Possible slope failure mechanisms caused by apple growing in Val di Non (Northern Italy)

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INTRODUCTION

This paper investigates the changes in slope stability conditions due to intensive apple farming. The study was applied to the Val di Non region, extending North-West from Trento (Northern Italy). Here apple orchards were planted, requiring supportive irrigation in the summer season. The Val di Non is crossed by the Trento-Malè railway, cutting extensively through the cultivated hilly areas, that slope gently towards the River Noce. Some cases of slope failures were reported in the past, with soil masses invading the railway track, fortunately causing no effects. However, in 2010 a shallow slide occurred in a nearby valley (Val Venosta); the soil mass slid rapidly downhill hitting a passing train and killing nine passengers. This study is aimed at understanding what failure mechanisms may occur when grasslands are transformed into intensive apple plantations.

METHODS

Stability conditions were evaluated and verified on the basis of the pore water pressure distribution within the slope. The evolution of pore water pressures was studied by using an average time history of rain, wind, relative humidity and temperature that lasts for one year. Calculations took into account precipitation, with associated runoff losses, water evaporation from the soil and induced by plant transpiration, infiltration due to irrigation. Evaporation and infiltration were related to the climate time history at ground level and to the suction-saturation response in the presence of grass (lawn) and apple trees (orchards). Lawn was used as a reference condition; the effects of the orchards were analyzed considering different water consumptions, increasing with the age of the trees, from one (new orchard) to five years (full production orchard). Plant transpiration was calculated using the Penman-Monteith equation. Two methods of irrigation were taken into account: sprinkler irrigation, feeding large volumes of water to account for surface runoff, and drip irrigation.
It was kept into account that when using the drip irrigation the roots, and accordingly the evapotranspiration, developed mainly close to the trees.
Using the computer code SEEP/W by Geostudio 2007, the distribution of the pore water pressure was determined for a soil column extending to a depth of 6 m below surface. At this depth a relatively impervious bedrock was encountered.
The natural groundwater table was set at depths of 5 m or 6 m, and infiltration was applied uniformly, when from sprinkler irrigation, concentrated along the tree rows, when from drip irrigation. All slope stability analyses were performed neglecting the reinforcing effects of the tree roots. Further, the ground surface was assumed to be planar, neglecting any localized increase of the natural slope angle. Such variations are typically caused by artificial cuts that are necessary to level out sloping grounds and to layout service roads.
Slope stability calculations were performed considering an infinite slope under seepage conditions; flow lines were assumed parallel to the ground surface and to the slip surface. The pore water pressures distribution was copied from the previous analyses to be applied on a plane perpendicular to the ground surface, the slip surface, the flow lines.
The shear strength of the soil was calculated using two approaches. For saturated conditions and positive pore water pressures, the classical Mohr-Coulomb failure criterion with zero effective cohesion and a constant value of the effective angle of shearing resistance phi‘=30° was used. For unsaturated conditions the contribution of suction in terms of shear strength increase was included using the relationship proposed by Bishop (1959); the chi parameter was determined using the Khalili and Khabbaz (1998) equation, to link the degree of saturation to the soil suction and the suction at the air entry value. Two possible failure mechanisms

were analyzed: deep seated slides, where the slip surface remained below the water table and the maximum inclination of the slope was 30°, shallow slides, where the slip surface remained above the water table and the slope dip at 32°-45° above horizontal.

RESULTS

It was found that the lowest values of suction in the upper 2 meters of soil occur from the end of the Summer season to the first half of the Fall season, and for new orchards. The maximum rise in the water table was registered in mid Summer for full-production orchards, while it continues rising for new orchards. In fact, new orchards, having small dimensions and little leaf area, produces small evapotranspiration despite an irrigation flux that is usually the same of that for the full-production orchards. Then, the most critical condition for shallow slide failures occurs with new apple orchards at the end of the Fall season (Figure 1). Deep seated slides are more likely to occur at the end of the year with new apple orchards, or in mid Summer for full-production orchards, when the effect of water volume losing due to evapotranspiration has not yet caused the water table lowering. The effects of a concentrated water loss, due to rupture of a main line or secondary pipe were also investigated. Assuming an outflow of 1 l/s for one hour, the analyses showed that after an interval of some minutes the soil around the pipe loses its strength completely and behaves like a fluid.

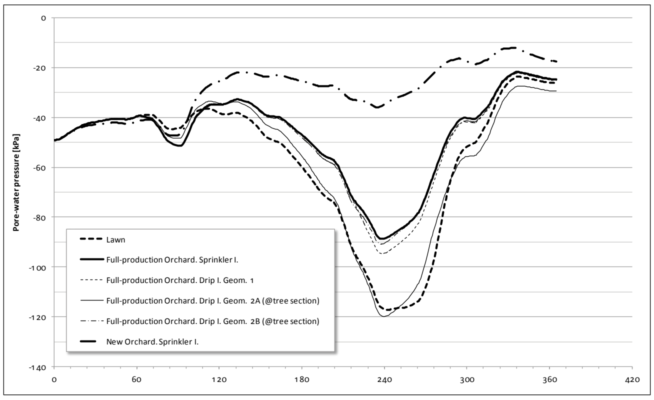

Figure 1. Pore water pressure at 1 m depth for lawn, new orchard or full-production orchard, with sprinkler or drip irrigation. Geom. 1: drip irrigation and evapotranspiration uniformly applied on the ground surface; Geom. 2A: drip irrigation and 70% tree evapotranspiration applied next to the trees, lawn evapotranspiration elsewhere; Geom. 2B: drip irrigation and 70% tree evapotranspiration applied next to the trees, 30% tree evapotranspiration elsewhere.

CONCLUSION

Results gave evidence that the combination of vegetation and irrigation system may produce significant reductions of the factor of safety with respect to sliding. The analyses showed that growing apple trees instead of grass may lower the stability of sloping areas, especially when trees are in their youngest ages and the water volume released by evapotranspiration is significantly smaller than the volume stored by irrigation. The reduction of the factor of safety is due to ground water level rising and soil suction reduction. In addition, soil water content dramatically increases after rupturing of a pipeline. Finally, the effect of the type of irrigation, sprinkler or drip, resulted less significant than the age of the orchard.

KEYWORDS

Apple orchard, slope failure, evapotranspiration, pore-water pressure, irrigation

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