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Spatial variability of grape yield and its association with soil water depletion within a vineyard of arid northwest China

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ABSTRACT

Spatially variable soil properties, combined with the complex interrelationship between crop yield with environmental factors often lead to spatio-temporal variability of crop yield across the field. The objectives of this study were to investigate spatial variability of grape yield and estimate the potential yield at various soil water depletion levels within a vineyard of arid northwest China. Grape yield and soil water contents at different times were measured at 135 georeferenced points in 2012, and 147 points in 2013 within a 7.6-ha vineyard. Geostatistical approach was used to describe the spatial variation in grape yield, while boundary line analysis was used to estimate the potential yield at various soil water depletion levels. Some selected soil properties between the low and high yield gap groups, defined as the difference between the actual yield and the estimated potential yield, were compared. The spatial structure of yield distribution in the field was similar between the two years. The upper boundary line between grape yield with soil water depletion was best fitted by a quadratic function for both years. When soil water depletion was relatively high, soil sand content and saturated hydraulic conductivity of 0–20 cm soil were found to be significantly different between the high and low yield gap groups, while none of soil properties in the top 40 cm soil were found to be important in determining the yield gap when soil water supply was limited. Boundary line analysis method could be a valuable tool in developing better management practices to improve overall yield according to available soil water conditions in the field.

1. Introduction

Soil water content is an important variable of farmland hydrological cycle, and also an important factor affecting crop growth and yield formation. Due to inherent spatial variability of soil properties, soil water content is highly variable in space at a field scale. Better understanding of soil water depletion variations at field scale and its relationship with crop yield would help develop better management practices for improving crop yield.

Soil water status within a vineyard has direct effects on vegetative growth, canopy microclimate, fruit growth, yield and quality, and the effect becomes particularly apparent at critical phonological stages of grapevine growth, such as new shoot and berry development stage (Serrano et al., 2012). Previous studies have assessed the interactive effect of water status on grapevine growth and yield under different irrigation treatments. Van Leeuwen et al. (2009) investigated vine shoot, berry weight and grape composition under different vine water status in a commercial vineyard in France, and found that water deficit stress anticipated shoot growth slackening and limited berry weight. Matthews and Anderson (1989) found that 30% to 40% yield increases can be obtained by increasing irrigation above the standard practice in a commercial hillside vineyard in Napa Valley near Saint Helena, California. The results of Medrano et al. (2003) indicated that moderate irrigation with about 30% potential evapotranspiration, compared with non-irrigation, could improve grape yield in two Spanish cultivars (Tempranillo and Manto Negro) of field-grown grapevine.

Soil properties, through altering soil water and nutrient status, play an important role in determining grape yield and quality. Previous studies have explored the relationship between soil properties (soil texture, organic matter, and etc.) and grape yield at field scale in attempts to develop better management practices for higher yield. Van Leeuwen et al. (2004) found that the 32% of total yield variation could be explained by the soil type, and yield on sandy soil was 32 and 62% higher than that on clayey and gravelly soil, respectively, from 1996 to 2000 in three Saint-Emilion vine-

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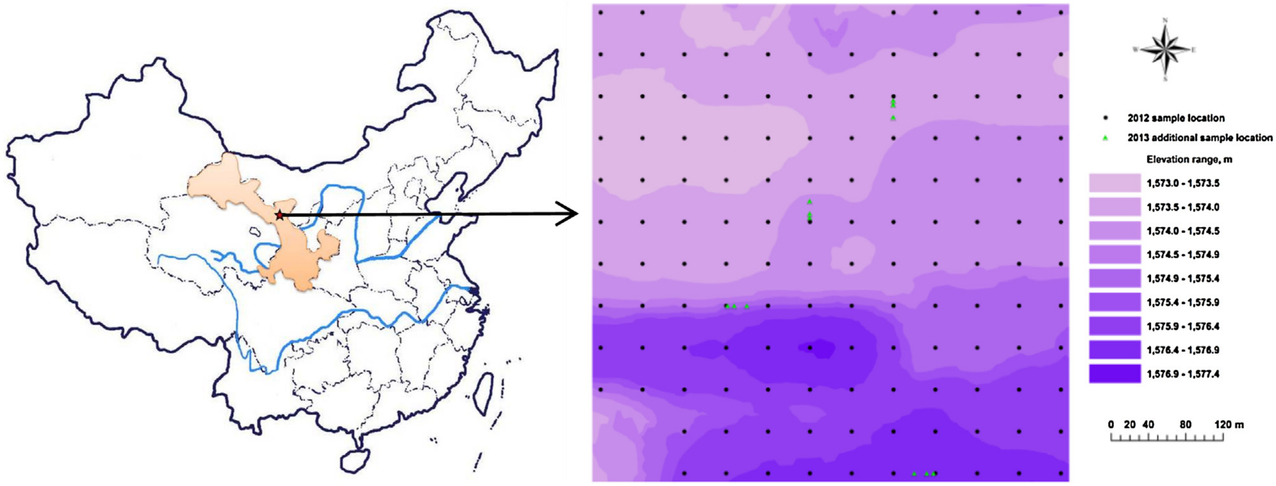

Fig. 1. The location of the experimental site in the country, along with layout of the sampling location and elevation map of the field.

yards in France. Tardaguila et al. (2011) found that yield per plant was strongly affected by a soil index that was a linear combination of soil thickness, organic matter content, clay and cation exchange capacity in a five hectare commercial vineyard in Spain. Other soil properties have been shown to have some effect on the yield of the vines, such as soil electrical resistivity, bulk density, penetration resistance, water holding capacity (Bellvert et al., 2012; Mugnai et al., 2012; Quezada et al., 2014; Reynolds et al., 2007; Rossi et al., 2013). Given that grape yield is determined by the combined effects of many factors, it is difficult, by using traditional correlation and regression methods, to pinpoint the relationship of yield with one single factor without the confounding effects from other factors.

The principle of boundary line approach was first introduced by Webb (1972), which attempts to separate yield responses to a single causal factor from responses to other independent variables that might affect the yield (Shatar and McBratney, 2004). The approach is based on the assumption that for a sufficiently large dataset, there are the maximum potential values for the response variable at different levels of a predictor variable of interest, and any points lower than the maximum values are limited by other predictor variables (Shatar and McBratney, 2004). To do the analysis, the response data are often subdivided into groups corresponding to the quantitative categories of the potential limiting factor of interest and a subset of the highest values was isolated from the response data within each group (Huang et al., 2008). Then the subset dataset was fitted as the boundary line using some statistical techniques. The boundary line represents the relationship between the response variable and the predictor variable without interferences of other independent variables. Points on the boundary line was considered as the maximum attainable values at the corresponding range of the predictor variable, which has important implications when applied into crop yield responding to a number of factors at as the yield potential at the site (Shatar and McBratney, 2004). The approach has been successfully used to assess response of crop growth or yield to a single soil property with the response could be limited by other factors. Shatar and Mcbratney (2004) identified yield responses to changes in soil properties (soil organic carbon content, K, pH and Fe) using boundary line analysis method in northern New South Wales. Huang et al. (2008) obtained the relationship between wheat yield data and wetness index by fitting the boundary line using the spline regression method in southwest Michigan in 1998, 2001, and 2004. Kitchen et al. (2003) reported that on the boundary line, yield decreased with increasing soil electrical conductivity at a Kansas field.

Boundary lines based on various independent variables could be used to estimate the maximum yield potential, and the difference between the estimated yield potential and the actual yield, i.e. yield gap, could be used to evaluate the yield status of the field (Fermont et al., 2009; Grassini et al., 2009; Hochman et al., 2009; Wairegi et al., 2010). The larger yield gap implies there is more room for improvement, and yield potential and yield gap maps could help identify low yield zones and yield-limiting factors of those areas.

In this study, a 2-year experiment was carried out in a typical mature vineyard in arid northwest China. The main objectives of this study were to investigate spatial variability of grape yield, and estimate the maximum attainable yield at different crop water consumption levels at the vineyard using the boundary line analysis method. Soil properties between the estimated high and low yield gap groups were also compared to explore the possible contributing factors to the lower yield over the field.

2. Materials and methods

2.1. Field description and data collection

The study was carried out at a 7.6 ha vineyard of the Shiyanghe Experimental Station for Improving Water Use Efficiency in Agriculture, Ministry of Agriculture (MOA), located in Huangtai, Wuwei, Gansu Province, China (N 37°52′20″, E 102°50′50″, and altitude 1581 m). Fig. 1 shows the location of an experimental site in the country. This region is limited in water resources with an average groundwater table of deeper than 25 m, mean annual precipitation of 164 mm and mean pan evaporation of about 2000 mm. The experiments were conducted during the period of April to October in 2012 and 2013.

The study area was about 275 m long and 275 m wide. The 2-year data were collected mostly from regular spaced points as shown in Fig. 1, with a 25-m apart in both east-west and north-south directions for each grid. Number of samples was set as large as possible within the labor and budget constraints, and sampling locations were spread evenly over the entire experimental vineyard to be representative of the field. In 2013, 12 additional sampling points with the distance to the respective grid points less than 25 m were added to have better estimates of varirogram model parameters (Fig. 1). As a result, there was a total of 135 and 147 points in 2012 and 2013, respectively. Elevation of each sampling point was obtained through a global positioning system (GPS, Trimble Recon, USA) and the digital elevation model (DEM) for the sampling area