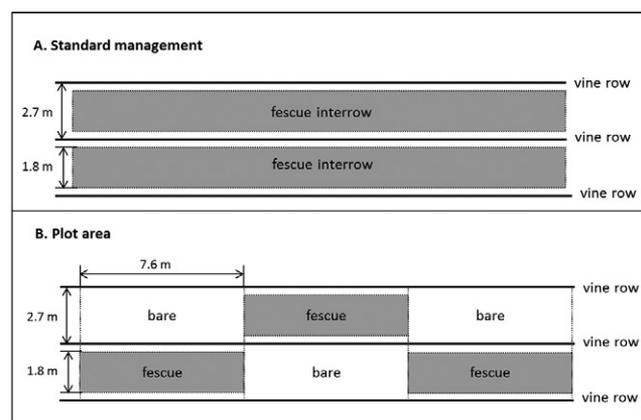

Fig. 2. (A) Standard management and (B) plot area layout at the vineyard site. The plot area was surrounded by standard management with fescue inter-rows on all sides.

treatment. A soil water content reflectometer (Model CS616, Campbell Scientific) was installed horizontally at 3-cm depth in each treatment. Soil temperature was measured by two thermocouples (Type E) installed at 1.5 and 4.5 cm depths for each treatment. Data from thermocouples, soil water content sensors, and heat flux plates were used to derive heat flux at the soil surface via a combination approach (Sauer and Horton, 2005). A barometer (Model PTB101b, Vaisala, Woburn, MA) was installed in one MBR system to measure atmospheric pressure. A tipping bucket rain gauge (Texas Electronics, Dallas, TX) measured precipitation. Sensors were connected to data loggers associated with MBR systems, thus data were recorded and output at the same frequency. One surface energy balance was computed for each treatment, using available MBR, net radiation, and soil heat flux data. The energy balance was computed for each 30-min interval and then recomputed using a moving average ($n = 3$) to provide hourly values. Estimates of the surface vapor flux (i.e., ET) were derived from the latent heat flux (LE) in the surface energy balance using the latent heat of vaporization for water.

Soil Water Content and Grapevine Stress

In addition to measurements described above, soil water content was also measured with soil water content reflectometers (30 min average) placed vertically at a depth of 10 to 40 cm in the middle of each plot and averaged for each treatment. This depth increment was selected to provide an integrated estimate of the upper profile, and so that the sensor body (8.5 cm length) could be buried below the surface to permit mowing. Gravimetric samples collected during the observation period were used to calibrate the relationship between sensor estimates and soil water content. Differences between sensors and samples were <0.05 cm³ cm^{-3} and were corrected by adjusting sensor values to match sampled values via a simple, plot-specific offset correction.

Additional soil samples were collected to measure soil water retention for interpretation of soil water content data. Soil cores (7.6 cm diam. by 7.6 cm height) centered at depths of 3.8, 11.4, and 42 cm were excavated using a Uhland core sampler from three positions across the vine row within the plot area. Low pressure water retention measurements (10, 33, 50 kPa) were performed on intact cores using a desorption method similar to that of Dane and Hopmans (2002). The volumetric water content at 33.3 kPa pressure was used as an estimate for field capacity (FC; Addiscott and Whitmore, 1991). Soil was oven-dried at 105°C and weighed to determine bulk density. Samples were then ground and passed through a 2-mm sieve. High pressure water retention measurements (100, 500, 1500 kPa) were determined using a desorption procedure similar to that of Dane and Hopmans (2002). Volumetric water content at 1500 kPa was used as an estimate of permanent wilting point (PWP; Soil Science Society of America, 1997).

Water stress was assessed with a pressure chamber (Model 600, PMS Instrument Company, Albany, OR) on grapevines that were surrounded by grassed inter-rows (i.e., conventional management). Following a method similar to Choné et al. (2001), stem water potential was determined using measurements from at least 15 mature leaves on 7 d throughout the 2011 grape growing season. Leaves were placed in Mylar (PMS Instrument Company, Albany, OR) bags 1 h before measurements to prevent transpiration so leaf water potential would equal stem water potential (Begg and Turner, 1970). Grapevine stress was assumed to occur if measured potential was < –1 MPa, based on the threshold discussed by Peacock et al. (1998) and Girona et al. (2006), and assuming correlation amongst stem and leaf water potentials (Williams and Araujo, 2002).

Vapor Pressure

Vapor pressure was calculated from temperature and relative humidity, measured with a relative humidity/temperature probe (Model HMP60, Vaisala,) placed inside a gill radiation shield (RM Young, Traverse City, MI) 30 cm above the inter-row surface, mid inter-row, with two replications per treatment. A single relative humidity/temperature probe was also placed 1.25 m above the inter-row surface, over a grassed inter-row. Only one measurement was collected as it was assumed that mixing would preclude distinguishing vapor pressure between small plot treatments at this measurement height due to the surrounding vineyard conditions (i.e., inadequate fetch). A relative humidity/temperature probe (Model HMP45, Vaisala) was also placed 3 m above the surface to measure above canopy climatic conditions. All vapor pressure measurements were recorded and averaged with the same frequency (30 min averages) used for other sensors. Treatment comparisons were performed using daytime means (0700–1900 h), including only days with complete data records. A heteroscedastic *t* test was performed considering data both by month, and over the entire growing season.

RESULTS AND DISCUSSION
Energy Balance and Evapotranspiration

From April 2011 to April 2012, average ambient temperature for the research site was 15°C, which was warmer than the historical average temperature of 13°C (State Climate Office of North Carolina, 1971–2000). Total precipitation for the study period was 1570 mm, compared to the historical average annual precipitation of 1190 mm. During the grape growing season (March–October), total precipitation and average temperature were 1110 mm and 19°C, respectively, compared to historical averages of 830 mm and 17°C, respectively.

Energy fluxes estimated from MBR systems for representative clear sky days throughout the study period are shown in Fig. 3. The fraction of available energy (AE = net radiation – soil heat flux) partitioned to LE for the fescue inter-row (Fig. 3A) ranged from 31 to 99%; partitioning varied with weather conditions and time of year. In the fescue treatment, LE averaged 92% of AE during the grape growing season, which indicates fescue was transpiring near its maximum rate. During the off season (November–February), LE accounted for only 63% of AE because of reduced grass growth and decreased atmospheric demand due to lower temperatures. For bare soil inter-row, LE ranged from 15 to 92% of AE (Fig. 3B). Partitioning again differed within the year, with LE averaging 73% of AE during the grape growing season but only 44% during the off season due to less atmospheric evaporative demand. There was a notable observed difference in AE between treatments, due primarily to increased soil heat flux in the bare soil plots (data not shown). Comparison of fescue LE to that of bare soil provided an indication of the consequence of active transpiration in the
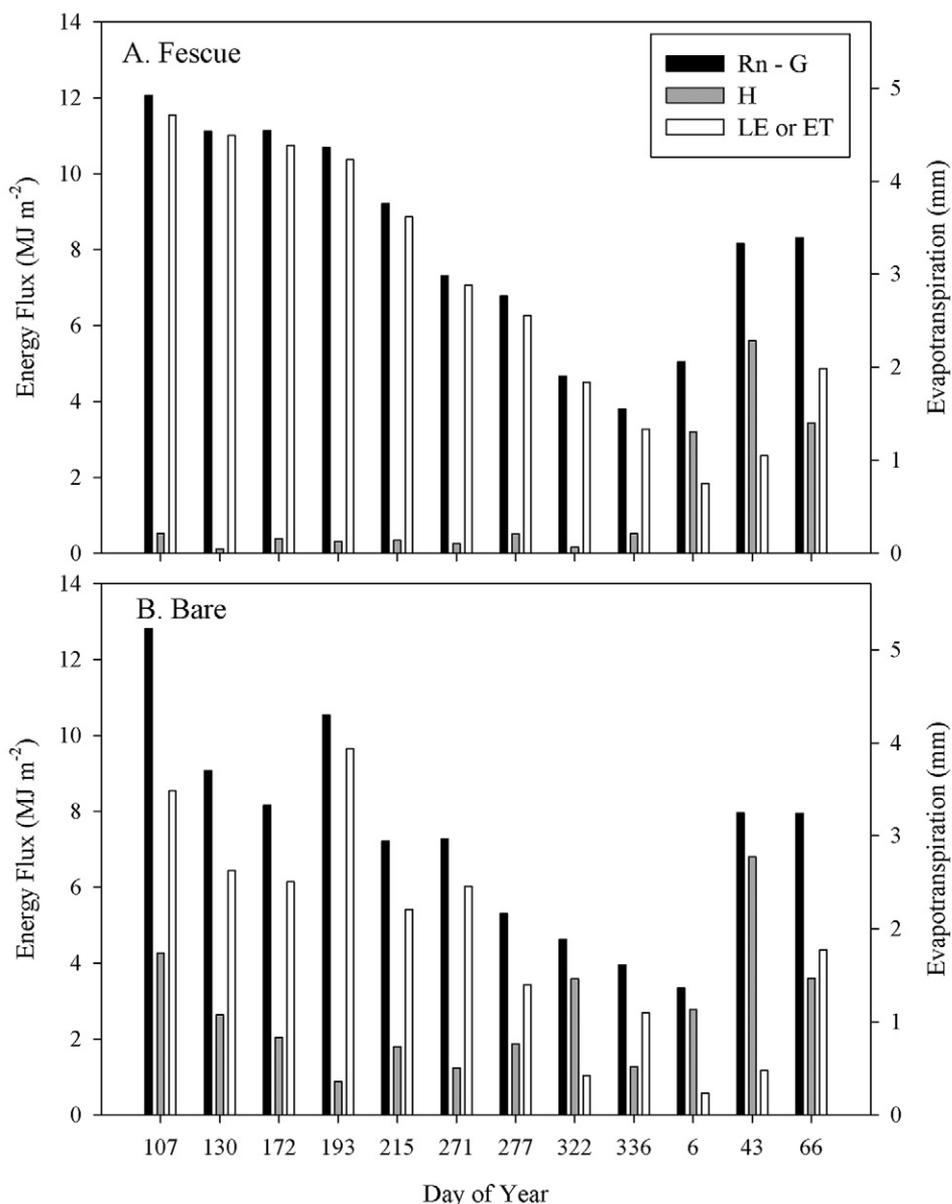
Fig. 3. Measured energy fluxes and evapotranspiration for (A) fescue and (B) bare soil inter-rows on selected dates, 2011–2012. Values between 0800 and 1800 h eastern standard time. R_n, net radiation; G, soil heat flux; H, sensible heat flux; LE, latent heat flux. Evapotranspiration (ET) is shown on the axis at the right.

inter-row (i.e. ET for fescue vs. evaporation only for bare soil). The observed differences in daily ET between fescue and bare soil ranged from 0.2 to 1.9 mm, with an average daily difference of 0.9 mm (Fig. 3). The average observed differences in daily ET between fescue and bare soil during the grape growing season and during the off season were 1.1 and 0.5 mm, respectively.

Evapotranspiration for May 2011 for both treatments is shown in Fig. 4. Cumulative ET observed for the bare soil inter-row was 78 mm, which is 32% less than cumulative ET observed for fescue inter-row, 115 mm. The ET in May for both treatments was much less than precipitation, 161 mm. Likewise, taking median observed ET for fescue (4.2 mm d^{-1}) during the growing season (Fig. 3), and comparing that to precipitation (1110 mm), fescue ET represented about 69% of the precipitation inputs. Alternately, bare soil ET (2.8 mm d^{-1}) represented only about 46% of precipitation inputs. We note that this was a relatively wet year compared to historical average precipitation. If similar values for inter-row ET are assumed typical (i.e., non-water-limited), but are compared to historical average growing season precipitation (830 mm), fescue and bare soil ET represent about 93 and 62% of precipitation, respectively. These values must also be put into the context of the vineyard system, when considering overall water use. The fescue inter-row represents only about 67% of the vineyard surface area (Fig. 2), thus while water use in this zone may be substantial, particularly relative to typical rainfall amounts, there remains a substantial fraction of precipitation water input available for the grapes. However, because fescue ET constitutes a larger proportion of precipitation in the inter-row zone compared to bare soil, a consequence of having fescue in the inter-row is increased water vapor entering the below-canopy atmosphere.
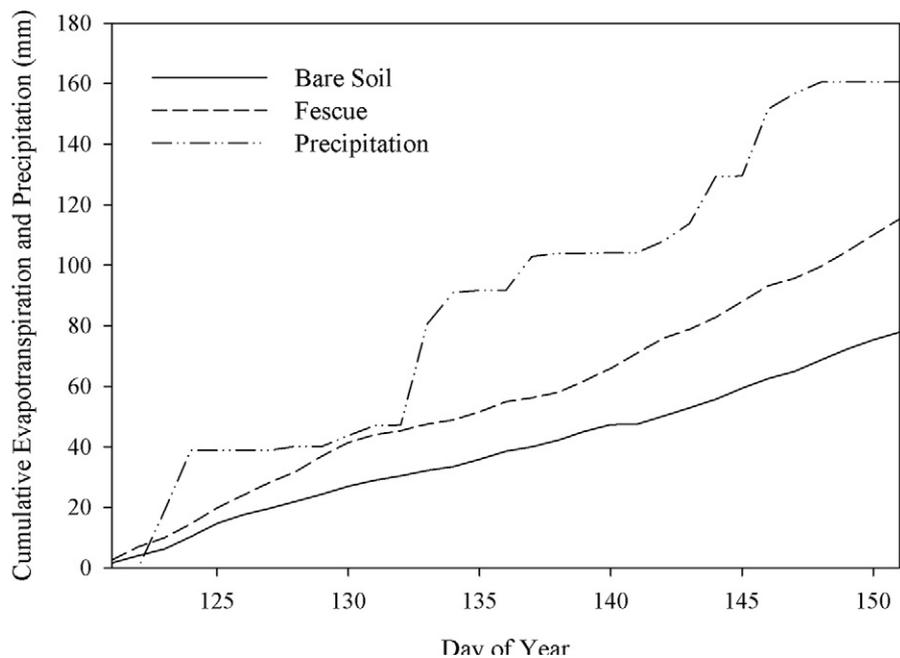
Fig. 4. Cumulative evapotranspiration for fescue and bare soil inter-rows, determined from micro Bowen ratio measurements, and precipitation, May 2011.
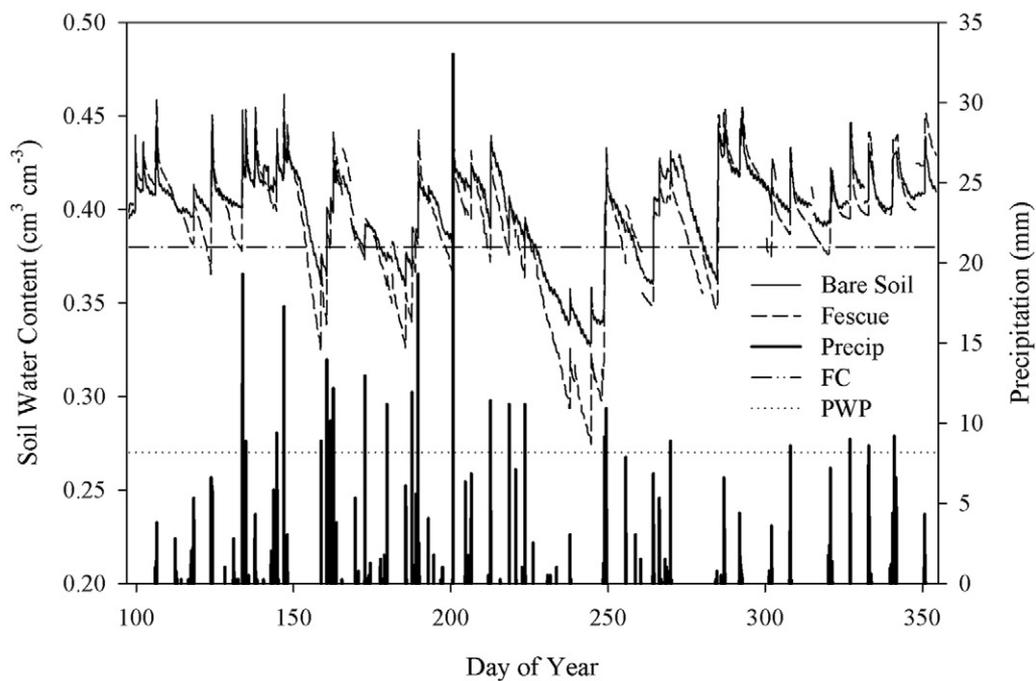

Fig. 5. Soil volumetric water content by treatment, field capacity (FC), permanent wilting point (PWP), and precipitation at the field site. Soil water content was averaged for three soil water content sensors per treatment at 10- to 40-cm depth.

Soil Water Content and Availability

Differences in ET between treatments should influence soil water content. Inter-row soil water content was occasionally lower for fescue when compared to bare soil (Fig. 5). Fescue also depleted soil water at a greater rate than bare soil following rainfall events as observed, for example, between day of year (DOY) 148 and 158 or 230 and 250. This is consistent with greater ET observed in fescue inter-rows. The same trend was observed throughout the grape growing season during dry-down periods (i.e., between rainfall events).

Soil water depletion from fescue, though possibly greater, should be put into context of effects on plant available water. Water retention measurements indicated that soil water contents are 0.38 cm^3 cm^{-3} and 0.27 cm^3 cm^{-3} at FC and PWP, respectively, which are typical for a sandy clay loam (USDA-NRCS, 1998). It has been reported that inter-row fescue competition for water and nutrients can reduce vegetative growth (Celette et al., 2008; Guerra and Steenwerth, 2012). In this study, soil water content within the fescue root zone approached PWP for a 2-wk interval in late August (DOY

Day of year	Stem water potential
	–MPa
140	0.48 (0.05)
166	0.45 (0.06)
181	0.43 (0.07)
199	0.29 (0.05)
209	0.39 (0.10)
227	0.39 (0.05)
244	0.53 (0.07)

238–250, Fig. 5). For the remainder of the growing season, soil water content for both treatments mostly remained within the range of readily available water (potential > –100 kPa corresponding to water content >0.32 cm^3 cm^{-3}), with slightly lower soil water content in fescue inter-row. As is evident from calculations using typical inter-row ET values (previous section), water use in the inter-row did not result in substantial soil water depletion, particularly because of large water contents at the start of the growing season. Consequently, only a modest advantage was realized from fescue ET in terms of limiting water availability during the measurement period.

Grapevine water stress measurements, collected on multiple days including when soil water content was at its lowest (DOY 245), indicated that soil water content was not low enough to cause water stress under typical management conditions in the surrounding vineyard (Table 1). Additional profile water content measurements, collected to a depth of 1 m in the surrounding vineyard as part of a separate study, likewise indicated that water was readily available in the profile (data not shown). As described above, it should be noted that the 2011 season was relatively wet compared to long-term averages, which may have lessened the effect of fescue ET on water availability to the grapes.

Vapor Pressure

Vapor pressure for fescue and bare soil inter-row conditions (30 cm height) is shown for four representative days during the early, mid, and late grape growing season in Fig. 6. (These days correspond to a subset of those shown in Fig. 3). Vapor pressure was generally greater in mid-season (DOY 172 and 193) compared to the early (DOY 107) and late (DOY 271) season for both treatments. When comparing treatments, differences in vapor pressure were subtle for the early season, but were larger at mid-season, approaching 8% at midday. A *t* test for daytime values during April to August, including 96 d with complete data records, indicated that treatment means were different ($P < 0.1$) with mean values of 20.2 and 20.6 hPa for bare soil and fescue, respectively. Considered by month within this interval, the greatest observed difference in daytime vapor pressure occurred in July (0.9 hPa, $P < 0.05$, 19 d included) and the smallest daytime differences occurred in May (0.4 hPa,
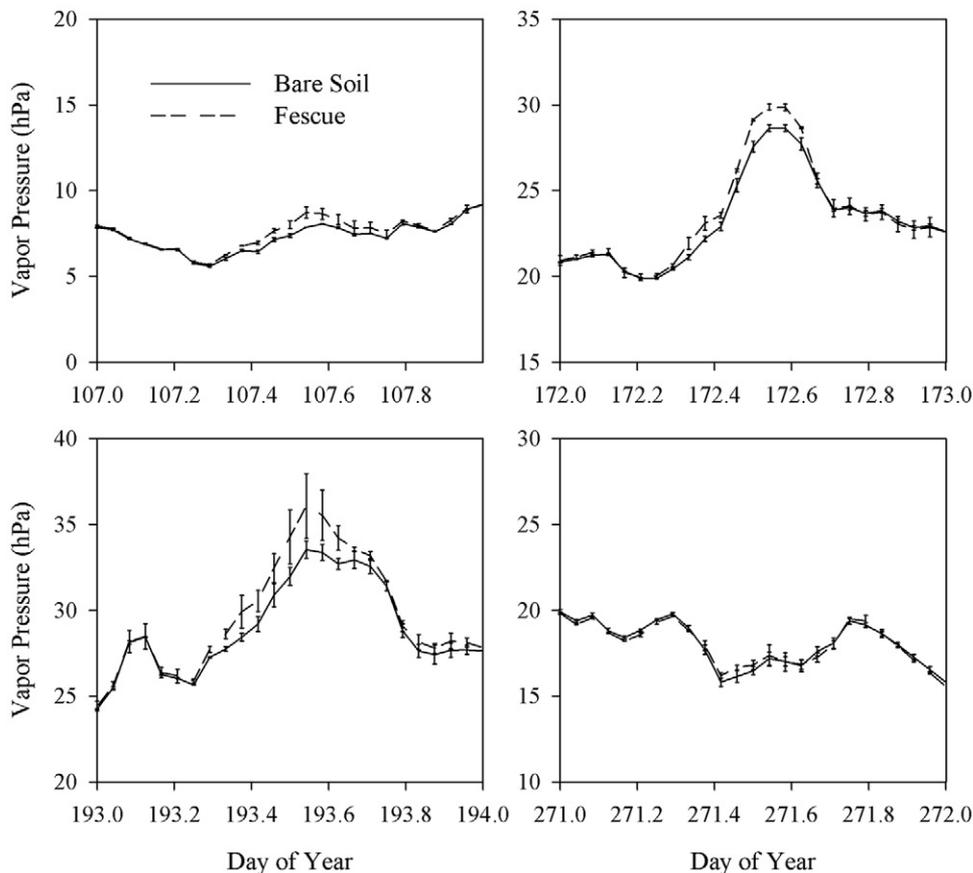

Fig. 6. Vapor pressure (30 cm height) measured above fescue and bare soil inter-rows for representative days during the grape growing season. Values are the means of two replicates for each treatment. Error bars indicate one standard deviation on either side of the mean. Note that each axis represents a different range, each encompassing 20 hPa for vapor pressure and 1 d for day of year.

$P < 0.05$, 28 d included), fescue having the greater mean vapor pressure in all cases.

Measured differences in vapor pressure, although significant, were relatively small. It is likely that with limited plot size in the present experiments, however, measurements at 30 cm height were subject to influences from the surrounding vineyard. In this case, it is likely that vapor pressure measurements from the bare soil plots were overestimates because of greater vapor contribution from fescue in the surrounding vineyard. Even at the height of the MBR vapor flux measurements (6 cm) there may be some influence (i.e., bare soil vapor flux overestimate) from the surrounding vineyard (Holland et al., 2013). Unfortunately, vineyard row dimensions and other practical considerations limit the extent of plot size within the vineyard.

As an example to put measured vapor pressure differences into context, we consider a disease threshold based on relative humidity. Optimal conditions for bunch rot occur at 94% relative humidity (Thomas et al., 1988). Relative humidity measured at 30 cm exceeded this threshold 1100 h during the grape growing season for fescue, compared to 709 h for bare soil (i.e., 43% more often for fescue). While measurements at 30 cm height in the inter-row are not identical to conditions within the canopy, elevated vapor pressure above grassed inter-rows suggests a potential concern that should be carefully considered.

Increased disease incidence and severity have been managed by application of fungicides, canopy management, removal of dead tissue, and site selection (English et al., 1990; Wolf, 2008; Giese, 2010). However, to further improve grapevine production in humid climates such as the southeastern United States, further adaptation may be needed. Management practices such as decreasing the width of grass, using grass that transpires less than fescue, or using mulch in the inter-row that limits the amount of water entering the canopy microclimate may help to reduce incidence and/or severity of common fungal diseases. These goals must, however, be considered in the context of goals aimed at enhancing water use competition between vines and the inter-row ground cover.

Conclusion and Future Research Need

We hypothesized that inter-row fescue is more effective at transferring water from soil when compared to bare soil evaporation, possibly limiting water availability for grapes, but also increasing inter-row vapor pressure. The MBR inter-row ET measurements suggest that vapor flux was greater for fescue inter-row compared to bare soil by as much as 50% during the grape growing season. However, based on soil water content and stem water potential, fescue water use did not translate into water availability low enough to create significant vine stress during a relatively wet season. Measured differences in vapor pressure between fescue and bare soil indicated that fescue inter-row ET resulted in increased humidity. Differences were small, but significant; based on fetch limitations, we expect that these differences may be underestimated.

Future work, examining biological significance of humidity for disease occurrence, and considering larger areas with consistent below canopy management for increased fetch, would help to test inferences drawn from this study. Despite some limitations, this preliminary study suggests the importance of ground cover management for vineyard humidity

considerations. Production of high quality wine grapes in warm, humid regions with poor internal soil drainage may require unique management systems, differing from those in more traditional grape growing regions and current local practices. Devising new management practices in the inter-row may be an appropriate local adaptation to reduce potential for grapevine fungal diseases and improve grape production in North Carolina and other warm, humid regions. There remains need to consider consequences of alternative management (e.g., bare soil or mulch) or to identify appropriate plant species for use as inter-row cover crops.

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