UNIVERSIDAD DE MÁLAGA

ACTUAL GEOMORPHOLOGICAL PROCESSES IN SLOPING VINEYARDS. A COMPARISON BETWEEN RUWER-MOSEL VALLEY (TRIER, GERMANY) AND MONTES DE MÁLAGA (MÁLAGA, SPAIN)

TESIS DOCTORAL

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ÍNDICE

ABSTRACT

Sloping vineyards are ones of the most degraded agricultural activities by human impacts and rainfall events. Specifically, in the vineyards of the Almáchar in the Montes de Málaga (Axarquía, Spain) and Waldrach in the Ruwer-Mosel valley (Trier, Germany), where the popular Moscatel and Riesling grape varieties are produced, land degradation has been reported by several authors, but not real quantifications of sediment and water losses.

Both of them are characterized by silty soils mainly on Palaeozoic schists and slates with different degrees of metamorphism, steep slopes (>30%), high rock fragment cover (>30%) and occasional generation of rills and gullies due to the use of heavy machinery, extreme rainfall events and trampling effect. Anyhow, farmers take measures against soil erosion, such as building rills to canalize the surface flow (called “agri-spillways”) and small walls of stones (“albarradas”) or the use of grass cover to reduce soil and water losses. However, they are not enough to avoid completely the problem.

Therefore, the two main aims of this PhD Thesis will be: i) to measure the spatiotemporal variations of the soil erosion processes in two specific sloping vineyards´ plots with conventional land use management under two different climate environments (the Mediterranean and Continental climate); and, ii) to find the main key factors (natural and anthropogenic) that could influence soil erosion processes after natural rainfall events and soil tillage practices.

Specifically, in the Montes de Málaga, the final results using the runoff experiments showed: i) a great capacity by rills to canalize large amounts of water and sediments; and, ii) higher water flow speeds (between 0.16 m s^{-1} and 0.28 m s^{-1}) and sediment concentration rates (up to 1538.6 g l^{-1}) than typically found in other Mediterranean areas and land uses (such as badlands, rangelands or extensive crops of olives and almonds). The speed of water flow and the sediment concentration were much higher in the shorter and steeper rill. We concluded that agri-spillways, given correct planning and maintenance, can be a potential solution as an inexpensive method to protect the soil in sloping Mediterranean vineyards. Meanwhile using a combined methodology of soil analysis, a small portable rainfall simulator, a Guelph permeameter and Gerlach troughs on one experimental, we detected: i) a high variability of soil erosion and permeability processes; b) an elevated concentration of silt particles and stoniness able to alter the hydrological processes; c) a high average of permeability and saturated hydraulic conductivity with elevated standard deviations; d) on the upper and the footslope positions the highest runoff coefficient and soil loss were registered. In conclusion, it was observed that the activation of the soil erosion processes was due to the distribution of the surface soil components (high roughness, several cracks and high stoniness and silt content), the steep slopes and the impact of the soil traditional tillage practices. These Mediterranean hillslope

vineyards registered a mixed Hortonian-Hewlettian model, which combines surface and sub-surface flow conditioned by the micro-topographical changes and its saturation degree.

In the Ruwer-Mosel Valley, the results showed high infiltration rates (near 100 %) and clear subsurface flow processes which were detected by rainfall simulations and permeability measurements performed at different times of the year in old, young and abandoned vineyards. The highest variations of the monitored rills (lateral and frontal movements) were noted before and during the vintage, when footsteps occurred concentrated during a short period of time (between September and October). The SUM showed that the old vineyard's erosion rates ranged from 3.3 to 3.8 Mg ha^{-1} yr^{-1}, which was similar to the Gerlach trough measurements, and we demonstrated that the soil erosion rates depended on rainfall characteristics and human disturbances due to tillage, harvest trampling, and compaction by heavy machinery. Data from the SUM in the young vineyard showed 62.5 Mg ha^{-1} yr^{-1} of soil loss, which is a consequence of severe soil disturbance during the planting of the new vineyard. Finally, to prove the reliability data, RUSLE also showed higher soil loss in the young vineyards (19.46 ha^{-1} yr^{-1}) than in the old ones (11.28 ha^{-1} yr^{-1}). As in the Montes de Málaga, a Guelph permeameter was used to quantify the permeability and saturated hydraulic conductivity at different slope positions and seasons (before and after harvest). Results showed that soil texture and OM were highly modified, and as consequence soil hydrology, after abandonment. We observed a significantly higher permeability (26.8 mm h^{-1}) and Kfs (8.4 mm h^{-1}) in the active vineyard soil than in the abandoned one (permeability of 14.2 mm h^{-1} and a Kfs of 5.4 mm h^{-1}). The soils of the active vineyard showed a greater variability among seasons and slope positions. In the abandoned vineyard, the results showed a high correlation of permeability and Kfs with gravel content and OM and a negative correlation with the clay fraction. Natural revegetation improved the soil water retention capacity. In the active vineyard, we could not find any relevant factor to explain the soil hydrological properties, and this may be attributed to the disturbance induced by human activities, such as machinery, trampling, and the use of herbicides.

Finally, we demonstrated that sloping vineyards in the Montes de Málaga (Spain) and the Ruwer-Mosel Valley (Germany) on bare soils can experience high soil erosion rates, but clear patterns were not demonstrated due to the human impact. The spatiotemporal distribution of hydrological and geomorphological processes is uneven and highly conditioned by several factors such as soil properties, tillage, rainfall intensity, the age of plantation and the hillslope morphology.

RESUMEN

Los espacios ocupados por viñedos muestran particularidades en el manejo agrícola y unas condiciones medioambientales identificables de suelo, clima, paisaje y topografía, con influencias directas en la composición de la uva. Actualmente, numerosos autores evidencian en sus estudios la importancia de los procesos de degradación que han sucedido en estas áreas durante décadas, inducidas por la implementación en los usos tradicionales del suelo de maquinaria pesada (tractores, cosechadoras, etc.), de nuevos productos químicos (fertilizantes, herbicidas, etc.) y por la intensificación de la producción. Todas estas actividades están afectando notablemente a uno de los componentes más importantes de los viñedos: el suelo. Por este motivo, en la ciencia del suelo y, en especial, en la geografía están aumentando los estudios que tienen como objeto detectar los flujos hídricos que activan las tasas de erosión y la transferencia de productos contaminantes a lo largo de las laderas.

En esta línea, numerosos autores han confirmado la importancia de los componentes superficiales y sub-superficiales del suelo, como elemento condicionante de todas estas dinámicas hidrológicas. Sin embargo, son menores las referencias en estos estudios al desplazamiento de los sedimentos y del agua en forma de escorrentía a lo largo de la ladera y sus factores condicionantes en laderas con fuertes pendientes (>30%). Sin duda, en áreas como los Montes de Málaga o el valle del Mosela, cuestiones sobre la dirección del flujo superficial, la variabilidad temporal de su intensidad o los factores que la condicionan deberían ser atendidas con premura si se pretende estudiar en profundidad para dicho medio su completa dinámica eco-geomorfológica. En numerosos estudios realizados en viñedos de España, Italia o Francia, ha quedado demostrado que en pocas hectáreas pueden confluir numerosos procesos que, detectados y cuantificados correctamente, pueden permitir proveer de información útil al agricultor y las empresas para diseñar estrategias sostenibles para su cultivo.

Los diferentes recorridos que el agua realiza, a través del sistema de poros y fracturas de los agregados del suelo, puede conllevar procesos tan variados como el transporte de solutos, iluviación y eluviación o lavado de materiales finos, infiltración-percolación, escorrentía superficial o sub-superficial, pseudogleyzación y/o gleyzación y variación de la cantidad de agua disponible para las plantas tras la lluvia. La dinámica erosiva en los viñedos se manifiesta a través de diferentes formas y procesos, entre los que rills y/o gullies (regueros y cárcavas) se muestran más activos. Estas incisiones surgen principalmente a partir de las pisadas y rodadas de los tractores utilizados para las diferentes labores agrícolas o por el efecto del golpeo de la gota de agua sobre los agregados.

Los estudios realizados sobre los viñedos en España también demuestran que los procesos geomorfológicos relacionados con la erosión y la degradación del medio son abundantes. Dentro de las áreas más estudiadas se encuentran las tradicionales áreas vitivinícolas de La Rioja y Navarra, los piedemontes pirenaicos, Galicia, Castilla y León o la Mancha y Madrid. No obstante, para los Montes de Málaga con una de las áreas vitivinícolas más importantes y antiguas del mundo, son escasos los trabajos que reparan en destacar los problemas erosivos acusados de sus laderas y su significado para la economía local tras las pérdidas generadas por la filoxera a principios del siglo XX.

Por su parte, en Alemania, con una elevada tradición en el cultivo de la vid y aterrazamientos en laderas de los valles del Mosela, Ahr o Rin, también se manifiestan problemas importantes de erosión. Algunos autores recogen cifras de pérdida de suelo en los viñedos oscilan entre las 0.2 t ha^{-1} año y 151 t ha^{-1}. A lo largo del Valle del Ruwer-Mosela, la Universidad de Trier elaboró numerosos estudios con parcelas experimentales desde los años 70 para explicar la relación existente entre las precipitaciones (en forma de agua y nieve) y el comportamiento de la pérdida de suelo a través de mecanismos de escorrentía superficial. Los suelos de estos territorios se caracterizan por unas elevadas tasas de infiltración, movilización de gravas y elementos finos (sobre todo limos), junto con unas proporciones altas de materia orgánica y una explotación intensiva con el uso de maquinaria.

Por lo tanto, los principales objetivos de este trabajo serán: i) medir la variación espacio-temporal de los procesos hidrológicos y geomorfológicos en dos parcelas experimentales localizadas en Almáchar en los Montes de Málaga (Axarquía, España) y Waldrach en el valle del Ruwer-Mosela (Trier, Alemania), ambos bajo dos contextos climáticos y manejos del suelo distintos; y ii) desentrañar qué factores (naturales y antropogénicos) son los desencadenantes de los procesos erosivos tras las lluvias y las prácticas agrícolas.

En primer lugar, en los Montes de Málaga, se ha optado para este estudio en utilizar una ladera dentro del curso del río Almáchar, tributario del río Vélez. La cuenca del río Almáchar se inscribe con una forma dendrítica o subdendrítica dentro de dos líneas de divisorias de aguas: por el norte un promontorio alomado que, desde la confluencia con el río Benamargosa, a 48 m.s.n.m. de altitud, asciende hasta el monte Santopitar, a 1020 m.s.n.m., pasando por el monte Carrión (756 m.s.n.m.), y que separa a esta cuenca de las de otros tributarios del río Benamargosa. Por el sur, otro promontorio alomado, alineado de este a oeste, semejante al anterior, con alturas similares y convergiendo también en el monte Santopitar (pasando por el cerro de Córdoba, 730 m.s.n.m.), separa la cuenca del río Almáchar de cauces que vierten directamente al mar. Geológicamente, su situación se enmarca dentro de la unidad fisiográfica de los Montes de Málaga, con la predominancia de materiales antiguos de edad precámbrica y paleozoica fuertemente metamorfizados, como las filitas, esquistos o cuarcitas, pertenecientes al Complejo Maláguide. A lo largo del curso fluvial, materiales del Holoceno como conglomerados, arenas y arcillas son transportados junto con los anteriores erosionados cada vez que se origina un episodio lluvioso. De forma particular, el área de estudio se sitúa a unos 300 m s.n.m. en 36°47’ 50’’N y 4°13’41’’ O. La ladera está orientada hacia el S-SSW y las parras están cultivadas, simplemente, respetando las curvas de nivel. La variedad de uva es *Moscatel de Alejandría,* utilizada para la elaboración de pasas y vino dulce. La vendimia se repite cada curso entre julio y agosto, llevada a cabo por personas del propio municipio (Almáchar), utilizando animales de carga para transportar la cosecha (mulos, burros, etc.). El laboreo se realiza a mano con herramientas como el pico, la azada o la pala y se mantiene el suelo desnudo con el uso de herbicidas.

Por su parte, el área de estudio que se localiza al oeste de Alemania en el valle del Mosela, dentro de una cuenca de drenaje de pequeña extensión (Ruwer), se incluye en la población de Waldrach (Trier-Saarburg, región de Renania-Palatinado). El valle del Ruwer-Mosela se encuentra al norte de la ciudad de Trier, al sur de la región del Sarre, al oeste del zócalo de Olewig y al sur del relieve del Feller Bach. Se conforma como una plataforma en forma de cuesta que desciende de norte a sur desde 500 a 200 m s.n.m. Desde un punto de vista geológico, destacan una base de grauwacas, pizarras y cuarcitas de la era Primaria, sobre las que se disponen sedimentos finos del Pleistoceno (Schröder, 1991). Concretamente, la zona de estudio se sitúa entre los 49°44'28 "N y 6°45'12" E y una altitud de 220-250 m. Las laderas están orientadas principalmente hacia el SW y S por lo que aprovechan la mayor intensidad de insolación para favorecer la fenología de los cultivos. Se han seleccionado dos parcelas con parras cultivadas recientemente (4 años) y otras más viejas de alrededor de 35 años. Las plantas están alineadas en hileras contrarias de la dirección de las curvas de nivel. La variedad de uva blanca plantada recibe el nombre de *Riesling* y es utilizada para realizar vinos de mesa en la bodega de la ciudad de Traben-Trabach. La vendimia se repite cada año entre los meses de octubre y noviembre con trabajadores normalmente inmigrantes y tractores de pequeño tamaño.

Desde un punto de vista geomorfológico, ambas laderas están sometidas a un complejo proceso de desmantelación por la actuación conjunta de la meteorización, erosión, transporte y sedimentación. Además, la intensidad de estos procesos muestra una gran variedad tanto espacial como temporal, ligado a las características geomorfológicas y edafológicas del terreno.

Para este trabajo, se han seleccionado dos áreas de estudio con condiciones ambientales muy diferentes, pero con una vocación agrícola común: el viñedo. De esta forma, hipótesis y posibles métodos de análisis son a la vez comunes y diferentes. En la tabla 1, se exponen los problemas comunes detectados para ambas áreas de estudio y, a continuación, en la tabla 2, se muestran los específicos de cada escenario.

Tabla 1. Hipótesis comunes para los viñedos de los Montes de Málaga y el valle del Ruwer-Mosela

Ámbito	Problemática común
Edafológico	Horizontes removidos y alterados Elevadas pérdidas de suelo Aparición de regueros y cárcavas efímeras Pérdida y lavado de nutrientes Elevada pedregosidad Tendencia al estrés hídrico en verano
Geomorfológico y geológico	Elevadas pendientes (>30%) Movilización de sedimentos a lo largo de la ladera Procesos de escorrentía superficial Erosión de origen antrópico Litología muy metamorfizada, esquistosa y fácilmente erosionable
Climático	Áreas vulnerables por el calentamiento global o los posibles efectos del cambio climático Tendencia a la concentración de los eventos lluviosos Elevación de las temperaturas
Agronómico Agrícola y enológico	Cultivo de la vid (*Vitis vitifera Sp.)* Eliminación de la cobertera vegetal natural Comportamiento fenológico de las parras común (pérdida de hojas, floración…) Utilización de sistemas de cultivo tradicionales Remoción constante del suelo Aplicación de herbicidas, pesticidas y demás productos fitosanitarios Elevado grado de pisoteo del suelo durante las tareas de laboreo, mantenimiento de la vid y vendimia

Tabla 2. Datos de partida según área de estudio

Ámbitos	Valle del Ruwer	Montes de Málaga
Edafológico	Suelos poco profundos (<1 metros)	Suelos de poco espesor (<0,4m)
	Elevada proporción de materia orgánica (>7%)	Baja proporción de materia orgánica (<5%)
	Procesos relacionados con suelos pardos (Braunerde)	Procesos de hidrólisis y fersialitización muy activos
	Elevadas tasas de infiltración	Elevadas tasas de escorrentía superficial concentrada en regueros y cárcavas efímeros
Geomorfológico y geológico	Mecanismos hidrológicos de ladera de tipo hewletiano (Hewlett, 1967): escorrentía subsuperficial	Mecanismos hidrológicos de ladera de tipo hortoniano (Horton, 1945): escorrentía superficial
	Pérdidas de sedimentos constantes y en pequeñas proporciones	Pérdidas de sedimentos concentradas en cortos intervalos de tiempo y en elevadas cantidades
	Perfil de la ladera regular (convexo)	Perfil de la ladera irregular
Climático	Lluvias repartidas a lo largo de todo el año, con picos en verano e invierno	Lluvias concentradas en pocos eventos lluviosos (nº<20) entre septiembre y abril. A partir de aquí, sequía estival acusada
	Posibilidad de heladas elevadas hasta la primavera	Elevadas temperaturas estivales que pueden llegar a quemar las hojas y los frutos de la vid
	Cultivos emplazados en exposiciones S, SW y SE	Cultivos emplazados en todas las exposiciones
Agrícola y enológico	Variedad de uva: Riesling	Variedad de uva: Moscatel
	Producto final obtenido: vino	Producto final obtenido: vino y pasas
	Utilización de maquinaria (tractores, motocultoras…)	Utilización de animales (burro, mula…)
	Vendimia: a mediados de octubre-noviembre	Vendimia: julio-agosto
	Métodos utilizados frente a la erosión: construcción de muros, taludes, aterrazamientos, canales de desagüe, remoción y movilización del suelo	Métodos utilizados frente a la erosión: sangrías, albarradas, labranza con aperos (pico, pala, azada…)

Para alcanzar los objetivos planteados en esta tesis, se pretende combinar a lo largo del estudio una serie de técnicas de análisis comunes para ambos lugares y, en otras ocasiones, se diseñarán métodos específicos adaptados a las condiciones de cada medio y los resultados previos obtenidos.

En primer lugar, se han realizado analíticas de suelos para comparar las principales propiedades físico-químicas de los suelos que afectan directamente a los procesos geomorfológicos como la textura, la pedregosidad, la materia orgánica, la capacidad de retención de agua, el pH o los carbonatos. También se han elaborado perfiles de suelos a diferentes posiciones de la ladera y descritos con la mayor exactitud sus horizontes para detectar posibles factores pedogenéticos.

Para este trabajo también se han monitoreado las variaciones climáticas y el manejo del suelo durante todo el estudio. Se ha contado con un pluviómetro totalizador en ambas parcelas y se han extrapolado datos de intensidad de lluvia y temperaturas. Para el monitoreo de las labores del manejo del suelo, se ha visitado el campo semanalmente y entrevistado a los agricultores.

A partir de campañas de campo en colaboración con estudiantes y compañeros del departamento, se han elaborado una serie de experimentos en momentos puntuales del año, con objeto de monitorear elementos concretos del paisaje (cárcavas o marcas botánicas) o simular eventos naturales a partir de técnicas artificiales. En el primer grupo (*monitoring*), se han realizado seguimientos de la evolución de regueros y cárcavas, y se han medido anualmente las marcas botánicas en los tocones de las parras como indicador pasivo del movimiento del suelo (SUM o *stock unearthing method*). Por último, se han utilizado para el caso malagueño seis cajas de sedimentos o *gerlach troughs* (de diseño propio) situadas a tres alturas de la ladera (parte alta, media y baja) para obtener dos repeticiones en cada lugar de la información obtenida. Para el caso alemán, cuatro cajas se han situado en la zona baja de la ladera, en viñedos recién plantados y otros con más de 35 años de edad. El procedimiento a seguir se ha adaptado para ambos contextos climáticos, siendo el vaciado tras cada evento (Montes de Málaga) o grupo de eventos (Ruwer-Mosela). A partir de los resultados se han obtenido datos de escorrentía (litros; l), pérdida de suelo/sedimentos (gramos; g) y concentración de sedimentos por cantidad de escorrentía (g/l).

Por otra parte, se plantea llevar a cabo una serie de experimentos in situ con objeto de determinar parámetros de pérdida de suelo o escorrentía (superficial o sub-superficial). En este grupo, estarían los experimentos de simulaciones de lluvia (sobre un anillo de 0,28 m^2 y una intensidad de 40 mm/h durante 30 minutos) y escorrentía (bombeo durante aproximadamente 7-10 minutos unos 1000 l de agua, controlando el recorrido con sensores de movimiento y trazadores) o medición de la permeabilidad (con un permeámetro de Guelph). Dichos experimentos y mediciones se llevarán a cabo coincidiendo con las posiciones de la ladera donde se llevó a cabo el muestreo de suelos (en las partes altas, medias y pie de la ladera) con objeto de contrastarlos con estos resultados. Los resultados han sido evaluados a partir de diferentes test estadísticos como los coeficientes de correlación de Spearman, ANOVA, Tukey o Mann Whitney.

Los resultados de este trabajo demostraron que los viñedos en pendiente de los Montes de Málaga (España) y del valle Ruwer-Mosel (Alemania) con suelos desnudos pueden experimentar altas tasas de erosión, pero sin demostrar patrones claros a simple vista debido al impacto del ser humano. La distribución espacio-temporal de los procesos hidrológicos y geomorfológicos es desigual y está altamente condicionada por factores muy específicos.

Al igual que en los viñedos con bajas pendientes (<5%), las tormentas, las prácticas agrícolas no sostenibles y los suelos desnudos son los principales factores que condicionan los procesos de erosión del suelo. Sin embargo, las pendientes pronunciadas posiblemente inducen aún más si cabe los procesos de erosión del suelo, oscilando desde tasas muy bajas a valores extremos debido a la energía gravitacional a favor de la dirección de la pendiente. Las futuras líneas de investigación deben enfocarse en dilucidar qué valor de la pendiente y en qué magnitud afectan a los procesos de erosión del suelo en comparación con las laderas no inclinadas, siempre bajo el mismo manejo del suelo e iguales condiciones ambientales como las propiedades del suelo, clima y la variedad de la parra.

También, se ha demostrado que las propiedades específicas del suelo en laderas empinadas también han desempeñado un papel notable para incrementar o reducir los procesos de erosión del suelo. Por ejemplo, se ha observado que el alto contenido de limos incrementa el tamizado natural de partículas finas después de eventos lluviosos o prácticas de labranza, lo que genera una reducción de la estabilidad de los agregados y la cohesión de partículas. Otra característica del suelo con un fuerte impacto en los procesos de erosión del suelo es la pedregosidad. Se ha confirmado como un factor de control de la erosión del suelo porque mejora: i) la infiltración y la permeabilidad; ii) la retención de suelo; y, iii) la conservación de los niveles de temperatura y retención de la humedad del suelo. Los dos primeros resultados (infiltración y permeabilidad) se midieron con éxito en los Montes de Málaga y el valle Ruwer-Mosel, y también fue confirmado por otras investigaciones en viñedos mediterráneos, suelos forestales, carreteras o bajo condiciones de laboratorio. Sin embargo, la relación entre la pedregosidad y la retención de humedad del suelo y la conservación de la temperatura, aunque detectado y confirmado por los viticultores, no se cuantificó. Por lo tanto, esta dinámica debería ser una línea de investigación que debería abordarse en el futuro. Sería interesante constatar si tanto la temperatura del suelo como la humedad del suelo en suelos muy pedregosas muestran o no cierta influencia sobre la estabilidad de los agregados, la cohesión del suelo, la materia orgánica y las actividades microbiológicas.

Otro resultado destacable es la consideración como factor principal el efecto del pisoteo de los viticultores. Se demostró que el número y la longitud de las vías de escorrentía tras el pisoteo varían con la pendiente (con las marcas botánicas en Waldrach y las cajas de sedimentos en Almáchar), el volumen de fragmentos de rocas, las arenas y limos varía. Observamos que antes y después de la poda, la fumigación con herbicidas, la labranza o la cosecha, es decir, durante el pisoteo, las fuentes de escorrentía, las pérdidas de suelo y sus vías principales se desconectaron o se conectaron entre sí. Este efecto no se remarcó tanto en investigaciones previas en viñedos sin fuertes pendientes. Sin embargo, estos hallazgos ya se remarcaron en algunos espacios urbanos de EE.UU. y en zonas de bosques con algunas investigaciones cualitativas previas. Sin embargo, el desarrollo de un método de cuantificación fue difícil y una solución parece difícil de lograr. En viñedos ecológicos en pendiente durante otra investigación realizada paralela a esta tesis, se observó una disminución del impacto del efecto de pisoteo sobre la erosión del suelo debido a la cubierta de herbáceos que se dejó. Posiblemente, no conservar el suelo desnudo sería la solución más factible.

Esta extrema desconexión y conexión detectada en viñedos en pendiente también está relacionada con otro proceso hidrológico detectado, que, aunque remarcado hace algunas décadas, tampoco se ha cuantificado debidamente desde entonces. En el caso del valle Ruwer-Mosel, después de la cosecha (desde noviembre a marzo) observamos en el campo que la compactación del suelo disminuyó y la infiltración aumentó (mayor en los viñedos jóvenes que en los viejos). Por otra parte, la humedad del suelo aumentó y la mejora de la agregación de las partículas finas también se vio afectada, mientras la cantidad de lluvia también disminuyó. Con respecto a esto, los valores de flujo de escorrentía mostraron algunos picos tras eventos de lluvia significativos, pero las tasas de pérdida de suelo disminuyeron drásticamente. Por lo tanto, los valores de concentración de sedimentos también fueron más bajos que en primavera o verano, con las primeras actividades de labranza y la vendimia. La primera hipótesis podría estar relacionada con la investigación publicada por Lasanta, (1985) en La Rioja (España), que apoya la presunción de que la superficie congelada mejora los flujos hídricos y, por lo tanto, aumenta la humedad del suelo (o contenido de agua en el perfil del suelo) y, por ende, la escorrentía a bajos niveles. Por otro lado, la segunda hipótesis son los mecanismos de flujo subsuperficial detectados por Hewlett y Hibbert (1967). Hoy en día, el flujo subsuperficial está bastante estudiado; sin embargo, se suele evaluar puntualmente mediante con el uso de funciones de pedotransferencia. Sin emabrgo, con métodos de experimentación en campo, todavía queda un largo camino por recorrer. En nuestro caso, con simuladores de lluvia confirmamos en invierno altos coeficientes de infiltración (cerca del 100%), con solo pequeños picos de coeficiente de escorrentía y valores insignificantes de cargas de sedimentos en suspensión. Mediante el uso de experimentos de simulación de lluvia en 2013, tratamos de cuantificar en tiempo real el flujo subsuperficial y la concentración de sedimentos: i) eliminando el horizonte A de piedras dentro del anillo del *plot*; ii) usar una tela de nylon hidrófila para proteger el suelo contra el efecto de salpicadura; y, iii) la excavación de un perfil de suelo vertical debajo del simulador (50 cm de profundidad y 150 cm de ancho). Sin embargo, de esta manera, el flujo subsuperficial era observable y confirmado por el perfil, pero fue imposible cuantificarlo. Esta alteración de la dinámica hidrológica natural debido a la labranza del suelo y el alto contenido de fragmentos de roca que implica una macro-porosidad alta, especialmente en los viñedos jóvenes, puede generar varios problemas de transporte de solutos, nutrientes y pérdidas de partículas finas, deslizamientos de tierra por procesos de *piping*, formación de surcos y regueros efímeros, degradación de las raíces y disminución de la productividad. Después de revisar la literatura científica para resolver este problema metodológico, resaltamos que hay una falta de métodos para realizar un monitoreo de la concentración de sedimentos suspendidos en el flujo subsuperficial y las cantidades totales de agua movilizada. Solo se pueden encontrar algunos ejemplos a escala de ladera en EE.UU. donde se midieron algunos eventos de lluvia durante meses o en un área fluvial en Japón. Por lo tanto, concluimos que también se necesita más investigación para cuantificar las pérdidas totales de suelo y agua, las principales vías de flujo y confirmar si este proceso es general en los viñedos en pendiente y si es relevante a nivel de volumen de transporte.

En Alemania, quedó bastante clarificado que durante las diferentes estaciones (antes y después de la vendimia), la escorrentía superficial y la escorrentía subsuperficial no fueron homogéneas, pero siguen una tendencia relativa relacionada con la labranza y la cosecha. Sin embargo, en los Montes de Málaga, encontramos un modelo mixto que actúa continuamente y de forma simultánea. Como mencionamos anteriormente, esta situación puede ser debida a la alta variabilidad de la distribución de los componentes superficiales del suelo, lo que genera cambios microtopográficos diferentes a lo largo de la ladera y pueden modificar su comportamiento natural. Las irregularidades debidas a la alta rugosidad y la esquistosidad de las rocas facilitan la erosión de los materiales, que adquieren una morfología laminar y una gran angularidad. La dirección del plano de los fragmentos de roca ofrece una mayor resistencia frente al transporte de los sedimentos a lo largo de la pendiente y causa altas diferencias microtopográficas. Por lo tanto, se puede considerar un posible modelo mixto Hortoniense-Hewlettiano, combinando flujo superficial y subsuperficial, transporte irregular de sedimentos y con diferentes impactos de la lluvia en el suelo a escala pedon, mostrando también diferentes patrones de umbrales de escorrentía. Los viñedos en pendiente de los Montes de Málaga mostraron claros mecanismos de conectividad y procesos de desconexión, en los que continuamente aparecen y desaparecen los procesos de infiltración, flujo superficial y flujo subsuperficial. Todos juntos conforman un patrón irregular desde la cumbre hasta el pie de la ladera, que desarrolla un sistema de retroalimentación continua. Esta alteración de la dinámica hidrológica natural también puede conllevar algunos problemas ambientales antes mencionados para el caso alemán. De esta forma, para el futuro, sería interesante profundizar en las variaciones temporales a escala *intraplot* relevantes a lo largo de las calles de las parras. Sería útil comparar la erosión del suelo y los procesos hidrológicos antes y después de la cosecha, entre diferentes años y bajo diferentes intensidades de lluvia mediante el uso de índices de conectividad.

Otra conclusión importante definida en esta investigación es el impacto de la edad del viñedo en los procesos de erosión del suelo. La edad de los viñedos como un factor clave que controla los procesos de erosión del suelo ha recibido una atención e interés mínimos por parte de la comunidad científica. Richter y Negendank (1977) publicaron en inglés el primer documento que mencionaba la posible influencia de la edad de la plantación en el valle de Ruwer-Mosel. Sin embargo, desde que destacamos la relevancia del tiempo desde la plantación como un factor determinante en la erosión del suelo mediante el SUM, afortunadamente, otros grupos de investigación también confirmaron esta causa interesante e influyente en la erosión. La diferencia de erosión del suelo en viñedos con diferentes edades ocurre debido a los procesos combinados de labranza y lavado superficial. La labranza ha demostrado ser un factor clave en la redistribución del suelo en tierras agrícolas. La superficie original del suelo en los viñedos durante la plantación es plana, lisa y con baja rugosidad. Las tasas de erosión del suelo pueden ser más altas en las parcelas más jóvenes que en las más antiguas debido a las perturbaciones del suelo tras plantar las cepas. La maquinaria trabaja sobre el suelo, pero también está compactándolo, por lo que la escorrentía se puede activar más fácilmente. Dicho efecto es muy eficiente en las parcelas de 1 a 3 años. Sin embargo, después de 3-4 años, la redistribución del suelo tras cada labranza resulta en un aumento de la rugosidad y, por consiguiente, en cambios microtopográficos. Tras la consolidación del material edáfico, las tasas de erosión a escala ladera pueden reducirse debido a que la conectividad de los flujos se reduce. Otro factor importante que reduce las pérdidas de suelo en los viñedos más viejos en comparación con los jóvenes es el aumento de la biomasa de la vid. Es importante destacar que la erosión del suelo está altamente determinada por el impacto de la gota y con el crecimiento de las vides después de algunos años, la erosión de la lluvia se reduce debido a la protección del suelo que proporcionan las hojas. La cubierta de hojas de vid contribuye a reducir la escorrentía en las hileras de vides, y como consecuencia la interceptación es mayor. El golpeteo en las hojas o la caída desde el tallo generan tasas de escorrentía más bajas.

Finalmente, también se han considerado algunas soluciones con objeto de ser implementadas en ambos viñedos en pendientes pronunciadas. En los Montes de Málaga, es importante destacar la importancia de la perfecta comunicación con los viticultores (Pepe Gámez y Antonio Tóbalo) y la bodega (Demore). Esta situación ha demostrado que las posibles soluciones que se implementarían en los Montes de Málaga pueden adaptarse a las características ambientales de la vid fácilmente y es muy posible que se prueben a corto plazo. Aunque el flujo preferencial de escorrentía no es uniforme, sí fue posible detectar el origen y confirmarlo con los agricultores. Por lo tanto, una posible solución pasaría por introducir una cubierta vegetal en forma de parches. Debido a la competencia del agua y los largos períodos de sequía, un suelo completamente cubierto de vegetación sería imposible y, seguramente, no aceptado por los viticultores. Sin embargo, solo algunos parches en la cima o a media ladera de aproximadamente 1x1 o 2x2 m^2 podrían ser herramientas muy útiles para detener el flujo de escorrentía y mejorar la infiltración. El mantenimiento y la inversión económica en esta solución no sería costosa, ya que los agricultores pueden, o bien plantar leguminosas que puedan usarse para la comida de los animales tras la siega, o usar directamente los restos de la poda de la vid. Además, el uso de aliviaderos agrícolas o sangrías, si están bien diseñados (dirección y ancho correctos) y bien conservados (vacíos de sedimentos y restos de poda u hojas), también se ha confirmado como un complemento excelente para canalizar el exceso de agua. Sin embargo, faltaría planificar la canalización de la escorrentía en grandes contenedores para más adelante utilizar el excedente de agua, por ejemplo, para riego.

Por otro lado, en el valle del Ruwer-Mosela, lamentablemente, la comunicación no fue tan fluida como en los Montes de Málaga, puesto que la bodega está muy lejos del área de estudio y no llegamos a coincidir durante el trabajo de campo con los propietarios. Sin embargo, durante la vendimia y el tiempo de la poda, nuestros resultados sí pudieron ser confirmados con informantes y agricultores extranjeros de Hungría, Eslovaquia o Polonia que acudían durante la vendimia a trabajar a Waldrach. Acorde a los resultados obtenidos, las dos soluciones principales observadas que podrían ser eficientes y útiles en los viñedos alemanes en fuertes pendientes serían el uso de la cubierta vegetal, que puede sí puede sobrevivir sin una competencia por el agua demasiado extrema, y el desarrollo de una maquinaria más ligera para la labranza.

CHAPTER 1. INTRODUCTION AND NECESSITY: SIX DECADES OF SOIL EROSION RESEARCH IN "TERROIR". THE STATE-OF-THE-ART

RODRIGO-COMINO, J. 2018: Five decades of soil erosion research in "terroir". The State-of-the-Art. Earth-science Review. 179, 436-447. DOI: 10.1016/j.earscirev.2018.02.014

CHAPTER 2. ASSESSMENT OF SOIL EROSION IN SLOPING VINEYARDS: A COMPARISON BETWEEN RUWER-MOSEL VALLEY (TRIER, GERMANY) AND MONTES DE MÁLAGA (MÁLAGA, SPAIN)

As we mentioned in the last chapter, soils are one of the most important environmental components to characterize a viticultural area (Bonfante et al., 2011; Resolution OIV/VITI 333/2010, 2010; Vaudour et al., 2015). Climatic (annual rainfall distribution and intensity, diurnal thermal fluctuations, heat storage capacity and solar reflectivity), geomorphological (slope, orientation and altitude) and phenological (vine variety and leaf density) characteristics are the most studied natural conditions to determine vineyard´s soil quality (Ashenfelter and Storchmann, 2010; Ramos et al., 2008; Ramos and Martínez-Casasnovas, 2009; Urhausen et al., 2011). Specifically, changes during the last century in human land use management and the increased occurrence of extreme rainfall events are introducing negative impacts on the conventional sloping vineyards, for example, in Germany or Spain.

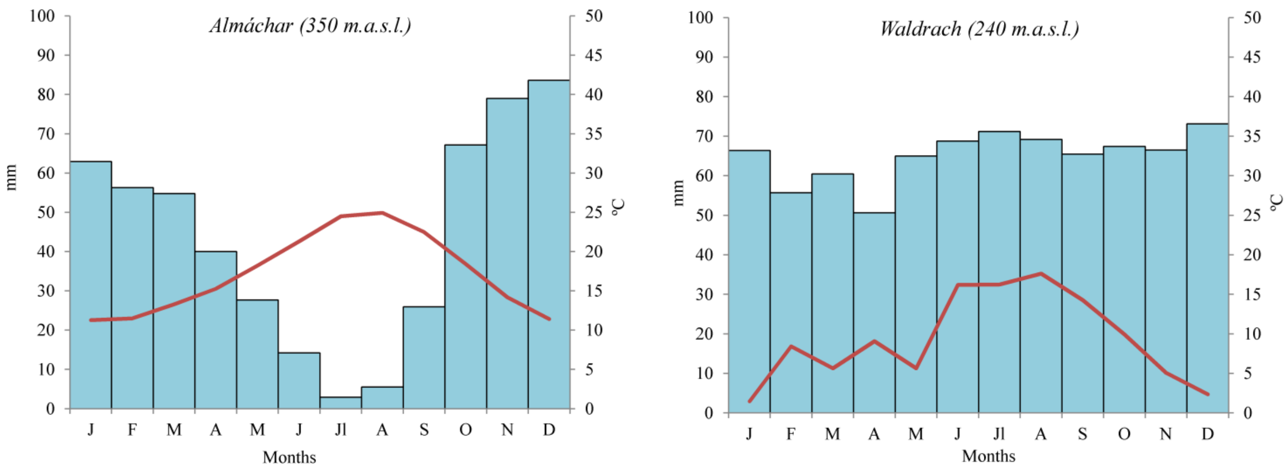
These land degradation processes are fundamentally caused by the increase of soil erosion and the alteration of the natural hydrological processes. Since the last century, these problems have been studied in different experimental areas such as the Ruwer-Mosel valley (Hacisalihoglu, 2007; Richter, 1980, 1979, 1975, Rodrigo Comino et al., 2015a, 2015b) and the Montes de Málaga (Blanco Sepúlveda and Gómez Moreno, 2006; Martínez Murillo and Ruiz Sinoga, 2003; Ruiz Sinoga, 1987; Senciales González, 1998). The main factors identified the last decades until this PhD Thesis were: i) steep slopes with inclinations from 15 to 40°; ii) soil profile disturbances during the initial plantation; iii) machinery´s impacts (in Germany); and, iv) more extreme rainfall events (increasing frequency).

However, there is a lack of information about the knowledge and quantification of intra-plot variations of hydrological and geomorphological processes due to rainfall and human impacts. This issue becomes indispensable to improve at long-term the grape production and quality (Chevigny et al., 2014; Raclot et al., 2009). At short- to medium- term periods, different techniques have been performed in European viticulture regions to measure, to quantify and to define these natural and anthropic processes. However, currently studies about soil erosion in sloping vineyards not focus on measuring intra-plot differences combining soil loss, runoff and infiltration variations during different seasons (before, during or after harvesting; in summer or winter), on different slope positions (shoulder, backslope or footslope), hillslope´s inclination higher than 15° or with plantations of different ages. Sloping vineyards were conducted as a part of big catchments and assessed by modelling techniques such as WEEP or RUSLE. So, there is also a lack of information related to continued field measures.

2.1. Research justification

Prior starting this study, it is important to highlight that we selected two different vineyards' environments because it would be a unique opportunity of paying attention to more and various eco-geomorphological and hydrological processes than, undoubtedly, in only one study area. Therefore, to clarify the problematics exposed in sloping vineyards, two experimental plots were installed and used as natural laboratory: one in the Montes de Málaga (Málaga, Spain) and another one in the Ruwer-Mosel valley (Trier, Germany). Although both vineyards are situated in two different countries, under different climate patterns (Fig. 1) and management practices, both of them are characterized by common problematics of sloping vineyards (Table 1): i) steep slopes (>20°); ii) bare soils due to the use of herbicides; iii) conventional tillage practices (use of machinery –Trier- and hand-made tillage –Málaga-); iv) similar lithological (metamorphic rocks such as slates and schists); and, v) pedological properties (high rock fragment and silt content).

Figure 1. Climate characteristics of Almáchar (Montes de Málaga, Spain) and Waldrach (Ruwer-Mosel valley, Germany).



* Climate data were obtained by extrapolation methods using linear and intersection estimations (Rodrigo Comino, 2013; Senciales González and Ruiz Sinoga, 2013).

Table 1. Common plot characteristics

Parameters	Description
Pedology	Altered and removed soil profle
	High soil and water losses
	Rill and ephemeral gullies formation
	Nutrient losses
	High rock fragment cover
	High silt content
Geomorphology and geology	Steep slopes (>30%)
	High amount of sediment transport
	High overland flow rates
	High tillage erosion registered by local researches
	Metamorphic lithology such as schists and slates
Climate	Vulnerable areas against climate change
	Perception of a temperature increase
	Perception of an increase of the rainfall amounts in few events
Agronomy and enology	Vineyard plantation (*Vitis vitifera Sp.).*
	Bare soils due to the application of herbicides
	Phenologic dynamics highly dependent on climate conditions
	Traditional land use managements
	Constant soil tillage
	Applicatiof phytosannitaries
	High trampling effect

2.2. Main goals

As we mentioned, in sloping vineyards, no information about real geomorphological and hydrological causes of land degradation processes and an accurate quantification at the intra-plot scale have been not yet carefully assessed. Therefore, the two main aims of this PhD Thesis will be: i) to measure and quantify the spatiotemporal variations of the hydrological and geomorphologic processes in two sloping vineyards under conventional land use managements and two different climate environments (the Mediterranean and Continental); and, ii) to find the main key factors (natural and anthropogenic) that could influence soil erosion processes after natural rainfall events and soil tillage practices.

2.3. Outcomes and results

During the research period, several articles were published with the aim of answering both research questions applying the same methods or sometimes adapted for each study area. Five papers (chapter 1, 5, 6, 7 and 9) will be presented for this PhD thesis. However, to complete the findings, information of other three papers (chapters 8, 10 and 11), as results of other international collaborations, were also added to make the complete PhD thesis. The first three sub-chapters are related to the Montes de Málaga (Spain):

Chapter 5. High variability of soil erosion and hydrological processes in Mediterranean hillslope vineyards (Montes de Málaga, Spain): Conventional Mediterranean vineyards from the Montes de Málaga (Axarquía region, Spain) are characterized by high average temperatures, extreme rainfall events during autumn and winter, elevated stoniness and steep slopes (20–50°). Traditionally, several problems of high soil loss, rill and ephemeral gully generation, and elevated runoff are observed by farmers, which are increasing land degradation processes and a decrease of the productivity. According to this, the main aims of this sub-chapter were: i) to quantify the initial soil loss, surface flow, and infiltration processes; ii) to characterize and describe the hydrological and geomorphological dynamics; iii) to detect the key factors, which control the soil erosion processes. For this purpose, a combined methodology was applied, using soil analysis, a small portable rainfall simulator and a Guelph permeameter on one experimental plot cultivated with vineyards with steep slopes.

- RODRIGO COMINO, J., Ruiz Sinoga, J.D., Senciales, J.M., Guerra Merchán, A.; Seeger, M., Ries, J.B. 2016. High variability of soil erosion and hydrological processes in Mediterranean hillslope vineyards (Montes de Málaga, Spain). *Catena*, 145, 274-284. DOI: 10.1016/j.catena.2016.06.012.

Chapter 6. Assessment of agri-spillways as a soil erosion protection measure in Mediterranean sloping vineyards: Suitable vineyard soils enhance soil stability and biodiversity which in turn protects roots against erosion and nutrient losses. There is a lack of information related to inexpensive and suitable methods and tools to protect the soil in Mediterranean sloping vineyards (>25° of slope inclination). In the vineyards of the Montes de Málaga (southern Spain), a sustainable land management practice that controls soil erosion is actually achieved by tilling rills in the down-slope direction to canalize water and sediments. Because of their design and use, we call them agri-spillways. In this sub-chapter, we assessed two agri-spillways (between 10 m and 15 m length, and slopes between 25.8° and 35°) by performing runoff experiments under extreme conditions (a motor driven pump that discharged water flows up to 1.33 l s^{-1} for 12 to 15 minutes: ≈1000 l).

- RODRIGO COMINO, J., Wirtz, S., Brevik, E.C., Ruiz Sinoga, J.D., Ries, J.B. 2017. Assessment of agri-spillways as a soil erosion protection measure in Mediterranean sloping vineyards. Journal of Mountain Sciences, 14 (6), 1009-1022. DOI:10.1007/s11629-016-4269-8

Chapter 7. Understanding soil erosion processes in Mediterranean sloping vineyards (Montes de Málaga, Spain): Sloping vineyards in the Mediterranean cultivated on bare soils show several types of evidence of soil erosion processes. However, little is known about the key factors that condition and enhance these processes at the intra-plot scale. There is a need to assess soil conservation methods to reach sustainability of vineyards and high grape quality, and for this, it is necessary to investigate the factors and rates of soil erosion processes under natural conditions. Therefore, the main goal of this part, conducted in traditional Mediterranean vineyards in Los Montes de Málaga (South Spain), was to carry out a precision analysis of the patterns of soil erosion and the soil surface components at the intra-plot scale. The analysis was performed after monitoring soil erosion processes during 25 natural rainfall events. Soil loss, overland flow, and runoff threshold were calculated using six Gerlach troughs. Fine soil particles and rock fragments were also assessed after each natural rainfall event and tillage practice.

- RODRIGO COMINO, J., Senciales J.M., Ramos, M.C., Martínez-Casasnovas, J.A., Lasanta, T., Brevik, E.C.; Ries, J.B.; Ruiz Sinoga, J.D. Understanding soil erosion processes in Mediterranean sloping vineyards (Montes de Málaga, Spain). Geoderma, 296, pp. 47-59. DOI: 10.1016/j.geoderma.2017.02.021

On the other hand, in the Ruwer-Mosel Valley (Germany), the results are shown in next three sub-chapters:

Chapter 8. Rainfall and human activity impacts on soil losses and rill erosion in vineyards (Ruwer Valley, Germany): Vineyards are one of the eco-geomorphological systems most conditioned by human activity in Germany. The vineyards of the Ruwer Valley (Germany) are characterized by high soil erosion rates and rill problems on steep slopes (between 23 and 26◦) caused by the increasingly frequent heavy rainfall events as well as deterioration due to incorrect land use management. The main objective of this subchapter is to determine and to quantify the hydrological and erosive phenomena in one vineyard in Germany during different seasons and under different management conditions (before, during and after vintage). For this purpose, a combined methodology was applied. Climatic (rainfall depth distributions and return periods), pedological (soil analysis and classification), geomorphological (sediment movements and rills evolution) and biological (botanic marks on the vines) variables were used on the two experimental plots in the village of Waldrach (Trier, a region of Rhineland-Palatinate).

- RODRIGO COMINO, J., Brings, C., Lassu, T., Iserloh, T., Senciales González, J.M., Seeger, M., Ruiz Sinoga, J.D., Ries, J.B. 2015. Rainfall and human activity impacts on soil losses and rill erosion in vineyards (Ruwer Valley, Germany). Solid Earth 6:823-837. DOI:10.5194/se-6-823-2015.

Chapter 9. The impact of vineyard abandonment on soil properties and hydrological processes: Soil and water resources are affected by land use changes such as land abandonment in vineyards. Changes in water resources and soil water dynamics can result in sudden alterations in erosion rates and trigger land degradation. In this study, we examined the impact of land abandonment on soil properties and hydrological processes in two paired plots: an active and an abandoned vineyard. Laboratory analyses were performed to assess texture, antecedent soil moisture, stoniness, soil water content, and organic matter (OM). A Guelph permeameter was used to quantify the permeability

(Per) and saturated hydraulic conductivity (Kfs) at different slope positions and seasons (before and after harvest).

- RODRIGO COMINO, J., Brings, C., Lassu, T., Iserloh, T., Senciales González, J.M., Seeger, M., Ruiz Sinoga, J.D., Ries, J.B. 2015. Rainfall and human activity impacts on soil losses and rill erosion in vineyards (Ruwer Valley, Germany). Solid Earth 6:823-837. DOI:10.5194/se-6-823-2015.

Chapter 10. Soil erosion in sloping vineyards assessed by using botanical indicators and sediment collectors in the Ruwer-Mosel valley: Steep slopes, erodible soils, rill and ephemeral gullies, compaction due to wheel traffic and human trampling are common features in vineyards around the world and result in high soil erosion rates, as we mentioned above. However, little is known about seasonal and spatial variations of soil erosion rates due to factors such as the impact of the vine plantation, harvest, and tillage on the soil redistribution over the long-term temporal scale. Therefore, the main goal of this part is to assess long-term soil erosion rates and the impact of management on sediment and runoff yield by means of Gerlach troughs and a topographical approach based on botanic benchmarks in two paired vineyards with different ages (3 and 35 years) located on the hillslope of the Ruwer-Mosel Valley (Germany). We studied: i) soil profiles and properties at different hillslope locations and ii) soil redistribution and erosion by means of topsoil level maps applying botanic benchmarks using the Stock Unearthing Method (SUM), RUSLE (Revised Universal Soil Loss Equation) and Gerlach troughs.

- RODRIGO COMINO, J., Quiquerez, A., Follain, S., Raclot, D., Le Bissonnais, Y., Casalí, J., Giménez, R., Cerdà, A., Keesstra, S.D., Brevik, E.C., Pereira, P., Senciales, J.M., Seeger, M., Ruiz Sinoga, J.D., Ries, J.B., 2016. Soil erosion in sloping vineyards assessed by using botanical indicators and sediment collectors in the Ruwer-Mosel valley. Agric. Ecosyst. Environ. 233, 158–170. doi:10.1016/j.agee.2016.09.009

Chapter 11. Temporal changes in soil water erosion on sloping vineyards in the Ruwer-Mosel Valley: Finally, we well known which reasons cause soil erosion in sloping German vineyards, but little is known about the effect of age of plantation on soil erosion, which is relevant to understand and design sustainable management systems. In the Ruwer-Mosel valley, young (1- to 4-years) and old (35- to 38-years after the plantation) vineyards were selected to assess soil and water losses by using two-paired Gerlach troughs over three years (2013–2015).

- RODRIGO COMINO, J.; Brings, C.; Iserloh, T.; Senciales, J.M.; Casper, M.C.; Seeger, M.; Brevik, E.C.; Ruiz Sinoga, J.D.; Ries, J.B. 2017. Temporal changes in soil water erosion on sloping vineyards in the Ruwer-Mosel Valley. Journal of Hydrology and Hydromechanics, 65, 4: 402-409 65. DOI: 10.1515/johh-2017-0022.

After each sub-chapter, specific discussions and conclusions will be presented to assess if the established goals were reached. Finally, an overall conclusion and which future research lines were also addressed.

References

Ashenfelter, O., Storchmann, K., 2010. Measuring the economic effect of global warming on viticulture using auction, retail, and wholesale prices. Rev. Ind. Organ. 37, 51–64. doi:10.1007/s11151-010-9256-6

Blanco Sepúlveda, R., Gómez Moreno, M.L., 2006. Agua y sociedad rural en los montes de Málaga: sistemas hidráulicos en el hábitat disperso del s. XIX. Baética Estud. Arte Geogr. E Hist. 28, 259–282.

Bonfante, A., Basile, A., Langella, G., Manna, P., Terribile, F., 2011. A physically oriented approach to analysis and mapping of terroirs. Geoderma 167–168, 103–117. doi:10.1016/j.geoderma.2011.08.004

Chevigny, E., Quiquerez, A., Petit, C., Curmi, P., 2014. Lithology, landscape structure and management practice changes: Key factors patterning vineyard soil erosion at metre-scale spatial resolution. Catena 121, 354–364. doi:10.1016/j.catena.2014.05.022

Hacisalihoglu, S., 2007. Determination of soil erosion in a steep hill slope with different land-use types: a case study in Mertesdorf (Ruwertal/Germany). J. Environ. Biol. Acad. Environ. Biol. India 28, 433–438.

Martínez Murillo, J.F., Ruiz Sinoga, J.D., 2003. Incidencia de algunas propiedades físicas de suelos en su respuesta hidrológica ante diferentes usos bajo condiciones mediterráneas (Montes de Málaga). Edafología 10, 57–62.

Martínez-Casasnovas, J.A., Ramos, M.C., Ribes-Dasi, M., 2005. On-site effects of concentrated flow erosion in vineyard fields: some economic implications. Catena 60, 129–146. doi:10.1016/j.catena.2004.11.006

Raclot, D., Le Bissonnais, Y., Louchart, X., Andrieux, P., Moussa, R., Voltz, M., 2009. Soil tillage and scale effects on erosion from fields to catchment in a Mediterranean vineyard area. Agric. Ecosyst. Environ. 134, 201–210. doi:10.1016/j.agee.2009.06.019

Resolution OIV/VITI 333/2010, 2010. Definition of vitivinicultural“Terroir”.The General Director of the OIV. Presented at the General assembly, Tbilisi (Georgia).

Richter, G., Negendank, J.F.W., 1977. Soil erosion processes and their measurement in the german area of the Moselle river. Earth Surf. Process. 2, 261–278. doi:10.1002/esp.3290020217

Rodrigo Comino, J., 2013. Cuantificación de los gradientes térmicos a nivel superficial a lo largo del Rheinland-Pfalz (Renania-Palatinado, Alemania). Baética Estud. Arte Geogr. E Hist. 75–98.

Rodrigo Comino, J., Brings, C., Lassu, T., Iserloh, T., Senciales, J., Martínez Murillo, J., Ruiz Sinoga, J., Seeger, M., Ries, J., 2015a. Rainfall and human activity impacts on soil losses and rill erosion in vineyards (Ruwer Valley, Germany). Solid Earth 6, 823–837. doi:10.5194/se-6-823-2015

Rodrigo Comino, J., Lassu, T., González, J.M.S., Sinoga, J.D.R., Seeger, K.M., Ries, J.B., 2015b. Estudio de procesos geomorfodinámicos en campos cultivados de viñedos sobre laderas en pendientes en el valle del Ruwer (Alemania). Cuad. Geográficos 54, 6–26.

Senciales González, J.M., 1998. El análisis morfológico de las cuencas fluviales aplicado al estudio hidrográfico. Norba Rev. Geogr. 155–184.

Senciales González, J.M., Ruiz Sinoga, J.D., 2013. Análisis espacio-temporal de las lluvias torrenciales en la ciudad de Málaga. Bol. Asoc. Geógrafos Esp. 7–24

Urhausen, S., Brienen, S., Kapala, A., Simmer, C., 2011. Climatic conditions and their impact on viticulture in the Upper Moselle region. Cl. Change 109, 349–373. doi:10.1007/s10584-011-0059-z

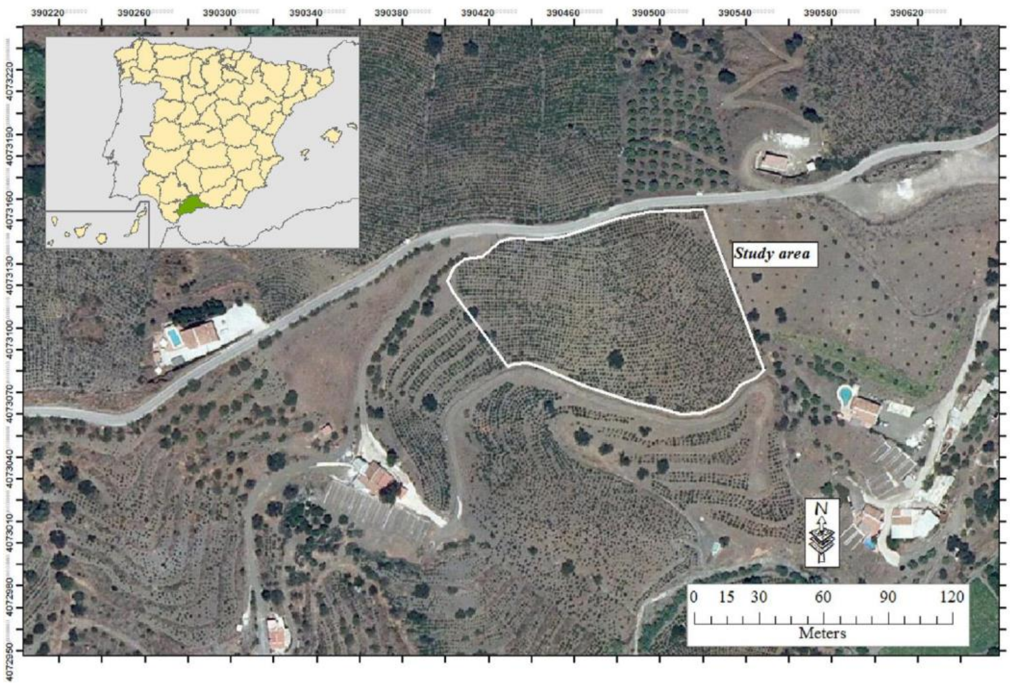
Vaudour, E., Costantini, E., Jones, G.V., Mocali, S., 2015. An overview of the recent approaches to terroir functional modelling, footprinting and zoning. SOIL 1, 287–312. doi:10.5194/soil-1-287-2015

CHAPTER 3. STUDY AREAS

3.1. Almáchar (Montes de Málaga, Spain)

The first experimental study site is located in the village of Almáchar (Fig. 1), which is situated in the Axarquía region in the Montes de Málaga relief (Andalucía, Spain).

Figure 1. Study area and location of the measurements and experiments.



3.1.1. Geological and pedological characteristics

From a geological point of view, the study area is located in the "Benamocarra unit" within the Internal Zone of the Betic Cordillera (Estévez-González and Chamón, 1978). Tectonically this unit is located on materials of the Alpujarride complex and under materials of the complex Malaguide. In general, this monotonous unit is composed of Palaeozoic dark schists, with approximately 700 m thickness. Estévez-González and Chamón (1978) describe two different facies: i) mica schists with well-developed schistosity, small garnets (1–2 mm) and intercalations of lenticular levels of white quartz and; ii) quartz-mica schists without garnets, which have less developed the schistosity, showing higher resistance than the first facies. These types of rocks are predominant along the eastern part of the studied area, especially in its upper part, characterized by a large number of rocky outcrops and slights. In general, these rocks have been subjected to intense deformation as testifies the axial schistosity axial plane linked to isoclinal folds and the abundant fractures of different scales. The schistosity shows an orientation which varies between N-S with dips of 40°–55° W and N140–165E with dips of 40–65° SW. Fractures have a variable orientation: i) N/NE to S/SW with dips between 55 and 85°E; ii) NW-SE with dips of 66–75°SW; iii) little signals of E-W with dips of 70–80°S.

Soils are typically Eutric Leptosols (IUSS Working Group WRB, 2014; Rodrigo Comino, 2014). These soils were characterized by Rodrigo Comino et al. (2016c): i) silt loam texture; ii) very low electrical conductivity values (0.1 dS m^{-1}); iii) general soil pH values of about 7; iv) bulk density up to 1.5 g cm^{-3} v) carbonate contents 1% because the main lithology is schist; and vi) a total organic carbon content between 1-2% due to the use of herbicides and tillage to eliminate vegetation growth.

3.1.2. Climatic and land management characteristics

The annual average rainfall depth is 520 mm and its highest concentration is distributed between October and January (78%) in a few extreme events, but with a high inter-annual variability. For example, since September until November in 2014 was collected a total rainfall of 343.6 mm, which 200.6 mm were obtained in only one event of two days. In 2015, since September until November, the total amount was reduced arranging 189.4 mm. In summer, between June and August, only a 4% of the total average rainfall depth is registered. In the study area, during May, June, July, and August (in 2014 and 2015) did not register any precipitation. The annual average temperature is 17.2 °C, with maximum average values in July and August (24.5–24.9 °C and minimum average values in December, January and February (11.3–11.5 °C).

The experimental plot is characterized by a conventional and traditional grape production with an irregular distribution of the marc of plantation along with high hillslopes (20–50°; Fig. 2). Several changes have been registered in the actual landscape due to the economic crisis of the viticulture sector, increasing abandoned lands and, with the insertion of new plantations of mango (*Mangifera indica*) and avocado (*Persea americana*) (Rodrigo-Comino, 2014; Rodrigo-Comino and Senciales-González, 2015).

The main variety of grape is Muscat of Alexandria, registered by a Spanish DO (Designation of Origin) with the name: “Málaga, Sierras de Málaga and Pasas de Málaga” (Fig. 2). The 2014 and 2015 harvests were carried out at the beginning of July by hand-made, due to the highest temperatures and the fast maturation of the grapes. The land management is characterized by: i) soil tillage with hoes and shovels before (April–May) and after vintage (October–December); ii) the application of herbicides to avoid the competence of water with other plants (November–December); iii) the utilisation of animals to recollect the grape production; and iv) the application of natural and organic soil amendments of domestic cows and goats (February–March).

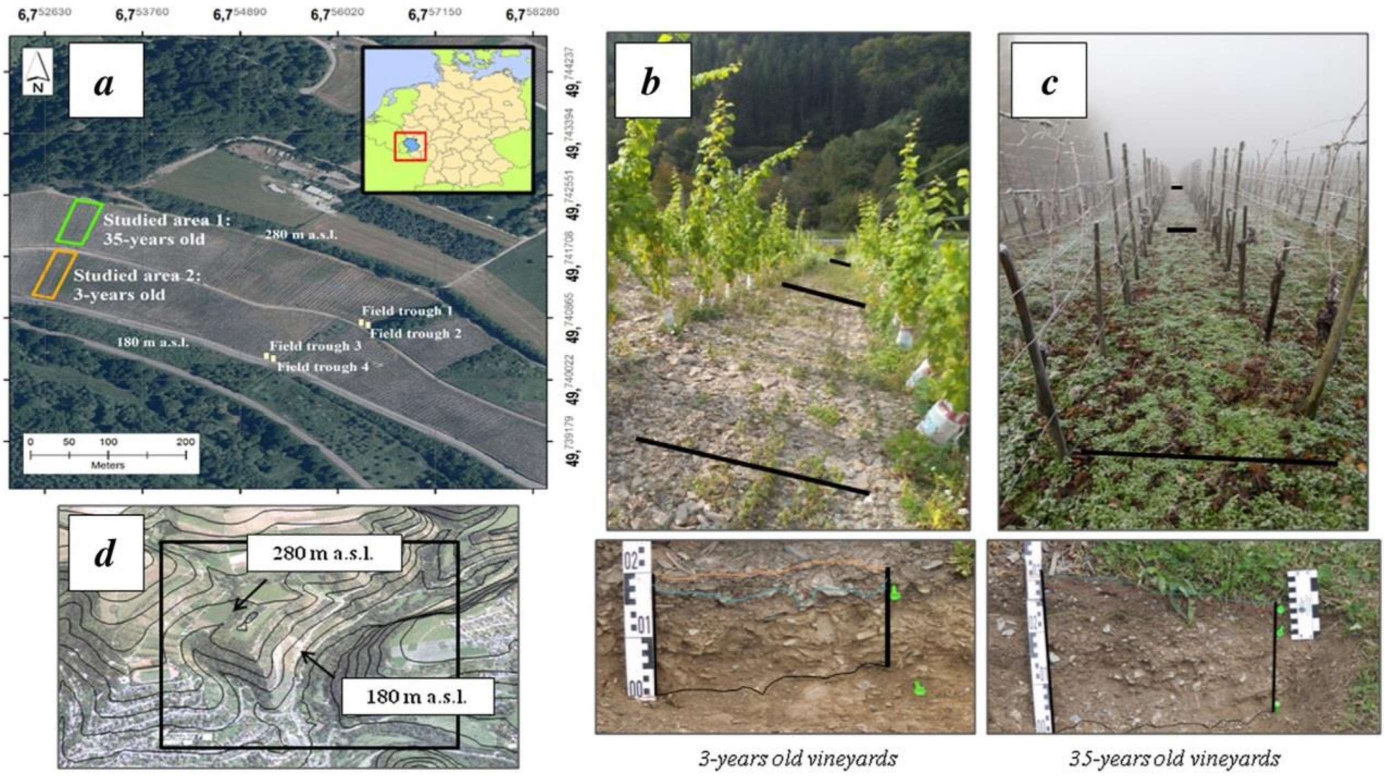
Historically, due to the steep soil erosion problems by the concentrated rainfall events and the steep slopes, the vine growers have developed rudimental protection measures in some places. The first protection measure is the “sangría” or “desaguadero”, composed by anthropic handmade rills, which collect and interrupt the surface flow and canalize the water directly to another principal rill. The second traditional technique is the stone walls ("albarrada" or "balate") situated along the upper slope to contain the soil across the slope. This second protection measure is included in the experimental area of this research.

Figure 2. Panoramic of the study plot (left side) and footslope part with vines during summer (right side)

3.2. Waldrach (Ruwer-Mosel valley, Germany)

The selected plots (Fig. 3) are located on the hillslopes of the Waldrach vineyards (49.7418N; 6.7524 E) in the Ruwer-Mosel Valley (Rhineland-Palatinate, Germany). The Ruwer-Mosel river flows in from the south from a plateau at the Hünsrück Mountains from about 500 m a.s.l. to approximately 200 m a.s.l. in the north (Richter, 1980).

Figure 3. Study area description.



a: Location of the 3-years and 35-years old vineyards and Gerlach troughs; b: soil profiles in 3-years old vineyards; c: soil profiles in 35-years old vineyards; d: topographical characteristics.

3.2.1. Geological and pedological characteristics

The study site is underlain by Devonian greywackes, slates, and quartzites partially overlain by Pleistocene silts deposited near the river. The whole study area can be subdivided into two parts: the 35-year-old vine stocks and the 3-year-old vine stocks (Fig. 4). The plot that corresponds to the 3-year-old vineyard has a total area of 0.043 ha and the plot for the 35-year-old vineyard was 0.065 ha. Slope angles vary from 15 to 30 with a convex morphology. Altitude ranges between 190 and 270 m a.s.l. Grass cover and trees are located downslope near the Ruwer-Mosel River. Upper, middle, and footslope sampling was carried out in the 3- and 35-years old vineyards.

Soils are classified as *leptic-humic Regosols* (IUSS Working Group WRB, 2014). Information about soil analysis procedures was explained in detail in Rodrigo Comino et al. (2016)

and was the same as in the Spanish vineyards. The highest stone content was observed in the young vineyard (59.7%). In the old vineyard stone content was 37.9%. Soil textures were silty loam in both plots. Silt was the most common particle size at the study site with an average of 64.7% in the old vineyard and 64.3% in the young one. The sand content averaged 26% in the old plot and 26.8% in the young one. Clay particles arranged from 8.9% (young vineyard) to 9.3% (old vineyard). High soil water content (SWC) at field capacity (FC) was documented for both areas, being close to 30%. At the wilting point (WP), values decreased to 12.3% in the old vineyard and 10.5% in the young one. Total organic carbon (TOC) was higher in the old vineyard (7.9%) than in the young one (6.1%) along the soil profile (0-25 cm). Carbonates content ($CaCO_3$) was low in both studied areas (from 0.9% to 1.2%). Electrical conductivity (EC) was considered extremely low, with values from 0.3 dS m^{-1} to 0.4 dS m^{-1}. Values of soil pH in the old vineyard were higher (7.2 with water solution and 6.4 in KCl) than in the young one (6.4 and 6.5, respectively). Therefore, no soil acidification trends were noted in the old vineyard. Even if the differences had been greater than 1, no soil acidification trend would have been.

Figure 4. Panoramic of the study plot (left side) and inter-row areas (right side)

3.2.2. Climatic and land management characteristics

The average annual rainfall is 765 mm and the maximum values occur in the summer months: 65–72 mm per month, mostly during summer thunderstorms. The lowest monthly precipitation is measured between February and April: 50–60 mm per month. Mean annual temperature is 9.3 C, with maximum average values in June, July and August (16.2–17.6 C) and minimum values in January and December (1.5–2.3 C). The grapevine variety is Riesling. Both plots are cultivated by the same wine grower and are characterized by the same traditional soil tillage and vine training system. The yearly soil management is as follows: i) mechanical soil tillage (20 cm depth) takes place before and after grape harvest from March–April to May, and from October to November; ii) grass cover in the inter-row (with maximum height of 20 cm) and in the rows (between 10 cm and 35 cm height); iii) a vine training system based on a plantation framework of 0.9 m x1.0 m and with the vine stocks slope-oriented to find equilibrium between leaves and the graft to maximize photosynthesis and sugar production and to favour mechanical soil tillage (Fig. 4); iv) redistributing of slate rock fragment cover to protect the surface against the rain splash effect and keep the soil temperature stable; and vi) the use of pesticides and herbicides during spring and summer to eliminate weeds. Along the embankments and inter-rows, rills formed adjacent to wheel tracks and footpaths.

REFERENCES

Estévez González, C., Chamón, C., 1978. Mapa Geológico y memoria explicativa de la Hoja de Málaga-Torremolinos (1.053-1067), escala 1:50.000.

IUSS Working Group WRB, 2014. World Reference Base for Soil Resources 2014, World Soil Resources Report. FAO, Rome.

Richter, G., 1980. On the soil erosion problem in the temperate humid area of Central Europe. GeoJournal 4, 279–287.

Rodrigo Comino, J., 2014. Los suelos de la provincia de Málaga: Revisión y actualización de las fuentes edafológicas según la clasificación de FAO-WRB. Servicio de Publicaciones y Divulgación Científica, Universidad de Málaga., Málaga.

Rodrigo Comino, J., Quiquerez, A., Follain, S., Raclot, D., Le Bissonnais, Y., Casalí, J., Giménez, R., Cerdà, A., Keesstra, S.D., Brevik, E.C., Pereira, P., Senciales, J.M., Seeger, M., Ruiz Sinoga, J.D., Ries, J.B., 2016a. Soil erosion in sloping vineyards assessed by using botanical indicators and sediment collectors in the Ruwer-Mosel valley. Agric. Ecosyst. Environ. 233, 158–170. https://doi.org/10.1016/j.agee.2016.09.009

Rodrigo Comino, J., Ruiz Sinoga, J.D., Senciales González, J.M., Guerra-Merchán, A., Seeger, M., Ries, J.B., 2016b. High variability of soil erosion and hydrological processes in Mediterranean hillslope vineyards (Montes de Málaga, Spain). Catena 145, 274–284. https://doi.org/10.1016/j.catena.2016.06.012

Rodrigo Comino, J., Senciales González, J.M., 2015. Ratio LE para el ajuste de perfiles longitudinales en cursos fluviales de montaña. Aplicación a la cuenca del río Almáchar (Málaga, España). Cuaternario Geomorfol. 29, 31–56.

Rodrigo Comino, J., Senciales González, J.M., González Moreno, J.M., 2014. La necesidad de considerar los riesgos climáticos en la introducción de cultivos tropicales en latitudes medias. El mango en el valle del Guadalhorce (Málaga). Investig. Geográficas 62, 127–141. https://doi.org/10.14198/INGEO2014.62.09

CHAPTER 4. MATERIALS AND METHODS

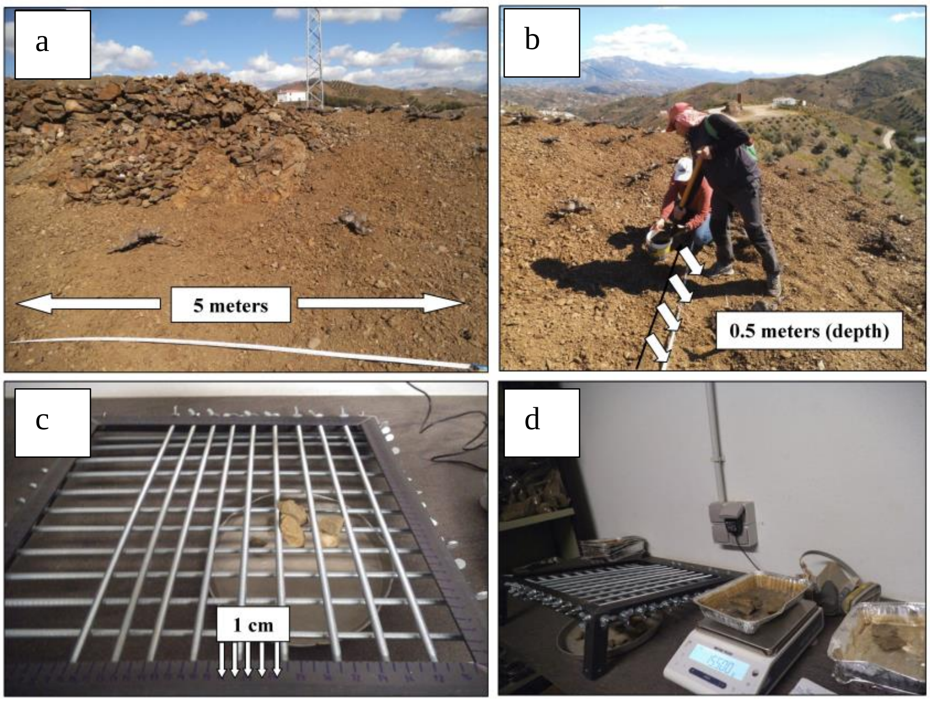
4.1. Soil analysis

In Almáchar and Waldrach, soil samples were collected during July and August of 2014 on the experimental areas from three different slope positions (shoulder, back- and footslope), two depths (0–5 cm and 5–15 cm) along inter-rows and under the vines and with three replicates (in total 36 samples, taking about 3–4 kg per sample). After sieving (<2 mm), different parameters were analysed in the laboratory in order to determine: texture, bulk density, total organic carbon, carbonates, electrical conductivity, pH, and soil water content.

Grain particle size between 0.004 mm and 2 mm was measured with a Coulter LS230, by combining different diffraction patterns of a light beam. 1 cm^3 steel cylinders were used to calculate the bulk density with undisturbed soil samples.

In Almáchar (Montes de Málaga, Spain), extra soil samples were also collected in April 2016 under dry conditions at four different slope positions (summit, shoulder, backslope and footslope) to calculate the stoniness and gravels. They were collected along a longitudinal profile of 5 m (Fig. 1a) and from the surface to 0.5 m depth (Fig. 1b) from each slope position (about 15 kg per sample). Samples were transported to the laboratory, air dried and weighted.

Figure 1. Stoniness sampling



Particle size distribution of the fine material (between 0.002 mm and 2 mm) was calculated using a Coulter LS230 particle size analyser, which combines different diffraction patterns from a light beam. Soil particles larger than 0.2 cm were sieved and divided into six intervals using an adjustable sieve of our own design (Fig. 1c and 1d): 0.2–0.5 cm, 0.5–2 cm, 2–4 cm, 4–6 cm, 6–8 cm and >8 cm.

The total of organic carbon was measured by weight difference, applying 430 °C (24 h) in a muffle furnace (Davies, 1974; Rosell et al., 2001). Electrical conductivity was measured by a digital conductivitymeter and carbonates with a Bernard calcimeter. pH was obtained in distilled water and KCl with a digital pH-meter with a relation of 1:5. Differences bigger than 1 between values of pH with H_20 and pH with KCl show the soil acidification trend. All these chemical parameters were analysed by their relations with salinity, texture, clay mineralogy, moisture content, ionic strength, temperature and bulk density properties (Gruber and Kosegarten, 2002; Jackson, 2014; Lesch and Corwin, 2003; Taylor et al., 2009).

Water-holding characteristics were calculated with a pressure plate extractor, corresponding to the field capacity (%) and the permanent wilting point (%), respectively.

Also, soil profiles were described to classify the type of pedon, using the methodology of FAO-WRB (IUSS Working Group WRB, 2014) and regional bibliography.

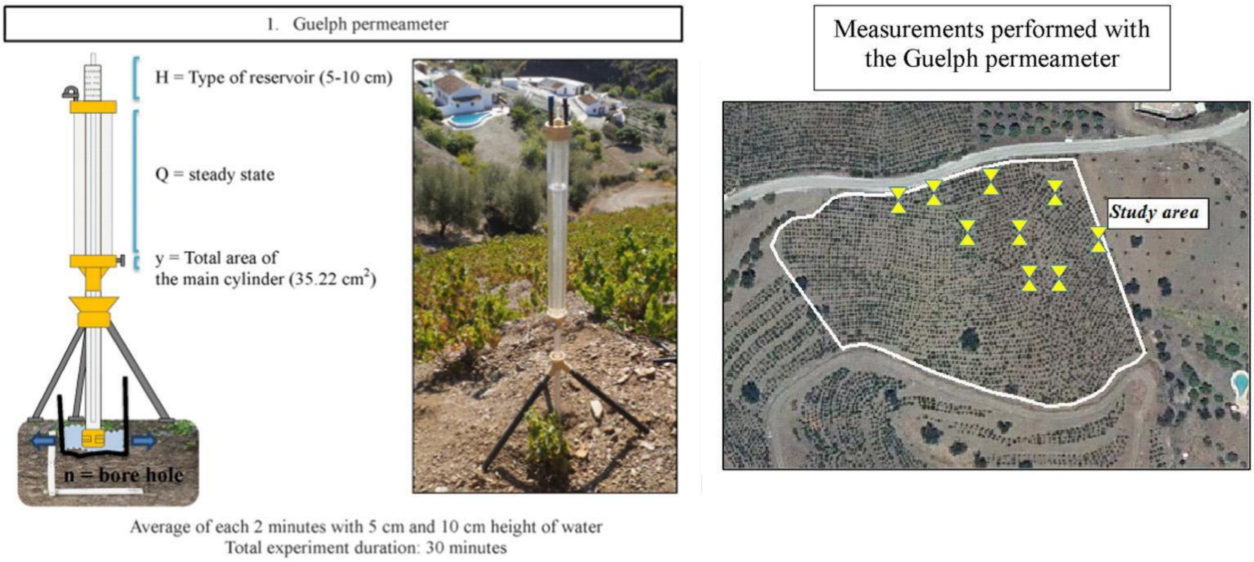
4.2. Field-measurements of permeability, saturated hydraulic conductivity and soil matrix flux potential

Several authors claimed that field measurements of the infiltration, the permeability and the hydraulic conductivity (Kf_s) provide more representative data than the laboratory measures (Kumar et al., 2010; Rienzner and Gandolfi, 2014). This is related to the possible influence of the small cracks and macropores of the soil aggregates (Bodhinayake and Cheng Si, 2004; Buczko et al., 2006). A large number of instruments and methods are available to measure the infiltration, the permeability and Kf_s (Archer et al., 2013; Bagarello et al., 2014; Cerdà, 1997; Gupta et al., 2006, 1993; Gwenzi et al., 2011; Huang et al., 2016, 2014; Jačka et al., 2014; Kodešová et al., 2010; MacDonald et al., 2012; Peter and Ries, 2013; Wu et al., 1992). In this research, a Guelph permeameter (GP) was applied. Through a modified Mariotte bottle device, the GP (Fig. 2.1) sends a constant water level discharge three-dimensionally into a small cylindrical borehole (Elrick et al., 1989; Elrick and Reynolds, 1992; Reynolds and Elrick, 1987; Reynolds and Lewis, 2012).

Each experiment in the field was carried out by following the designed protocol by Rodrigo-Comino et al., (2016b): i) the standard procedure to prepare the permeability well was performed by following the recommendations of the Guelph permeameter manual (Soil moisture Equipment Corp, 2008); ii) two measurements for the same borehole (between 10–25 cm depth and 4–10 cm radius) were carried out, the first was with 5 cm water level in well and the second one with 10 cm; iii) the total duration for each measurement was 30 min or when the principal reservoir reached the total emptying (76 mm); iv) the observations must be recollected every 2 min, measuring the time with a digital stopwatch; v) steady rates (cm min^{-1}) were calculated with the average of the total measurements. Final results with the GP will show the hydrodynamic processes between 10 and 25 cm depth of soil in mm h^{-1}.

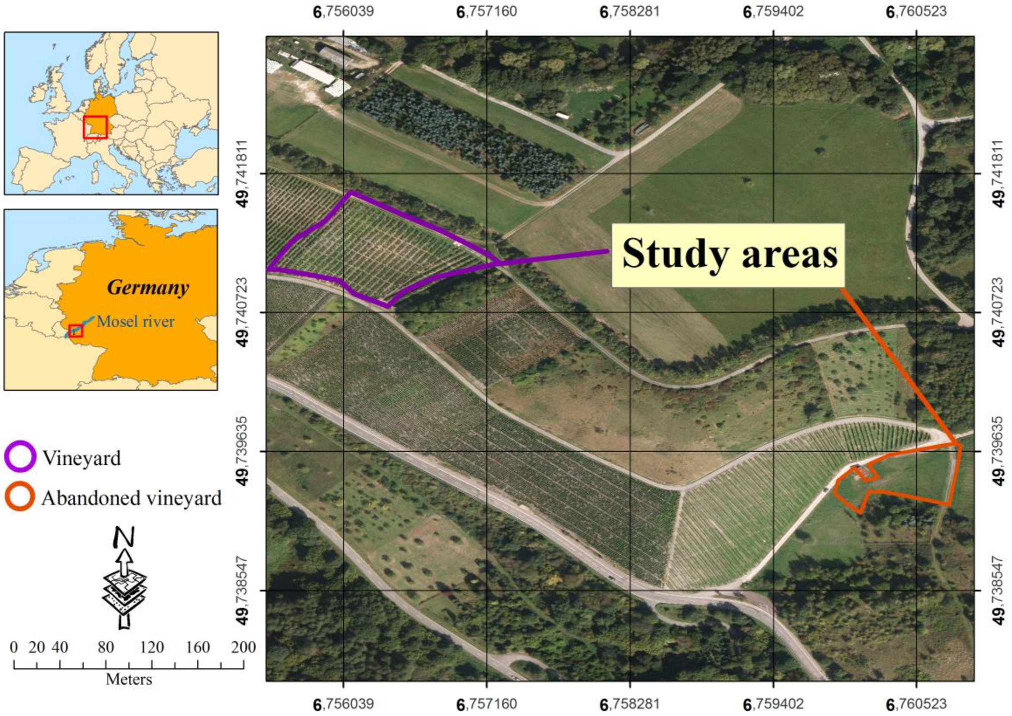
In Málaga, nine experiments (Fig. 2) were realized with three repetitions at different slope positions of the studied area (upper, middle and foot parts) in September.

Figure 2. Guelph permeameter and distribution of experiments in field.



In Germany, the old vineyard plot (>35-years old) was compared with an abandoned plot. Both of them were considered to be paired because they are on the same hillslope with the same topographical characteristics (slope and aspect) and share the same land use: the vineyard. The abandoned plot was planted during 1970 with similar tillage practices to the active one and was abandoned in 1990 because of its low productivity and economic problems. The vineyard and the abandoned plot have similar slope angles and aspect (southwest) ranging from 10 to 25° (Fig. 3). There was a total of 21 measurements in the vineyard and 27 in the abandoned plot, taken at different slope positions (shoulder, backslope, and footslope), before (June, July, and August) and after harvest (November and December). Five measurements in the vineyard and one in the abandoned plot were eliminated due to the fact that the soil became saturated or the entire reservoir was emptied into the borehole in <2 min, showing high permeability rates not representative of reality. This problem was considered to be the main limitation of this method, caused by high stoniness, as on several occasions it was really difficult to get a correct borehole without cracks.

Figure 3. Localisation of the cultivated and abandoned vineyards



Finally, with the obtained results were calculated the permeability rate (1), the Kf_s (2) and the soil matrix flux potential (3) (Reynolds, 1986; Reynolds and Elrick, 2002; Rodrigo Comino et al., 2016b; Zhang et al.,1998):

$$(1)\ \text{Infiltration rate} = \left(\frac{\frac{y*Q1}{1000}}{2\pi(\alpha * H1)}\right) * 60\ [\text{mm h}^{-1}]$$

$$(2)\ Kf_s = \left(\frac{C1*Q1}{2\pi H1^2+\pi a^2 C1+2\pi\left(\frac{H1}{\alpha}\right)}\right) * 600\ [\text{mm h}^{-1}]$$

$$(3)\ \Phi = \left(\frac{C1*Q1}{(2\pi H1^2+\pi a^2 C1)\ \alpha+2\pi(H1)}\right) * 6000\ [\text{mm}^2\ \text{h}^{-1}]$$

y= area of the combined reservoir (35.22 cm^2)
α = macroscopic capillary length parameter
Q1 = quasi-steady flow rate out of the permeameter and into the soil (cm min^{-1})
H1 = the first head of water established in borehole (cm)
C1 = shape factor
a = borehole radius (cm)

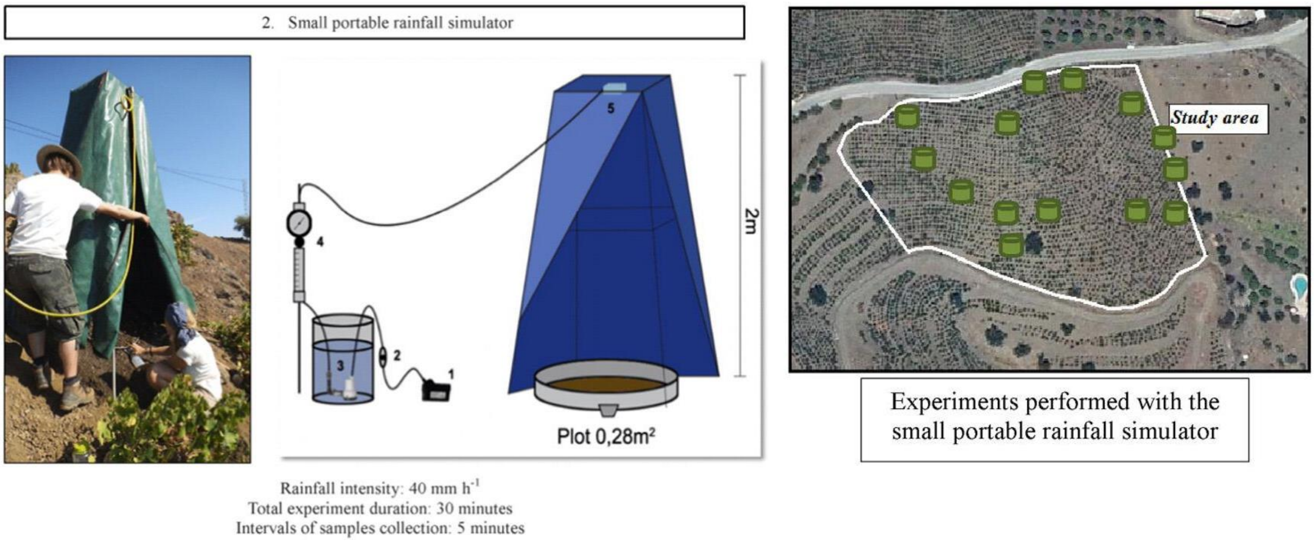
4.3. Rainfall simulations

Soil loss, runoff, sediment concentration and infiltration rates were calculated using a small portable rainfall simulator. Rainfall simulator (Fig. 4) is a nozzle type simulator, based on the one designed by Cerdà (1998a, 1998b, 1999), Lasanta et al. (2000) and calibrated by Ries et al. (2009). Finally, it has been modified and described in detail by Iserloh et al. (2012). The major parts of the rainfall simulator are a square metal frame (0.45 m × 0.45 m) with one nozzle (Lechler 460 608), four telescopic aluminum legs in order to position the nozzle at a height of two meters above the plot. During rainfall experiments, the aluminum linkage is covered by a rubber tarpaulin to avoid wind influences. The test plot is circular, with a diameter of 60 cm and an area of approximately 0.28 m^2. The plot outlet is V-shaped and placed at the deepest point of the plot at surface level. With a flow control and a 12 V low-pressure bilge pump, a controlled and reproducible simulated rainfall can be adjusted. The rainfall simulator was calibrated by Iserloh et al. (2013a, 2013b) for a rainfall intensity of 40 mm h^{-1}.

Test duration per rainfall simulation was 30 min on upper, middle and foot slope. Before the beginning of the experiments, slope (°), vegetation and stone cover (%) and, roughness (%) with the chain method (Saleh, 1993) were measured. During the experiment, runoff with eroded material was collected in plastic bottles. The 30 min of the different experiments were partitioned into six measuring intervals of five minutes duration. At the beginning of a new interval, the bottles were changed. The amount of runoff was measured gravimetrically for each bottle.

The collected water with sediments in each bottle was filtrated separately with circular fine-meshed filter papers (Munktell©, Prod.-Nr. 3.104.185, b2 µm mesh-width). The filters were dried to constant weight at 105°C and weighted thereafter for determining suspended sediment load (SSL). Finally, it is possible to calculate runoff, suspended sediment concentration (SSC) and infiltration rate.

Figure 4. Small portable rainfall simulator and spatial distribution of the experiments



In the Montes de Málaga, fourteen rainfall simulations were performed at three different heights of the study area (Fig. 4): i) upper slope: n = 5; middle slope: n = 4 and; foot slope: n = 5.

In the Ruwer-Mosel valley, in alternate varying months, eight rainfall simulations were carried out under different soil moisture conditions. During the first four simulations in August (2012) the soil moisture was between 20 and 30%, while in October and December (2013) it was between 10 and 20%. From October to November, the same results were obtained: total infiltration. Therefore, the last rainfall simulation experiment was carried out in December (2013); to understand the reason of the 100 % infiltration, the stony A horizon was removed inside the metal ring. The main purposes were to (i) confirm the increased infiltration and (ii) investigate the relationship between the process and the soil surface components. A hydrophilic nylon fabric was used to protect the soil from the splash effect. A vertical soil profile was caved underneath the simulator (50 cm depth and 150 cm width) in order to observe the infiltration dynamic. In this manner, subsurface flow was observable (Fig. 5) by the profile and the metal collector; however, it was impossible to quantify it.

Figure 5. The rainfall simulation in December.

(a) A horizon eliminated (between 5 and 7 cm); (b) before simulation; (c) profile to 0.5 m below (1.5 m × 0.5 m) with the sediment collector; (d) situation of simulator ring; (e) concurrent rainfall simulation, (f) subsurface flow during the experiment.

4.4. Runoff experiment in two agri-spillways

Two north facing agri-spillways (Rill 1 and Rill 2) in the Montes de Málaga were chosen to test the ability of the agri- spillways to reduce soil erosion and canalize water discharges. These handmade rills collect and interrupt the surface flow and canalize the water outflow directly to another main rill or river. Rill 1 is nearly 15 m long with an average inclination of 25.8° and a contribution area of approximately 128 m^2. Rill 2 has a length of 10.2 m with an average inclination of 35° and drains a contributing catchment area of approximately 118 m^2.

Table 1. Agri-spillways characteristics and runoff experiment parameters per run.

	Agri-spillway 1	Agri-spillway 2
Length (m)	15	10.2
Slope (°)	25.8	35.04
Contribution area (m^2)	128	118
Run	*A*	*B*
Inflow intensity (l s^{-1})	1.08	0.7
Duration (s)	925	1434
Tracer 1 start (min)	03:30	03:30
Tracer 2 start (min)	07:00	07:00
Position mesh point 1 (m)	3.6	3.6
Position mesh point 2 (m)	8.54	8.54
Position mesh point 3 (m)	12.6	12.6

The standardized approach of the method used in this study was tested with successful results in different Mediterranean study areas (Wirtz et al. 2010, 2012, 2013). In this case, an adapted runoff experiment was carried out due to the high slopes. Two repetitions for each agri-spillway (about 15 minutes between them) were conducted under dry (1A and 2A) and wet conditions (1B and 2B). Intensity, longitudinal placement of mesh points along the rill and duration of the overland flow on the tested features are also presented in Table 1.

To briefly summarize the experimental procedures, a plastic container with 1000 l with water (Figure 6a) and a motor driven pump with a constant discharge between 0.7 l s^{-1} and 1.33 l s^{-1} (maintained from 12 to 15 minutes) was placed on the shoulder. Three measuring points were established in each rill (MP, Figure 6b) and a small flume with a pressure transducer (Ecotech DL/n, V2.35) was installed at the end of each agri-spillway. The flow velocity was measured at three times: i) initial velocity of the waterfront (Figure 6c); ii) at 3:30 minutes using a red tracer colour; and, iii) at 6:30 (Agri-spillway 1) and 7 minutes (Agri-spillway 2) using a blue tracer colour (Figure 6d). All measurements were noted for each meter using a chronograph.

Morphological characteristics were measured for two dimensions: longitudinal and transverse. The longitudinal slope gradient was measured using a spring bow with one-meter range and a digital air lever (paying attention to possible knick- points). Transverse rill cross sections were measured at each measuring point with a laser in 0.02 m steps before and after the first run and after the second run.

The runoff height was continuously monitored in the small flume at the end of the agri-spillways by the pressure transducers. Runoff at the outflows was measured volumetrically at regular intervals for runoff curve calibration (Figure 6e). Suspended sediment transport was measured at each mesh point four different times: the first as soon as the waterfront reached the sampling point; the second (3:30 min) and third (between 6:30 and 7 min) during the experiment; and the fourth at the end of the experimental run. After that, the sediment concentration was determined by filtration of the samples in the laboratory. These samples provided information about the sediment concentration in the portion of the flow that could be collected in bottles with a volume of approximately 0.3 l, but large stones or organic materials such as leaves or vine-branches bigger than the opening of the bottle were excluded in the final measurements.

Figure 6. Runoff experiment methodology

4.5. Geometrical rills monitoring

Three rills with different geomorphological origins were chosen for the monitoring (R1, R2 and R3) in the Ruwer Mosel valley (Fig. 7).

Figure 7. Rill monitoring.

(a) Weekly geometrical rill monitoring: width and depth; (B) vintage: vine growers use rills to ascend or descend the vineyards generating rills; (d) rills along the inter-row areas.

The rills were divided into 1 m sections. Between September and December, the width, depth and slope angle of the sections along rills were measured. The first rill (R1) was caused by the wheel tracks and it was nearly 30 m long (30 sections), starting from the bottom of the embankment. The average inclination of the rill was 28° and had approximately a contributing catchment area of 600 m^2. The second (R2) and third (R3) rills were located on the embankments with steeper slopes (34 and 31.7°) and had smaller contributing catchment areas (19 and 25 m^2*)*.

R2 (near a wall and drainage channel) was 7 m length (7 sections), and R3 was around 10 m (10 sections). Both were caused by the footsteps of vine workers. The methods of Govers and Poesen (1988), Vandekerckhove et al. (2003) and Wirtz et al. (2012) were followed to measure their changes in geometry.

In order to calculate weekly the geometrical variation of transects, the geometrical channel cross-section index (CSI) was calculated (Dingman, 2008; Quiquerez et al. 2008):

(4) CSI $= W/Y$

where W represents the width and Y the depth (both in centimetres). Note that while the quotient is more elevated, the widening process of rills is faster than the deepening process. Furthermore, the standard deviation was added to distinguish when averages were obtained with equal or unequal values. Consequently, two types of analyses with the geometrical channel cross-section index (Dingman, 2008; Quiquerez et al., 2008) were elaborated. The inclination was measured with a clinometer in grates. First, the total average values per section were used to detect the most vulnerable transects, which were mostly modified by geomorphological changes both temporally and spatially. The second calculation aimed to show the geometrical variation of each rill between the monitoring phases with the standard deviation (before, during and after vintage).

4.6. Application of the revised universal soil loss equation (RUSLE) and curve method number (CMN)

The revised universal soil loss equation (RUSLE; Dabney et al. 2012, 2014) were calculated for the area surrounding to the agri-spillways and for the German plots to compare the experiments and measures with empirical models. For the Spanish vineyards, average values were obtained from the soil properties and ICONA (1982) (see Table 2).

Table 2. RUSLE parameters calculations for Almáchar vineyard plot

Factor		Result
R	Rainfall-runoff erosivity factor	76.25
K	Soil erodibility factor	0.89
LS	Slope length factor/ slope steepness factor	24.31
C	Cover-management factor	0.3
P	Support practice factor	0.15

K factor was obtained from our recorded soil analysis and the calculated data from the adjusted index for Rhineland-Palatinate region (Casper et al., 2013) with better results than the general values calculated for Germany (Sauerborn, 1994) (see Table 3).

Table 3. RUSLE parameter calculations.

	Factors	Results
R	Rainfall-runoff erosivity factor	54.31
K	Soil erodibility factor	0.22
LS	Slope length factor/ slope steepness factor	21.27
C	Cover-management factor	0.3
P	Support practice factor	0.15

The runoff curve number method (CNM) adapted to the Mediterranean basin (Senciales 1999) were calculated to add information about soil erodibility and to estimate what rainfall intensity (mm h^{-1}) would be required to generate the simulated runoff used in our runoff experiments Eq. (5).

$$(5) Q = \frac{CxIxA}{0.36}$$

Where *Q* is the total flow discharge in m^3 h^{-1} (3.2 m^3 h^{-1} for agri-spillway 1 and 4.7 m^3 h^{-1} for 2), *C* is the runoff coefficient (%), *I* is the rainfall intensity (mm h^{-1}), *A* corresponds to the total area (km^2) and 0.36 is an empirical constant. For the RUSLE calculations, the *K* factor was obtained using our soil analysis and the *R* factor was 76.25 MJ ha mm h^{-1} after adjusting the values with an adapted index for southern Spanish regions (ICONA, 1988). The other components of RUSLE were calculated from Rodrigo Comino et al. (2016c).

4.7. Application of the stock unearthing method (SUM)

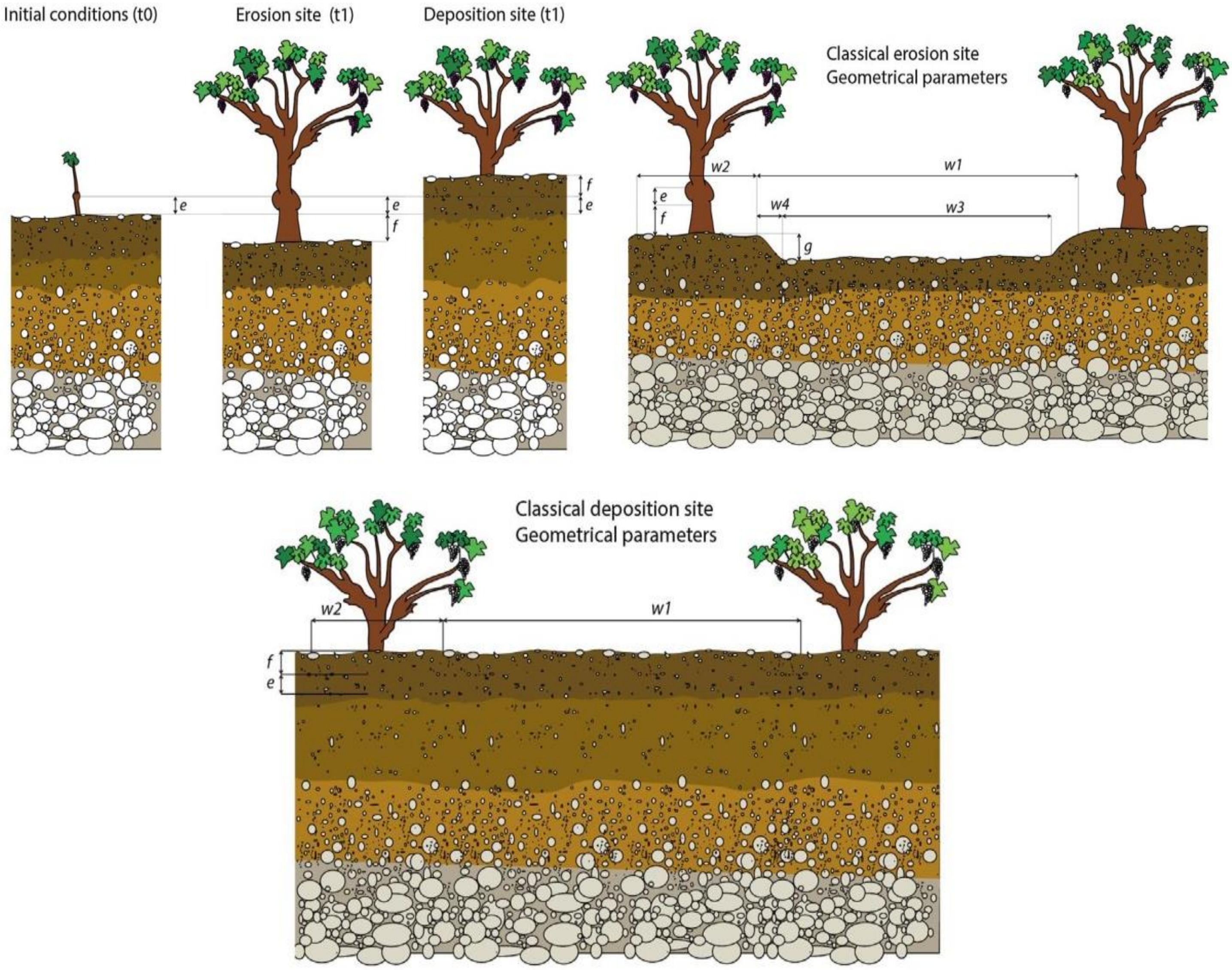
4.7.1. Procedure in field

After the *Phylloxera* crisis in the early 20th century, *Vitis vinifera* was grafted with the American scion of controlled species such as *Vitis rupestris*, *Vitis riparia* and *Vitis berlandieri*. The distance between frontal marks on the graft union and the soil surface at the day of the plantation is considered to be equal from one vine to the other (Fig. 8, t_0). The distance between frontal marks on the graft union (visible on grape vines) and the soil surface was measured for the two field units during the measurement period to allow us to determine the amount of erosion or deposition (Fig. 8, t_1). The graft union distance (unearthing distance) can have either an unearthing or buried signal, which reflects the evolution of the soil surface topography since initial plantation (Brenot et al., 2008), following the indications of the vine-growers. The main hypothesis is based on a stable distance at initial conditions that can vary with time, depending on the local sediment budget due to erosion or deposition dynamics (t_1). The main limit of this method is that it is established on the assumption that the topsoil surface remains almost planar (Fig. 8, w_1 and w_2), without a generation of uncertainty due to soil surface roughness (Fig. 8, w_3 and w_4) generated by rills, footpaths, and wheel tracks (Paroissien et al., 2010; Rodrigo Comino et al., 2015a, 2015b). However, this method allows information to be obtained from a large surface area and investigation of the spatial variability of soil erosion. The conditions described in Brenot et al. (2008) were confirmed with the vine growers during the field work as follows: there is a very low vertical growth of the graft after the vineyard planting; ii) the recommendations concerning the graft union elevation at the vineyard at the date of planting were followed so that this elevation is considered to be constant at the plot scale; and, iii) the measurement errors are negligible compared to the observed unearthing or burying of vine rootstock.

In total, 1200 graft unions were measured for every vine stock (720 measurements in the 35-years vineyard and 480 in the 3-years one) from the end part of the graft union to the actual topsoil level in the downslope direction. When high roughness generated little steps or the grass cover limited the visibility of the measurements, both elements were carefully eliminated to level the soil with the nearby current topsoil level. Graft unions were planted approximately 2 cm above the original topsoil level to avoid soil moisture, freezing, and fungi. Therefore, a subtraction of 2 cm was applied to all the measurements. For the calculations, the age of the old vines was homogenized as 35, 36 and 37 years, respectively for 2013, 2014 and 2015.

Contour maps based on this high density of unearthing measurements for each stock were created using an inverse distance weighted interpolation method to determine the evolution of the topsoil surface from 2013 to 2015. This method, which keeps measured values at sample sites, was preferred to other interpolation methods because a smaller root mean square error can be achieved (Dirks et al., 1998; Goovaerts, 1999; Wang et al., 2013). The obtained maps were used to quantify the topsoil height evolution and to access the spatial structure of erosion processes.

Figure 8. The use of frontal marks on the graft union and the visible actual rootstock of grape vines to determine erosion or deposition.



4.7.2. Soil loss quantification

The total soil loss (Mg ha^{-1} yr^{-1}) was calculated as the volume difference between the present soil surface topography (Fig. 8, t_1) and initial soil surface topography (Fig. 8, t_0) estimated from SUM measurements. The sides of the polygon were defined as the distance between each vine stock (0.9 m 1 m), while the height corresponded to the distance between the botanic marks on the graft union and the visible actual rootstock. Total soil loss was estimated from the erosion–deposition (ER, Mg ha yr^{1}) equation proposed by Paroissien et al. (2010):

(6) Er = (Vol × Ds)/(St × Av)

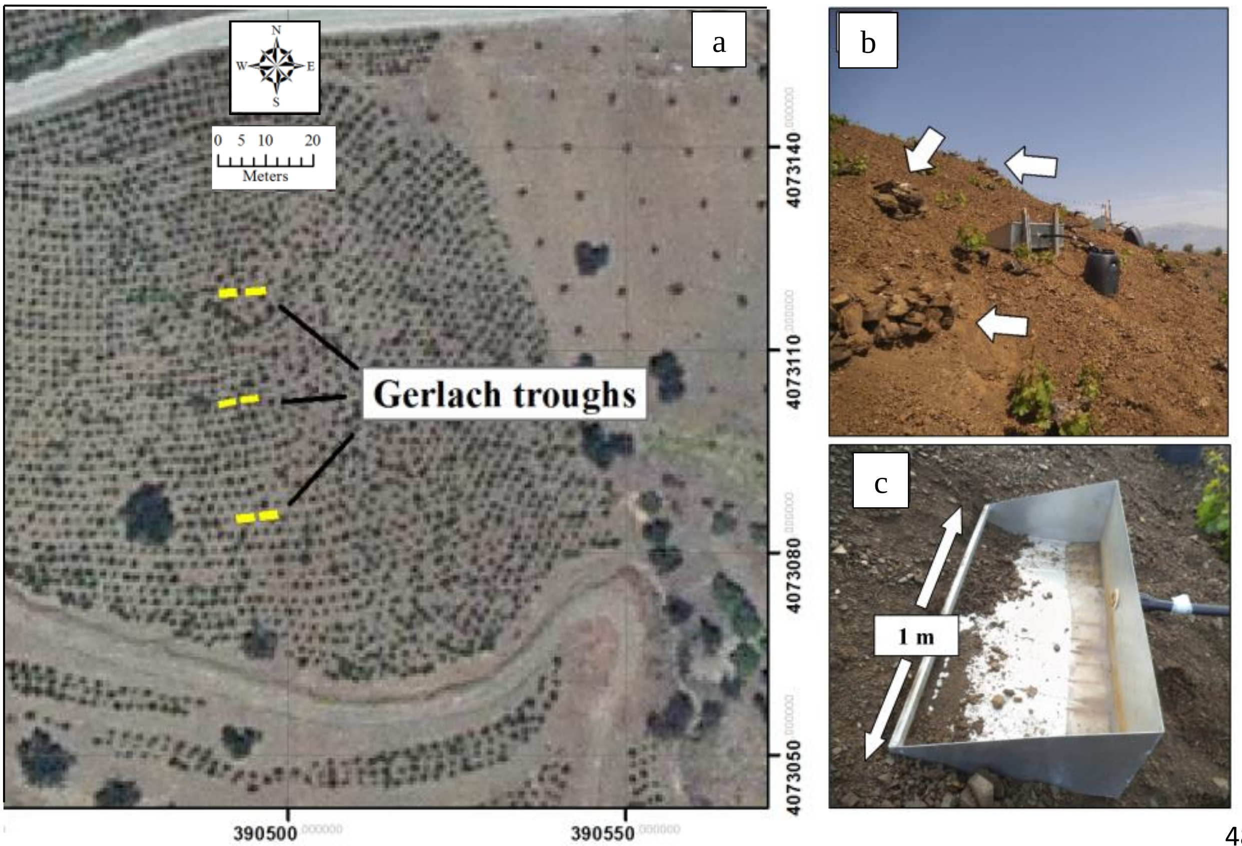
Where volume (vol, m^{3}), the total area field (St, ha), the age of the vines (Av, yr) and the bulk density (Ds, Mg m ^{3}) were applied. Reference values for bulk density were mean soil bulk density measured on the 36 soil samples collected in 2014 (Rodrigo Comino et al., 2015a,b). For the 3-years old vineyards, 1.14 Mg m ^{3} was used for bulk density. For the 35-years old vineyards, the bulk density was 1.4 Mg m ^{3}. Both values are the average of the soil samples collected from two different depths (0–5 and 5–15 cm) using steel cylinder.

4.8. Soil erosion quantification, patterns, and runoff thresholds

4.8.1. Gerlach troughs in Almáchar (Montes de Málaga, Spain)

In the Montes de Málaga, six Gerlach troughs (Gerlach, 1967) were used in this research. Each sediment collector had a width of 100 cm and was situated in the inter-rows of the vineyards. Two-paired troughs were situated on the shoulder, backslope, and footslope (Figure 9). The monitoring period duration was from 11.2014 to 03.2016. They were provided with a slanted front edge to prevent scouring or undercutting of the trough. Troughs were connected to collecting tanks (60 L) to be prepared for extreme rainfall events, which can exceed the total storage capacity of each sediment collector (50 L up to the spillway). A Hellmann-rain gauge was placed close to the experimental plot to measure rainfall amounts after each event. Each sediment collection was taken after each rainfall event.

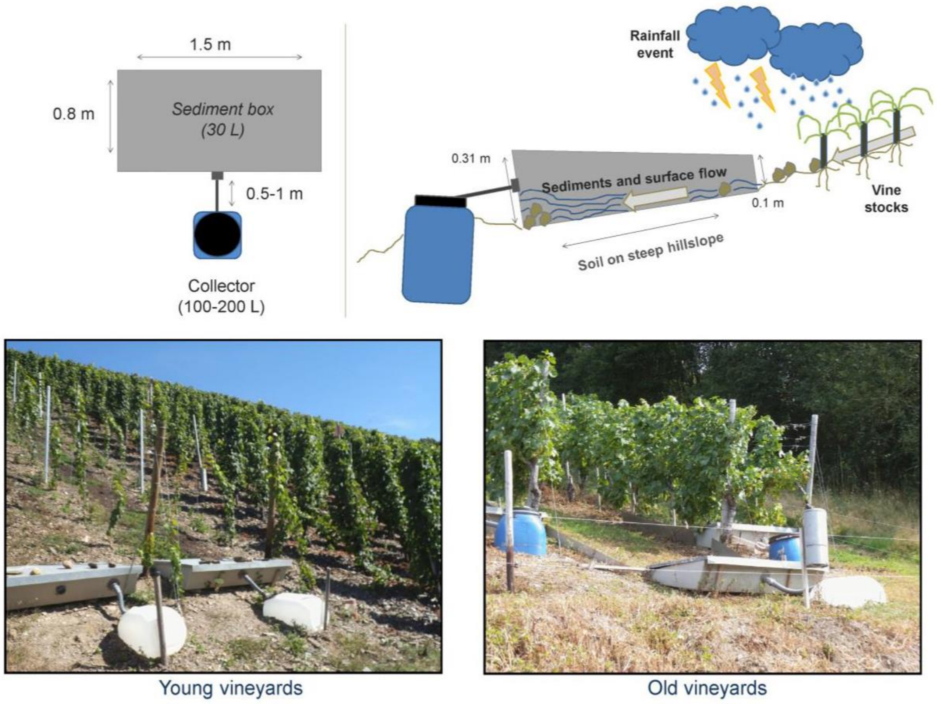
Figure 9. Gerlach troughs´ positions



4.8.2. Gerlach troughs in Waldrach (Ruwer-Mosel valley, Germany)

Over a period of three years (2013–2015), four Gerlach troughs were located at the bottom of the young and old vineyards in the Ruwer-Mosel valley, respectively. Following the same format, four sediment collectors, but with a width of 150 cm, were placed in the inter-rows and part of the rows (Fig. 10). They were equipped with a slanted front edge to prevent scouring or undercutting of the trough. Additionally, all of them were connected to collecting tanks (200 L) to be prepared for extreme rainfall events, which can exceed the total storage capacity of the collector (30 L up to the spillway). Two Hellmann rain gauges were placed close to the Gerlach troughs in both vineyards to measure rainfall amounts from each natural event. The maintenance of the equipment and sampling were performed every one to three weeks. All single events were summed up as annual (2013, 2014 and 2015) and seasonal intervals (December–February, March–May, June–August and September–November).

Figure 10. Gerlach troughs in old and young vineyards.



4.8.3. Laboratory procedures

All samples were taken to the laboratory for drying, weighing and quantifying soil loss (g), overland flow (L) and sediment concentration (g L^{-1}). Particle size distribution of fine materials and rock fragments were calculated for all rainfall events and each Gerlach trough by applying the same method described above. Amounts of soil loss, surface flow, and sediment concentration were calculated in g, L and g L^{-1}, respectively. The open soil erosion plots gave information about the soil

(g) and water losses (L) but the contributing area is uncertain. This is why the soil erosion rates or overland flow are shown in g m^{-1} and L m^{-1}, respectively.

The main limit of this tool is that the open soil erosion plots give information about soil and water losses but the contributing area is uncertain. This is why the soil erosion rates are shown in g m^{-1} and L m^{-1}. Maintenance of the equipment, emptying sediments, and overland flow, was performed after each rainfall event.

4.8.4. Runoff thresholds

In the Montes de Málaga, the runoff thresholds were calculated linear estimations using data from every recorded overland flow and rainfall event by slope position were adjusted to get the correspondent values for overland flows of about 0.1 L m^{-1}, 1 L m^{-1}, and 10 L m^{-1}. For each Gerlach trough, an R^2 higher than 0.985 was found. Finally, to characterize the type of overland flow, a scatter plot was developed using the recorded soil samples. We avoided outliers such as the 200.1 mm event to obtain a trend without uncommon rainfall events. Moreover, results were verified with field observations when some of the recorded rainfall events were occurring.

4.8.5. Soil erosion rates variability

In the Ruwer-Mosel valley, to assess soil erosion variability, an index for the replicated erosion plots proposed by Nearing et al. (1999) was applied (Eq. 7):

(7) $R_{diff} = M2 - M1$

where M1 and M2 are paired values of every soil loss and overland flow quantifications from two replicate plots. These values can oscillate between 0 and 1 when M2 is equal to M1, no relative differences exist among the paired values.

4.8.6. Stoniness and soil texture analysis

For every collected event in the Montes de Málaga vineyards, particle size distribution of the fine material (between 0.002 mm and 2 mm) was also calculated using a Coulter LS230 particle size analyser, which combines different diffraction patterns from a light beam. Soil particles larger than 0.2 cm were sieved and divided into six intervals using an adjustable sieve of our own design: 0.2–0.5 cm, 0.5–2 cm, 2–4 cm, 4–6 cm, 6–8 cm and >8 cm.

4.9. Climatic extrapolations and land use monitoring

In Málaga, total rainfall after each event was measured with a Hellmann-rain gauge. These data were compared and completed with the extrapolated data from the nearby climatic stations of

IFAPA (Instituto de Investigación y Formación Agraria y Pesquera), Red Hidrosur and REDIAM (Red de Información Ambiental de Andalucía). Due to the lack of a complete climatic data record in the study area, values of rainfall (all with N30 years of data) were extrapolated from latitude, longitude, and altitude above sea level: Colmenar-Torrijos (718 m; 36.828N, −4.357W), Contadoras (758 m; 36.811N, −4.382W), Olías (421 m; 36.776N, −4.323W), Rincón de la Victoria (7 m; 36.722N, −4.279W), Moclinejo (433 m; 36.772N; 4.251W), Comares (731 m; 36.851N, −4.247W), Benamargosa (96 m; 36.837N, −4.191W), Benamocarra (126 m; 36.792N, −4.159W) and Vélez-Málaga (60 m; 36.78N, −4.099W).

In the Ruwer-Mosel Valley, also rainfall intensity had to be extrapolated. In order to obtain the rainfall data, an extrapolation of the gradients data at surface level was made by using the data from the peripheral agroclimatic stations of the German Meteorological Service (Deutscher Wetterdienst) and the Dienstleistungszentrum Ländlicher Raum/Rheinland-Pfalz. Due to the lack of a complete climatic data set in the study area, values of rainfall and temperature (all with more than 30 years of data) must be extrapolated from the following (latitude, longitude and altitude above sea level): Mertesdorf (211 m; 49.7722, 6.7297), Hermeskeil (480 m; 49.6556, 6.9336), Trier-Zewen (131.5 m; 49.7325, 6.6133), Trier-Petrisberg (265 m; 49.7492, 6.6592), Trier-Irsch (228 m; 49.7259, 6.6957), Deuselbach (480.5 m; 49.7631, 7.0556), Konz (180 m; 49.6883, 6.5731), Bernkastel-Kues (120 m; 49.9186, 7.0664) and Weiskirchen (380 m; 49.5550, 6.8125).

Calculations were carried out by applying linear estimations and intersections with the axis, using rainfall and elevation data with Excel 2010 software (Senciales González and Ruiz Sinoga, 2013).

Furthermore, the different tillage practices applied in the studied vineyards were monitored and described during the study period through interviews with the vine-growers.

4.10. Statistical analyses

Descriptive statistics were conducted in several parts of the research in order to see the mean values, standard deviations, median, and maximum and minimum values. Also, different statistical tests were conducted after checking the normal distribution of the data.

Spearman rank coefficient was used to observe the statistical significance of soil erosion and rainfall events or human interventions and soil properties, which did not show parametric distributions. SPSS v. 23.0 software (IBM, USA). On the contrary, to observe the differences between the soil loss and overland flow results from the paired-Gerlach troughs in different slope positions, a Mann-Whitney Rank Sum Test and an ANOVA-analysis with the SigmaPlot 13 statistical software were conducted.

For the agri-spillways, potential statistical differences at the three sampling times (at the beginning of the experiment, at 3 and 6 minutes) for runoff speed were also calculated using a one-way ANOVA (between runs and tracers), a Mann-Whitney Rank Sum Test (initial waterfront between runs) and a Tukey test (every paired-moment) with SigmaPlot 13 (Systat Software, Inc.). Also, again a one-way ANOVA analysis was applied to measure the differences between the soil profiles before and after each run in both agri-spillways.

REFERENCES

Archer, N.A.L., Bonell, M., Coles, N., MacDonald, A.M., Auton, C.A., Stevenson, R., 2013. Soil characteristics and landcover relationships on soil hydraulic conductivity at a hillslope scale: A view towards local flood management. J. Hydrol. 497, 208–222. https://doi.org/10.1016/j.jhydrol.2013.05.043

Bagarello, V., Castellini, M., Di Prima, S., Iovino, M., 2014. Soil hydraulic properties determined by infiltration experiments and different heights of water pouring. Geoderma 213, 492–501. https://doi.org/10.1016/j.geoderma.2013.08.032

Bodhinayake, W., Cheng Si, B., 2004. Near-saturated surface soil hydraulic properties under different land uses in the St Denis National Wildlife Area, Saskatchewan, Canada. Hydrol. Process. 18, 2835–2850. https://doi.org/10.1002/hyp.1497

Brenot, J., Quiquerez, A., Petit, C., Garcia, J.-P., 2008. Erosion rates and sediment budgets in vineyards at 1-m resolution based on stock unearthing (Burgundy, France). Geomorphology 100, 345–355. https://doi.org/10.1016/j.geomorph.2008.01.005

Buczko, U., Bens, O., Hüttl, R.F., 2006. Tillage effects on hydraulic properties and macroporosity in silty and sandy soils. Soil Sci. Soc. Am. J. 70. https://doi.org/10.2136/sssaj2006.0046

Casper, M., Grigoryan, G., Heinemann, G., and Bierl, R. 2013. Auswirkungen des Klimawandels auf die Ressource Wasser in Rheinland-Pfalz – Rheinland-Pfalz Kompetenz-Zentrum für Klimawandelfolgen, in: Schlussberichte des Landesprojekts Klima und Landschaftswandel in Rheinland-Pfalz (KlimLandRP), 2, Wasser Modul, Trier, Germany.

Cerdà, A., 1998. Effect of climate on surface flow along a climatological gradient in Israel: a field rainfall simulation approach. J. Arid Environ. 38, 145–159. https://doi.org/10.1006/jare.1997.0342

Cerdà, A., 1998. Relationships between climate and soil hydrological and erosional characteristics along climatic gradients in Mediterranean limestone areas. Geomorphology 25, 123–134. https://doi.org/10.1016/S0169-555X(98)00033-6

Cerdà, A., 1997. The effect of patchy distribution of Stipa tenacissim aL. on runoff and erosion. J. Arid Environ. 36, 37–51. https://doi.org/10.1006/jare.1995.0198

Dabney, S.M., Yoder, D.C., Ferruzzi, G.G., 2014. Forage Harvest Representation in RUSLE2. Agron. J. 106, 151–167. https://doi.org/10.2134/agronj2013.0059

Dabney, S.M., Yoder, D.C., Vieira, D. a. N., 2012. The application of the Revised Universal Soil Loss Equation, Version 2, to evaluate the impacts of alternative climate change scenarios on runoff and sediment yield. J. Soil Water Conserv. 67, 343–353. https://doi.org/10.2489/jswc.67.5.343

Davies, B.E., 1974. Loss-on-Ignition as an Estimate of Soil Organic Matter1. Soil Sci. Soc. Am. J. 38. https://doi.org/10.2136/sssaj1974.03615995003800010046x

Dingman, S. L. 2003. Fluvial Hydraulics, Oxford Press University, New York, USA.

Dirks, K.N., Hay, J.E., Stow, C.D., Harris, D., 1998. High-resolution studies of rainfall on Norfolk Island: Part II: Interpolation of rainfall data. J. Hydrol. 208, 187–193. https://doi.org/10.1016/S0022-1694(98)00155-3

Elrick, D. e., Reynolds, W. d., Tan, K. a., 1989. Hydraulic conductivity measurements in the unsaturated zone using improved well analyses. Ground Water Monit. Remediat. 9, 184–193. https://doi.org/10.1111/j.1745-6592.1989.tb01162.x

Elrick, D.E., Reynolds, W.D., 1992. Methods for analyzing constant-head well Permeameter data. Soil Sci. Soc. Am. J. 56, 320–323. https://doi.org/10.2136/sssaj1992.03615995005600010052x

Gerlach, T., 1967. Hillslope troughs for measuring sediment movement. Rev. Geomorphol. Dyn. 17, 173.

Goovaerts, P., 1999. Geostatistics in soil science: state-of-the-art and perspectives. Geoderma 89, 1–45. https://doi.org/10.1016/S0016-7061(98)00078-0

Govers, G., Poesen, J., 1988. Assessment of the interrill and rill contributions to total soil loss from an upland field plot. Geomorphology 1, 343–354. https://doi.org/10.1016/0169-555X(88)90006-2

Gruber, B., Kosegarten, H., 2002. Depressed growth of non-chlorotic vine grown in calcareous soil is an iron deficiency symptom prior to leaf chlorosis. J. Plant Nutr. Soil Sci. 165, 111–117. https://doi.org/10.1002/1522-2624(200202)165:1<111::AID-JPLN111>3.0.CO;2-B

Gupta, R.K., Rudra, R.P., Dickinson, W.T., Patni, N.K., Wall, G.J., 1993. Comparison of saturated hydraulic conductivity measured by various field methods. Trans. ASAE 36, 51–55. https://doi.org/10.13031/2013.28313

Gupta, R.K., Rudra, R.P., Parkin, G., 2006. Analysis of spatial variability of hydraulic conductivity at field scale. Can Biosyst Eng 48, 1.55-1.62.

Gwenzi, W., Hinz, C., Holmes, K., Phillips, I.R., Mullins, I.J., 2011. Field-scale spatial variability of saturated hydraulic conductivity on a recently constructed artificial ecosystem. Geoderma 166, 43–56. https://doi.org/10.1016/j.geoderma.2011.06.010

Huang, M., Rodger, H., Barbour, S.L., 2014. An evaluation of air permeability measurements to characterize the saturated hydraulic conductivity of soil reclamation covers. Can. J. Soil Sci. 95, 15–26. https://doi.org/10.4141/cjss-2014-072

Huang, M., Zettl, J.D., Lee Barbour, S., Pratt, D., 2016. Characterizing the spatial variability of the hydraulic conductivity of reclamation soils using air permeability. Geoderma 262, 285–293. https://doi.org/10.1016/j.geoderma.2015.08.014

Iserloh, T., Ries, J.B., Arnáez, J., Boix-Fayos, C., Butzen, V., Cerdà, A., Echeverría, M.T., Fernández-Gálvez, J., Fister, W., Geißler, C., Gómez, J.A., Gómez-Macpherson, H., Kuhn, N.J., Lázaro, R., León, F.J., Martínez-Mena, M., Martínez-Murillo, J.F., Marzen, M., Mingorance, M.D., Ortigosa, L., Peters, P., Regüés, D., Ruiz-Sinoga, J.D., Scholten, T., Seeger, M., Solé-Benet, A., Wengel, R., Wirtz, S., 2013a. European small portable rainfall simulators: A comparison of rainfall characteristics. Catena 110, 100–112. https://doi.org/10.1016/j.catena.2013.05.013

Iserloh, T., Ries, J.B., Cerdà, A. and Echeverría, M.T., Fister, W., Gei\s sler, C., Kuhn, N.J., León, F.J., Peters, P., Schindewolf, M., Schmidt, J., Scholten, T., Seeger, M., 2013b. Comparative measurements with seven rainfall simulators on uniform bare fallow land. Z. Für Geomorphol. Suppl. 57, 11–26.

ICONA, 1988. Agresividad en la lluvia en España. Pub. ICONA, Mo. Agricultura, Pesca y Alimentación, Madrid.

IUSS Working Group WRB, 2014. World Reference Base for Soil Resources 2014, World Soil Resources Report. FAO, Rome.

Jačka, L., Pavlásek, J., Kuráž, V., Pech, P., 2014. A comparison of three measuring methods for estimating the saturated hydraulic conductivity in the shallow subsurface layer of mountain podzols. Geoderma 219–220, 82–88. https://doi.org/10.1016/j.geoderma.2013.12.027

Jackson, R.S., 2014. Wine science. Principles and Applications., Fourth Edition. ed. Elsevier, London.

Kodešová, R., Šimůnek, J., Nikodem, A., Jirků, V., 2010. Estimation of the Dual-Permeability Model Parameters using Tension Disk Infiltrometer and Guelph Permeameter All rights reserved. No part of this periodical may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher. Vadose Zone J. 9. https://doi.org/10.2136/vzj2009.0069

Lasanta, T., García-Ruiz, J.M., Pérez-Rontomé, C., Sancho-Marcén, C., 2000. Runoff and sediment yield in a semi-arid environment: the effect of land management after farmland abandonment. Catena 38, 265–278. https://doi.org/10.1016/S0341-8162(99)00079-X

Lesch, S.M., Corwin, D.L., 2003. Using the dual-pathway parallel conductance model to determine how different soil properties influence conductivity survey data. Agron. J. 95, 365–379. https://doi.org/10.2134/agronj2003.3650

MacDonald, A.M., Maurice, L., Dobbs, M.R., Reeves, H.J., Auton, C.A., 2012. Relating in situ hydraulic conductivity, particle size and relative density of superficial deposits in a heterogeneous catchment. J. Hydrol. 434–435, 130–141. https://doi.org/10.1016/j.jhydrol.2012.01.018

Nearing, M.A., Govers, G., Norton, L.D., 1999. Variability in soil erosion data from replicated plots. Soil Sci. Soc. Am. J. 63, 1829–1835.

Paroissien, J.-B., Lagacherie, P., Le Bissonnais, Y., 2010. A regional-scale study of multi-decennial erosion of vineyard fields using vine-stock unearthing–burying measurements. Catena 82, 159–168. https://doi.org/10.1016/j.catena.2010.06.002

Peter, K.D., Ries, J.B., 2013. Infiltration rates affected by land levelling measures in the Souss valley, South Morocco. Z. Für Geomorphol. 57, 59–72. https://doi.org/10.1127/0372-8854/2012/S-00124

Quiquerez, A., Brenot, J., Garcia, J.-P., Petit, C., 2008. Soil degradation caused by a high-intensity rainfall event: Implications for medium-term soil sustainability in Burgundian vineyards. Catena 73, 89–97. https://doi.org/10.1016/j.catena.2007.09.007

Reynolds, W.D., Elrick, D.E., 2002. Constant head well permeameter (vadose zone), in: Dane, J.H., Topp, G.C. (Eds.), Methods of Soil Analysis. Soil Science Society of America, Inc., Madison, WI (USA), pp. 844–858.

Reynolds, W.D., Elrick, D.E., 1987. A laboratory and numerical assessment of the Guelph permeameter method. Soil Sci. 144, 282–299.

Reynolds, W.D., Lewis, J.K., 2012. A drive point application of the Guelph Permeameter method for coarse-textured soils. Geoderma 187–188, 59–66. https://doi.org/10.1016/j.geoderma.2012.04.004

Rienzner, M., Gandolfi, C., 2014. Investigation of spatial and temporal variability of saturated soil hydraulic conductivity at the field-scale. Soil Tillage Res. 135, 28–40. https://doi.org/http://dx.doi.org/10.1016/j.still.2013.08.012

Rodrigo Comino, J., Brings, C., Lassu, T., Iserloh, T., Senciales, J., Martínez Murillo, J., Ruiz Sinoga, J., Seeger, M., Ries, J., 2015a. Rainfall and human activity impacts on soil losses and rill erosion in vineyards (Ruwer Valley, Germany). Solid Earth 6, 823–837. https://doi.org/10.5194/se-6-823-2015

Rodrigo Comino, J., Lassu, T., González, J.M.S., Sinoga, J.D.R., Seeger, K.M., Ries, J.B., 2015b. Estudio de procesos geomorfodinámicos en campos cultivados de viñedos sobre laderas en pendientes en el valle del Ruwer (Alemania). Cuad. Geográficos 54, 6–26.

Rodrigo Comino, J., Ruiz Sinoga, J.D., Senciales González, J.M., Guerra-Merchán, A., Seeger, M., Ries, J.B., 2016a. High variability of soil erosion and hydrological processes in Mediterranean hillslope vineyards (Montes de Málaga, Spain). Catena 145, 274–284. https://doi.org/10.1016/j.catena.2016.06.012

Rodrigo Comino, J., Seeger, M., Senciales, J.M., Ruiz-Sinoga, J.D., Ries, J.B., 2016b. Variación espacio-temporal de los procesos hidrológicos del suelo en viñedos con elevadas pendientes (Valle del Ruwer-Mosela, Alemania). Cuad. Investig. Geográfica 42, 281–306. https://doi.org/10.18172/cig.2934

Rosell, R.A., Gasparoni, J.C., Galantini, J.A., 2001. Soil organic matter evaluation, in: Lal, R., Kimble, J., Follet, R., Stewart, B. (Eds.), Assessment Methods for Soil Carbon. Lewis Publishers, USA, pp. 311–322.

Saleh, A., 1993. Soil roughness measurement: Chain method. J. Soil Water Conserv. 48, 527–529.

Sauerborn, P. 1994. Erosivität der Niederschläge in Deutschland, Ein Beitrag zur quantitativen Prognose der Bodenerosion durch Wasser in Mitteleuropa, edited by: Bonner Bodenkundliche Abhandlungen Band, 13, Bonn, Germany.

Senciales González, J.M., 1999. Redes fluviales. Metodología de análisis, Estudios y ensayos. Málaga.

Senciales González, J.M., Ruiz Sinoga, J.D., 2013. Análisis espacio-temporal de las lluvias torrenciales en la ciudad de Málaga. Bol. Asoc. Geógrafos Esp. 7–24.

Soil moisture Equipment Corp, 2008. Model 2800K1 Guelph Permeameter Operating Instructions, Soilmoisture Equipment Corp. ed. Santa Barbara, CA.

Taylor, J.A., Coulouma, G., Lagacherie, P., Tisseyre, B., 2009. Mapping soil units within a vineyard using statistics associated with high-resolution apparent soil electrical conductivity data and factorial discriminant analysis. Geoderma 153, 278–284. https://doi.org/10.1016/j.geoderma.2009.08.014

Vandekerckhove, L., Poesen, J., Govers, G., 2003. Medium-term gully headcut retreat rates in Southeast Spain determined from aerial photographs and ground measurements. Catena 50, 329–352. https://doi.org/10.1016/S0341-8162(02)00132-7

Wang, K., Zhang, C., Li, W., 2013. Predictive mapping of soil total nitrogen at a regional scale: A comparison between geographically weighted regression and cokriging. Appl. Geogr. 42, 73–85. https://doi.org/10.1016/j.apgeog.2013.04.002

Wirtz, S., Seeger, M., Ries, J.B., 2012. Field experiments for understanding and quantification of rill erosion processes. Catena 91, 21–34. https://doi.org/http://dx.doi.org/10.1016/j.catena.2010.12.002

Wirtz, S., Seeger, M., Ries, J.B., 2010. The rill experiment as a method to approach a quantification of rill erosion process activity. Z. Für Geomorphol. NF 54, 47–64.

Wirtz, S., Seeger, M., Zell, A., Wagner, C., Wagner, J.-F., Ries, J.B., 2013. Applicability of different hydraulic parameters to describe soil detachment in eroding rills. PLoS ONE 8, 1–11. https://doi.org/10.1371/journal.pone.0064861

Wu, L., Swan, J.B., Paulson, W.H., Randall, G.W., 1992. Tillage effects on measured soil hydraulic properties. Soil Tillage Res. 25, 17–33. https://doi.org/10.1016/0167-1987(92)90059-K

Zhang, Z.F., Groenevelt, P.H., Parkin, G.W., 1998. The well-shape factor for the measurement of soil hydraulic properties using the Guelph Permeameter. Soil Tillage Res. 49, 219–221. https://doi.org/10.1016/S0167-1987(98)00174-3

CHAPTER 5. HIGH VARIABILITY OF SOIL EROSION AND HYDROLOGICAL PROCESSES IN MEDITERRANEAN HILLSLOPE VINEYARDS (MONTES DE MÁLAGA, SPAIN)

- RODRIGO COMINO, J., Ruiz Sinoga, J.D., Senciales, J.M., Guerra Merchán, A.; Seeger, M., Ries, J.B. 2016. High variability of soil erosion and hydrological processes in Mediterranean hillslope vineyards (Montes de Málaga, Spain). *Catena*, 145, 274-284. DOI: 10.1016/j.catena.2016.06.012.

CHAPTER 6. ASSESSMENT OF AGRI-SPILLWAYS AS A SOIL EROSION PROTECTION MEASURE IN MEDITERRANEAN SLOPING VINEYARDS

- RODRIGO COMINO, J., Wirtz, S., Brevik, E.C., Ruiz Sinoga, J.D., Ries, J.B. 2017. Assessment of agri-spillways as a soil erosion protection measure in Mediterranean sloping vineyards. Journal of Mountain Sciences, 14 (6), 1009-1022. DOI:10.1007/s11629-016-4269-8

CHAPTER 7. UNDERSTANDING SOIL EROSION PROCESSES IN MEDITERRANEAN SLOPING VINEYARDS (MONTES DE MÁLAGA, SPAIN)

- RODRIGO COMINO, J., Senciales J.M., Ramos, M.C., Martínez-Casasnovas, J.A., Lasanta, T., Brevik, E.C.; Ries, J.B.; Ruiz Sinoga, J.D. Understanding soil erosion processes in Mediterranean sloping vineyards (Montes de Málaga, Spain). Geoderma, 296, pp. 47-59. DOI: 10.1016/j.geoderma.2017.02.021

CHAPTER 8. RAINFALL AND HUMAN ACTIVITY IMPACTS ON SOIL LOSSES AND RILL EROSION IN VINEYARDS (RUWER VALLEY, GERMANY)

- RODRIGO COMINO, J., Brings, C., Lassu, T., Iserloh, T., Senciales González, J.M., Seeger, M., Ruiz Sinoga, J.D., Ries, J.B. 2015. Rainfall and human activity impacts on soil losses and rill erosion in vineyards (Ruwer Valley, Germany). Solid Earth 6:823-837. DOI:10.5194/se-6-823-2015.

CHAPTER 9. THE IMPACT OF VINEYARD ABANDONMENT ON SOIL PROPERTIES AND HYDROLOGICAL PROCESSES

- RODRIGO COMINO, J.; Bogunović, I.; Mohajerani, H.; Pereira, P. Cerdà, A., Ruiz Sinoga, J.D. Ries. J.B. The impact of vineyards abandonment on soil water movement in sloping terrain of Ruwer-Mosel valley. Vadose Zone. DOI:10.2136/vzj2017.05-0096

CHAPTER 10. SOIL EROSION IN SLOPING VINEYARDS ASSESSED BY USING BOTANICAL INDICATORS AND SEDIMENT COLLECTORS IN THE RUWER-MOSEL VALLEY

- RODRIGO COMINO, J., Quiquerez, A., Follain, S., Raclot, D., Le Bissonnais, Y., Casalí, J., Giménez, R., Cerdà, A., Keesstra, S.D., Brevik, E.C., Pereira, P., Senciales, J.M., Seeger, M., Ruiz Sinoga, J.D., Ries, J.B., 2016. Soil erosion in sloping vineyards assessed by using botanical indicators and sediment collectors in the Ruwer-Mosel valley. Agric. Ecosyst. Environ. 233, 158–170. doi:10.1016/j.agee.2016.09.009

CHAPTER 11. TEMPORAL CHANGES IN SOIL WATER EROSION ON SLOPING VINEYARDS IN THE RUWER-MOSEL VALLEY. THE IMPACT OF AGE AND PLANTATION WORKS IN YOUNG AND OLD VINES

- RODRIGO COMINO, J.; Brings, C.; Iserloh, T.; Senciales, J.M.; Casper, M.C.; Seeger, M.; Brevik, E.C.; Ruiz Sinoga, J.D.; Ries, J.B. 2017. Temporal changes in soil water erosion on sloping vineyards in the Ruwer-Mosel Valley. Journal of Hydrology and Hydromechanics, 65, 4: 402-409 65. DOI: 10.1515/johh-2017-0022.

CHAPTER 12. OVERALL DISCUSSION

As in non-sloping vineyards (<5%), extreme rainfall events, non-suitable agricultural practices, and bare soils are the main driving factors that condition soil erosion processes. However, steep slopes possibly enhance soil erosion processes from low rates to high extreme values due to the gravitational energy along the downslope direction (Fox et al., 1997; Kinnell, 2009; Nadal-Romero et al., 2014). Future research lines should be focused on the quantification of in which magnitude slope inclination affects soil erosion processes in comparison to non-sloping ones under the same soil management and environmental conditions such as soil properties, climate and vine variety.

Also, it was demonstrated that specific soil properties developed in steep slopes have played a remarkable role in order to enhance or avoid soil erosion processes. For example, the high silt content enhances the natural sieving of fine particles after rainfall events or tillage practices, the reduction of aggregate stability and particle cohesion (Ben Slimane et al., 2015; Ramos et al., 2000; Rodrigo Comino et al., 2016). Another soil characteristic with high impact on soil erosion processes is the rock fragment cover. They were also observed as a factor of soil erosion control by promoting: i) infiltration and permeability; ii) higher subjection and retention of soil loss than areas non-covered by rock fragments; and, iii) conservation of temperature levels and retention of soil humidity. The first two results (infiltration and permeability) were successfully measured in the Montes de Málaga and the Ruwer-Mosel valley, and it was also confirmed by other researchers in Mediterranean vineyards (Rodrigo-Comino et al., 2017), forestry soils, roads or under laboratory conditions (Jomaa et al., 2012; Jordán-López et al., 2009; Nyssen et al., 2001; Poesen et al., 1990; Poesen and Lavee, 1994). However, the other last finding (soil humidity retention and temperature conservation), although detected and confirmed with the vine-growers, were not quantified. Thus, this dynamic should be another research line that should be addressed in the future: the influence of rock fragments in soil moisture and temperature. Possibly, both soil temperature and moisture will show an impact on aggregate stability, soil cohesion, organic matter and microbiological activities (Cerdà, 2001; Certini et al., 2004; van Wesemael et al., 1995).

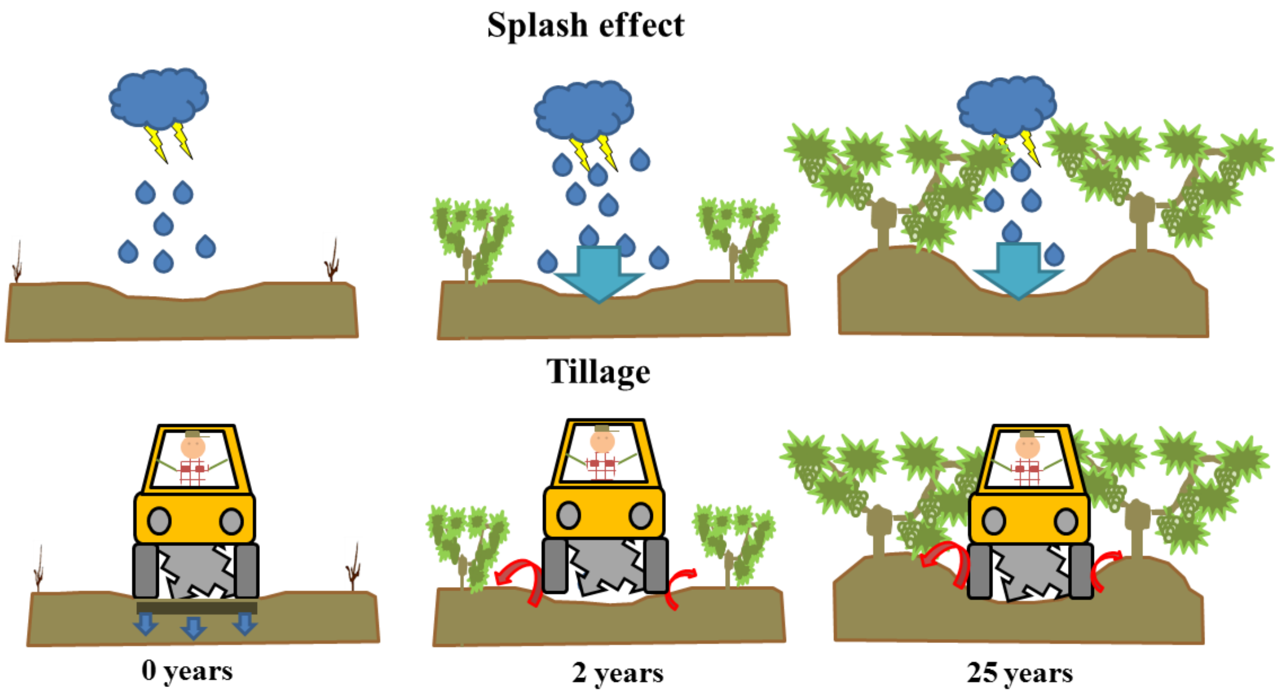
Another big issue detected and considered as a main driving factor in this PhD for sloping vineyards, but not quantified, was the trampling effect. It was demonstrated that the number and length of pathways for runoff varies with the slope, the volume of rock fragments, and the textural class and also with the antecedent conditions of tillage, but also after the vine grower´s activities. We observed that before and after the pruning, herbicide spraying, tillage or vintage, runoff sources, soil losses and their main pathways were disconnected or connected. This effect was not remarked in previous research in non-sloping vineyards (Napoli et al., 2017; Novara et al., 2011; Prosdocimi et al., 2016; Ramos, 2006). However, these findings also coincided for urban places and forest in previous research conducted by Brevik and Tibor (2014) and Quinn et al., (1980). However, the development of a quantification methods remains difficult nowadays and its solution difficult to be achieved. Only, for sloping organic vineyards during the investigation that we conducted (Kirchhoff et al., 2017), a decrease of the impact of the trampling effect on soil erosion was observed due to the grass cover.

These extreme disconnections and connections detected in sloping vineyards are also related to another detected hydrological process, which was possibly a few decades ago detected, but not quantified. In the case of the Ruwer-Mosel valley, after harvesting (from November to March) we observed in the field that soil compaction decreased and the infiltration increased (higher in the young vineyard than in the old ones) (Rodrigo Comino et al., 2016b). Moreover, soil moisture increased enhancing the aggregation of the fine particles, meanwhile, rainfall depth also decreased. Regarding this, overland flow values showed some peaks, but soil losses rates decreased. Therefore, sediment concentration values were also lower than in spring or summer. The first hypothesis is related to the research published by Lasanta, (1985) in La Rioja (Spain), which supported the presumption that the frozen surface enhances the hydric fluxes and, for instance, increasing soil moisture (or water content into the soil profile) when ice is melted and can be mobilized. On the other hand, the second hypothesis is the mechanisms of sub-surface flow detected by Hewlett and Hibbert (1967). Nowadays, subsurface flow is highly studied; however, they are only assessed punctually by using pedotransfer functions (Archer et al., 2013; Bodner et al., 2013; Nasri et al., 2015). Rodrigo-Comino et al., (2015a) and Rodrigo-Comino et al., (2016a) using a small portable rainfall simulator in winter confirmed in the Mosel valley the high infiltration coefficients (near 100%) with only little peaks of runoff coefficient with negligible suspended sediment loads values. This alteration of the natural hydrological dynamics due to the soil tillage and the high rock fragment content that implies a high macro-porosity, especially in the young vineyard, can generate several problems of solute transport, nutrients and fine particle losses, landslides by piping processes, formation of rills and ephemeral gullies, degradation of the roots and decrease of the productivity (Merritt et al., 2003). By using rainfall simulation experiments in 2013, we tried to quantify at real-time sub-surface flow and sediment concentration (Rodrigo Comino et al., 2015b) by: i) removing, the stony A horizon inside the ring plot; ii) using a hydrophilic nylon fabric to protect the soil against the splash effect; and, iii) caving a vertical soil profile underneath the simulator (50 cm depth and 150 cm width). However, in this manner, subsurface flow was observable and confirmed by the profile, but it was impossible to quantify it. After revising scientific literature in order to solve this methodological problem, we highlight that there is a lack of methods in order to conduct a monitoring of suspended sediment concentration on sub-surface flow and total amounts of mobilized water. Only some examples at hillslope scale in USA measuring a few rainfall events during two months (Pilgrim and Huff, 1983) or at catchment area in Japan (Terajima et al., 1997) can be found. Therefore, we concluded that further research is also needed to quantify the total soil and water losses, the main flow pathways and to confirm if this process is general in sloping vineyards and relevant.

Since in Germany it was clear that during different seasons, surface runoff and subsurface runoff are uneven, but follow a relative trend related to the tillage and the vintage, in the Montes de Málaga, we find a mixed model acting paralel. As we mentioned, this situation can be due to the high variability of the distribution of the soil surface components, which generates several different microtopographical changes along the hillslope modifying its natural behaviour. The irregularities due to the high roughness and the schistosity of the rocks facilitate the weathering of the materials, which acquire a laminar morphology and high angularity. This aspect of the rock fragments offers greater resistance to transport the sediments along the slope and cause high microtopographical variabilities. So, a possible mixed Hortonian-Hewlettian model can be considered, combining surface and subsurface flow, irregular sediment transport and different impacts of the rainfall on the soil at microscale showing different runoff threshold patterns (Cerdà, 2001; Imeson and Lavee, 1998; Ruiz Sinoga and Martinez Murillo, 2009). The sloping vineyards of the Montes de Málaga showed clear mechanisms of connectivity and disconnectivity processes (Appels et al., 2011; López-Vicente et al., 2013; Poeppl et al., 2017), in which continuously appears and disappears the processes of infiltration, overland flow, and subsurface flow. All together perform a pattern from the summit to the footslope, which develops a continuous feedback system. This alteration of the natural hydrological dynamic can also carry out environmental problems. In this way, for the future, it would be interesting to look deeper in relevant high intraplot temporal variabilities along the inter-rows and rills. It would be useful to compare soil erosion and hydrological processes before and after harvesting, between different years and under different rainfall intensities by using connectivity indexes (Cavalli et al., 2008; López-Vicente et al., 2015; Ortiz et al., 2017).

Another important conclusion found in this research is the impact of the age of the vineyard on soil erosion processes. The age of vineyards as a key factor controlling soil erosion processes has received minimal attention and interest from the scientific community. Richter and Negendank (1977) published in English the first paper mentioning the possible influence of the age of plantation in the Ruwer-Mosel valley. However, since we highlight the relevance of the time since plantation as a driving factor in soil erosion by using the SUM (stock unearthing method) (Rodrigo-Comino et al., 2015a, 2015b), fortunately, other research groups have found interesting causes and conclusions (Cerdà et al., 2017; Rodrigo Comino et al., 2017). The difference of soil erosion in vineyards with different ages occurs due to the combined processes of tillage and surface wash (Fig. 1).

Figure 1. The two combined causes to observe differences between vineyards of different ages (Rodrigo-Comino et al., 2017)



Tillage has been shown to be a key factor in soil redistribution in agricultural land (Bogunovic et al., 2017). The original soil surface in vineyards during plantation is flat, smooth and with low roughness. The soil erosion rates can be higher in the younger plots than in the older ones due to soil disturbances from the recent plantation. The plantation works compacted and smoothed the soils, thus runoff is easily activated and very efficient in the 2-3-year-old plots. However, after 3-4 years, tillage redistribution results in an increase in roughness and microtopographical changes with some material already located under the rows, which enhance an increase of the ridges under the vines due to tillage (and probably due to splash as well). This consolidation of the ridges is able to reduce erosion rates at the slope and partial slope scales because the connectivity of the flows and most of the geomorphological activity was concentrated in the inter-row. Another, important factor that reduces soil losses in older vineyards in comparison with the young ones, is the increase in the vine biomass. It is important to emphasize that soil erosion is highly determined by raindrop impact (Fernández-Raga et al., 2017) and with the growth of the vines after some years, rainfall erosivity is reduced due to the soil protection they provide (Fig. 1). As mentioned Rodrigo-Comino et al., (2017): "*The vine leaves cover contributes to reduce the runoff in the vine rows, which is as a consequence of interception. The stemflow and throughfall promote lower runoff rates in the ridge where weeds also grow. The row area is covered by vegetation and soil materials are accumulated* *due to tillage, splash, and the fact that the vegetation growing in the row catches and holds the soil tilled or splashed into it*".

Finally, some solutions were considered to be implemented in both sloping vineyards and planned to be transferred to the stakeholders.

In the Montes de Málaga, it is important to highlight the importance of the perfect communication with the vine-growers (Pepe Gámez and Antonio Tobalo) and winery (Dimobe). This situation has shown that the possible solution to be implemented is more adapted to the environmental plot characteristics and highly possible to be soon included. After observing that the preferential flow is uneven, but possible it was possible to detect the origin, vegetation cover or some kind of mulch could be introduced as patches. Due to the water competence and long dry periods, a complete covered soil would be impossible and, surely, not accepted by the vine growers. However, only some patches on the summit, shoulder or backslope of about 1x1 or 2x2 m^2 could perfectly stop the overland flow and enhance the infiltration. The maintenance and economical invest in this solution is not expensive since farmers can plant some kind of leguminous that could be also used for animal´s meals or used chipped branches. Moreover, the use of agri-spillways, if they are also well-designed (correct direction and width) and well-conserved (empty of sediments and chipped branches or leaves), can also perfect complements to canalize the exceed of the water in big containers to be used (e.g. irrigation).

On the other hand, in the Ruwer-Mosel valley, unfortunately, the communication was not so fluent than in the Montes de Málaga with the winery, because it is far away from the study area and we did not coincide in the field. The field work and results were confirmed with local informants and some local farmers and foreign workers from Hungary, Slovakia or Poland that worked during the vintage. The two main solutions that could be efficient and useful in the German vineyards are the use of vegetation cover, which can survive without too extreme water competence, and the development of lighter machinery for tillage.

References

Ben Slimane, A., Raclot, D., Evrard, O., Sanaa, M., Lefevre, I., Le Bissonnais, Y., 2015. Relative contribution of rill/interrill and gully/channel erosion to small reservoir siltation in Mediterranean environments. Land Degrad. Dev. 27, 785–797. doi:10.1002/ldr.2387

Brevik, E.C., Tibor, M.A., 2014. Impact of Camping on Soil Properties at Strawberry Lake, North Dakota, USA. Presented at the EGU General Assembly Conference Abstracts, p. 1137.

Cerdà, A., 2001. Effects of rock fragment cover on soil infiltration, interrill runoff and erosion. Eur. J. Soil Sci. 52, 59–68. doi:10.1046/j.1365-2389.2001.00354.x

Certini, G., Campbell, C.D., Edwards, A.C., 2004. Rock fragments in soil support a different microbial community from the fine earth. Soil Biol. Biochem. 36, 1119–1128. doi:10.1016/j.soilbio.2004.02.022

Fox, D.M., Bryan, R.B., Price, A.G., 1997. The influence of slope angle on final infiltration rate for interrill conditions. Geoderma 80, 181–194. doi:10.1016/S0016-7061(97)00075-X

Hewlett, J.D., Hibbert, A.R., 1967. Classics in physical geography revisited. Hewlett, J.D. and Hibbert, A.R. 1967: Factors affecting the response of small watersheds to precipitation in humid areas. In Sopper, W.E. and Lull, H.W., editors, , New York: Pergamon Press, 275-90. | SRS Publication. Sopper WE Lull HW Ed. N. Y. Pergamon Press For. Hydrol. 275–290.

Jomaa, S., Barry, D.A., Brovelli, A., Heng, B.C.P., Sander, G.C., Parlange, J.-Y., Rose, C.W., 2012. Rain splash soil erosion estimation in the presence of rock fragments. Catena 92, 38–48. doi:10.1016/j.catena.2011.11.008

Jordán-López, A., Martínez-Zavala, L., Bellinfante, N., 2009. Impact of different parts of unpaved forest roads on runoff and sediment yield in a Mediterranean area. Sci. Total Environ. 407, 937–944. doi:10.1016/j.scitotenv.2008.09.047

Kinnell, P.I.A., 2009. The impact of slope length on the discharge of sediment by rain impact induced saltation and suspension. Earth Surf. Process. Landf. 34, 1393–1407. doi:10.1002/esp.1828

Nadal-Romero, E., Petrlic, K., Verachtert, E., Bochet, E., Poesen, J., 2014. Effects of slope angle and aspect on plant cover and species richness in a humid Mediterranean badland. Earth Surf. Process. Landf. 39, 1705–1716. doi:10.1002/esp.3549

Nyssen, J., Haile, M., Poesen, J., Deckers, J., Moeyersons, J., 2001. Removal of rock fragments and its effect on soil loss and crop yield, Tigray, Ethiopia. Soil Use Manag. 17, 179–187. doi:10.1111/j.1475-2743.2001.tb00025.x

Poesen, J., Ingelmo-Sanchez, F., Mucher, H., 1990. The hydrological response of soil surfaces to rainfall as affected by cover and position of rock fragments in the top layer. Earth Surf. Process. Landf. 15, 653–671. doi:10.1002/esp.3290150707

Poesen, J., Lavee, H., 1994. Rock fragments in top soils: significance and processes. Catena 23, 1–28. doi:10.1016/0341-8162(94)90050-7

Quinn, N.W., Morgan, R.P.C., Smith, A.J., 1980. Simulation of soil erosion induced by human trampling. J. Environ. Manage. 10, 155–165.

Ramos, M.C., Nacci, S., Pla, I., 2000. Soil sealing and its influence on erosion rates for some soils in the Mediterranean area. Soil Sci. 165, 398–403.

Rodrigo Comino, J., 2013. Cuantificación de los gradientes térmicos a nivel superficial a lo largo del Rheinland-Pfalz (Renania-Palatinado, Alemania). Baética Estud. Arte Geogr. E Hist. 75–98.

Rodrigo Comino, J., Iserloh, T., Lassu, T., Cerdà, A., Keestra, S.D., Prosdocimi, M., Brings, C., Marzen, M., Ramos, M.C., Senciales, J.M., Ruiz Sinoga, J.D., Seeger, M., Ries, J.B., 2016. Quantitative comparison of initial soil erosion processes and runoff generation in Spanish and German vineyards. Sci. Total Environ. 565, 1165–1174. doi:10.1016/j.scitotenv.2016.05.163

Rodrigo-Comino, J., García-Díaz, A., Brevik, E.C., Keestra, S.D., Pereira, P., Novara, A., Jordán, A., Cerdà, A., 2017. Role of rock fragment cover on runoff generation and sediment yield in tilled vineyards: Role of rock fragments on erosion in vineyards. Eur. J. Soil Sci. doi:10.1111/ejss.12483

Senciales González, J.M., Ruiz Sinoga, J.D., 2013. Análisis espacio-temporal de las lluvias torrenciales en la ciudad de Málaga. Bol. Asoc. Geógrafos Esp. 7–24.

van Wesemael, B., Poesen, J., de Figueiredo, T., 1995. Effects of rock fragments on physical degradation of cultivated soils by rainfall. Soil Tillage Res. 33, 229–250. doi:10.1016/0167-1987(94)00439-L

CHAPTER 13. CONCLUSIONS

Two main aims were formulated for this PhD thesis: i) to measure and quantify the spatiotemporal variations of the hydrological and geomorphological processes in sloping vineyards under conventional land use management and different climate environments (the Mediterranean and Continental); and, ii) to find the main key factors (natural and anthropogenic) that could influence soil erosion processes after natural rainfall events and soil tillage practices.

By analysing the study cases of the Montes de Málaga (Spain) and the Ruwer-Mosel Valley (Germany), we demonstrated that sloping vineyards on bare soils can experience high soil erosion rates, but that clear patterns were not directly associated with or due to the human impact. The spatiotemporal distribution of hydrological and geomorphological processes is uneven and highly conditioned by several factors. In table 1, we summarized all of these factors and conclusions found by using all the material published during the research period (2013-2017).

Table 1. Final conclusions extracted after studying the Ruwer-Mosel valley and the Montes de Málaga vineyards.

<table>
<tr><th>Field</th><th>Ruwer-Mosel valley</th><th>Montes de Málaga</th></tr>
<tr><td rowspan="4">Pedology</td><td>Soil depths (25-30 cm): Ao+Ap+C/R</td><td>Soil depths (15-30 cm): Ap+C/R</td></tr>
<tr><td>High organic matter content (>7%)</td><td>Low organic matter content (<5%)</td></tr>
<tr><td>High macro-porosity = high soil moisture along the soil profile</td><td>High weathereing</td></tr>
<tr><td colspan="2">High rock fragment cover (>35%) stope water and soil losses</td></tr>
<tr><td rowspan="3">Geomorphology</td><td>Hewlettian hydrological mechanisms (Hewlett and Hibbet, 1967): subsurface flow</td><td>Mixed hydrological mechanisms (Cerdà, 2001b; Imeson and Lavee, 1998; Ruiz Sinoga and Martinez Murillo, 2009)</td></tr>
<tr><td>Constant soil and water losses, but with higher peaks before and during the harvesting</td><td>Soil and water losses concentrated in few extreme rainfall events</td></tr>
<tr><td colspan="2">Microtopographical changes highly affect soil loss and flow pathways</td></tr>
<tr><td rowspan="4">Human impacts</td><td>The age of plantation confirmed as a driving factor of soil erosion</td><td>Hand-made tillage enhance micro-topographical changes and connectivity-disconnectivity processes</td></tr>
<tr><td colspan="2">Bare soils increase splash effect, overland flow and pollutant transport downslope direction</td></tr>
<tr><td>Tractor compacts soil, enhance overland flow and default infiltration</td><td>The use of agri-spillways, since correctly designed, can be considered as useful tool to control soil erosion</td></tr>
<tr><td colspan="2">Trampling effect</td></tr>
</table>

Final results showed that: i) steep slopes enhance soil and water losses from low to high extreme values due to the gravitational energy along the downslope direction; ii) specific soil properties developed in steep slopes play a remarkable role in order to enhance or avoid soil erosion processes such as silt and rock fragment cover; iii) trampling effect and machinery impact play an important role by compacting the soil and, subsequently, conditioning the highest peaks of soil erosion during the harvesting and pruning seasons; iv) mechanisms of sub-surface flow in Germany and mixed Hortonian-Hewlettian model in Spain are the main hydrological processes affecting the irregular sediment transport and different impacts of the rainfall on the soil at the microscale showing different runoff threshold patterns; v) the age of vineyards as a key factor controlling soil erosion processes; vi) tillage has been shown to be a key factor in soil redistribution and, subsequently, in soil roughness and the generation of rills, ephemeral gullies, and soil accumulation.

Finally, as solutions to be transferred to the stakeholders, we conclude that in Málaga vegetation cover or some kind of mulch could be introduced as patches. Moreover, mulch can be combined with the use of agri-spillways, if they are also well designed (correct direction and width) and well maintained (empty of sediments and chipped branches or leaves). The latter provides additional benefits by channeling overland flow into man-made reservoirs such as large water storage containers where it can be used for other activities (e.g. irrigation). In Germany, the use of vegetation cover, which can survive without too extreme water competence, and the development of lighter machinery for tillage would be the most important soil erosion control measures.