

AGGREGATE BREAKDOWN AND SOIL SURFACE SEALING UNDER RAINFALL

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I certify that this thesis is my own original work
and all sources have been acknowledged.

Guy William Geeves

This work is dedicated to my parents, Elaine and Don Geeves, who have given me
unconditional love and support throughout my life.

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Abstract

Aggregate breakdown is an important process controlling the availability of fine soil material necessary for structural sealing of soil surfaces under rainfall. It may be caused by slaking resulting from rapid soil wetting and by physical dispersion resulting from direct and indirect energetic raindrop impacts. Relationships have been proposed by others predicting steady infiltration rate and saturated hydraulic conductivity from final aggregate size following high energy rainfall on initially dry, uncovered soil surfaces. Under these extreme conditions, both rapid wetting and energetic raindrop impact result in maximum aggregate breakdown and surface sealing. Knowledge of the relative importance of these two agents under less severe conditions and knowledge of how increased aggregate stability due to conservative soil management may ameliorate them should improve prediction and management of aggregate breakdown and surface sealing.

This study has isolated and quantified effects of rapid soil wetting and energetic raindrop impact on aggregate breakdown and surface sealing. Simulated rainfall was applied to re-packed soils from differing tillage treatments on light textured soils from near Cowra and Condobolin in New South Wales, Australia. Aggregate breakdown was assessed using aggregate size distribution, determined by wet sieving and summarised by a range of statistics. The degree of breakdown was assessed after 66 mm of simulated rainfall whilst the rate of change in aggregate size distribution was assessed by sampling after 5, 10, 15, 30 and 60 mm. The degree of surface sealing was assessed using final surface hydraulic conductivity after 66 mm rainfall calculated from inferred infiltration and measured sub-seal soil water potential. The rate of surface sealing was assessed prior to ponding using cumulative rainfall volume at ponding and throughout the post-ponding phase by decline in surface hydraulic conductivity as a function of cumulative rainfall kinetic energy. Two levels of raindrop kinetic energy flux and three wetting treatments were used to isolate effects of these agents of aggregate breakdown and surface sealing.

Significant surface aggregate breakdown was observed when either rapid soil wetting or highly energetic raindrop impact were allowed to occur. The majority of the data suggest a negative interaction between the two agents. When soil was initially dry rapid soil wetting was the dominant agent causing rapid aggregate breakdown, generally within the first 5 mm of rainfall. When rapid soil wetting was prevented by tension pre-wetting, energetic raindrop impact was the dominant agent and was able to cause aggregate breakdown of an almost equivalent degree. This breakdown occurred over a period lasting for up to 30 mm of rainfall. In contrast, the rate and degree of surface sealing were influenced primarily by raindrop kinetic energy with highly energetic impact leading to significant surface sealing, irrespective of soil wetting. For the soils studied, it was concluded that structural sealing of surface soil, could be significantly reduced by protecting the soil surface from energetic raindrop impact but that prevention of surface aggregate breakdown required amelioration of both processes.

In addition to the negative interaction referred to above, a positive interaction was observed whereby energetic raindrop impact occurring concurrently with rapid soil wetting caused a greater degree of aggregate breakdown and a greater degree of surface sealing than energetic raindrop impact occurring subsequent to rapid soil wetting. The effect on surface sealing may be explained by the effect of lower sub-seal water potential that necessarily results from initially dry soil condition required for concurrent rapid wetting. However, the effect on aggregate breakdown remains unexplained.

Notwithstanding the above, permeability was reduced under high kinetic energy rainfall even when soil wetting was reduced to very slow rates by tension pre-wetting. Likewise, surface sealing did occur under low kinetic energy rainfall for the least stable soil following rapid soil wetting. It was concluded that threshold soil wetting rates and threshold rainfall energy levels, proposed by others, are either not applicable to these soils or are negligible.

The rate and degree of aggregate breakdown was also dependent on the soil with the Cowra soil being more stable than the Condobolin soil. Greater aggregate stability brought about by conservative tillage treatments at both soil locations retarded and reduced surface sealing. Unvalidated simulation modelling was used to illustrate possible effects for the soil water balance. In contrast to the conclusions of Loch (1994b), that were based on soils throughout eastern Queensland, the soil water balance simulations predicted that the residual benefits in ameliorating surface sealing resulting from improved aggregate stability could significantly reduce point runoff under the lower intensity winter rainfalls experienced in southern New South Wales.

Limited testing with Condobolin soil following tension pre-wetting showed that rainfall intensity, varying over the range from 16.5 to 66 mm h⁻¹, had little effect on the decline in surface hydraulic conductivity as a function of cumulative rainfall kinetic energy. This contrasts with greater seal permeability under higher rainfall intensities observed by Romkens *et al.* (1985) and others. It is proposed that an alternative explanation exists for the observations of Romkens *et al.* based on reduction in seal permeability due to lower sub-seal water potential under lower intensity rainfall.

Post-ponding reduction in K_{sat} under high kinetic energy rainfall exhibited exponential decline as a function of cumulative raindrop kinetic energy as proposed by Moore (1981b). However, inferred rates of decline prior to ponding were more rapid than measured post-ponding rates suggesting that infiltration models using only a single exponential rate of surface K_{sat} decline based on post-ponding measurements may be in error. Potential for error is greatest at early times for loose soil that is highly susceptible to sealing.

Pre-ponding decline in surface aggregation was also relatively more rapid than post-ponding decline. This discrepancy was evident irrespective of soil pre-wetting. From this it was concluded that the more rapid initial aggregate breakdown and surface sealing was due, at least in part, to processes other than aggregate slaking due to rapid soil wetting. An explanation has been proposed as follows. Raindrops initially fall on aggregates that have not

been subjected to rainfall and therefore each drop has the capacity to cause greater aggregate breakdown than subsequent raindrops that fall on aggregates or soil fragments that have been strong enough to survive preceding rainfall impacts. Such a mechanism could provide an alternative explanation of the findings of Baumhardt *et al.* (1991) who found that less cumulative raindrop kinetic energy was necessary to achieve a given reduction in surface conductance when the cumulative energy was supplied through lower energy drops.

Relationships predicting rates of surface sealing using aggregate breakdown under rainfall and aggregate stability were evaluated. Post-ponding infiltration rate and surface K_{Sat} were related to aggregate size by exponential functions. The proportion of surface aggregates less than 0.125 mm in diameter provided slightly more consistent relationships. Parameters of fitted relationships differed among wetting pre-treatments suggesting that the influence of sub-seal water potential on surface K_{Sat} must be considered whenever such relationships are developed or applied. Aggregate stability determined by wet sieving was related to rainfall volume required for ponding, final K_{Sat} and final aggregate size but only for initially dry soil suggesting that such relationships may be unique to the rainfall, soils and flow conditions used to develop them.

This study has established the relative importance of rapid soil wetting and energetic raindrop impact in both aggregate breakdown and surface sealing over a range of antecedent soil water and rainfall conditions. It has quantified the effectiveness of culturally induced aggregate stability in ameliorating effects of these two important agents and illustrated the potentially significant consequences for the soil water balance. It has quantified temporal patterns of surface sealing and aggregate breakdown and proposed an alternative mechanism explaining more rapid aggregate breakdown during the initial stages of rainfall. It has identified possible explanations for effects of rainfall intensity on surface sealing observed in other studies. It has also partially evaluated a mechanism proposed to explain important effects of subseal water potential on seal permeability found in this and other studies. These significant findings have been used with the findings of other studies to amend the conceptual model proposed by Le Bissonnias (1990). The amended model gives a more complete description of the relationships between parameters and processes determining aggregate breakdown and structural surface sealing under rainfall.

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