The effect of residue mixing, clay content and drying and rewetting on soil respiration and microbial biomass

A thesis submitted in fulfilment of the degree of Doctor of Philosophy

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Dedicated to my parents and my wife

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Abstract

Organic matter decomposition in terrestrial system is of vital importance for nutrient cycling and ecosystem function. Soil microorganisms are the key drivers of decomposition which regulates the availability of inorganic nutrients through immobilisation and mineralisation. The size of the soil organic C pool is twice that of C in the atmosphere and more than twice of that in vegetation. Thus, organic matter decomposition in soil greatly influences the C flux between soil and the atmosphere. Therefore understanding factors influencing organic matter decomposition is important for climate change mitigation and soil fertility. In this thesis, the effects of residue mixing, removal of water-extractable organic C, clay subsoil addition to sandy soil and drying and rewetting on decomposition were investigated.

Organic matter decomposition is influenced by both internal and environmental factors. Plant residues are an important source of soil organic C and decomposition of plant residues has been studied extensively. However, residues from different species or above- and below-ground residues are often mixed and less is known about factors influencing decomposition of residue mixtures. Shoot and root residues of three Australian native perennial grass species [Wallaby grass (*Danthonia sp)*; *Stipa sp and* Kangaroo grass (*Themeda triandra*)] and barley (*Hordeum vulgare L*.) were mixed to create nine different residue mixtures (1:1 mixture). Soil respiration was measured over 18 days. Cumulative respiration in residue mixtures differed from the expected value (average of cumulative respiration of individual residues) in most cases with synergistic interactions occurring in 56 % of the mixtures (expected < measured value), antagonism in 22 % (expected > measured value). Synergism occurred when residues with relative similar decomposition

rate were mixed, while antagonism occurred when the decomposition rate of individual residues differed strongly. Furthermore, a negative correlation was found between the change in microbial biomass C (MBC) and available N concentration between the start of the experiment and day 18 and cumulative respiration on day 18. The interaction with respect to cumulative respiration was not reflected in MBC and available N concentrations. Cumulative respiration and MBC concentration were greater in soil amended with residues with higher water-extractable organic C (WEOC) concentration, compared to those with lower WEOC concentration, either individually or as in mixtures.

Between 2 and 30 % of organic C in residues is water-extractable and its importance in stimulating decomposition has been shown previously. Water-extractable organic C can be leached by heavy rainfall or irrigation, but little is known about the effect of addition of residues from which the WEOC was removed by extraction or leaching on microbial activity and biomass. Shoot residues of barley (*Hordeum vulgare L.*) were extracted five times for maximal removal of WEOC or were leached up to eight times to partially remove WEOC. Maximum WEOC removal decreased both soil respiration and MBC concentration in the first week, but MBC concentration at the end of the experiment was greater with extracted residues compared to the original residues. With leached residues, partial removal also reduced respiration rate in the first 10 days. However, MBC concentration was greatest with residue leached eight times, suggesting great substrates utilisation efficiency.

In South Australia a large area of land is covered by sandy soils (3.2 million ha), with a heavy textured soil underneath, so called 'duplex soil'. Due to the lack of binding sites for organic matter and nutrients and large pore size, sandy soils are often characterised by low organic matter content, low nutrient and water retention capacity and rapid organic matter decomposition. Addition of clay-rich subsoil to sandy soil has been shown to increase crop yield and water retention in sandy soils. Additionally, clay particles could bind organic matter. However, little is known about the effect of clay subsoil addition to sandy soil on soil respiration after addition of residue mixtures. Clay subsoil was added to a sandy top soil at 10 and 30 % (w/w). Residues of barley (*Hordeum vulgare L.*) and two native perennial grass species (*Danthonia sp* and *Themeda triandra*) were added individually or as 1:1 mixture. Increasing clay addition decreased cumulative respiration and extractable C concentration in soil with individual residues and mixtures. No interaction was observed in terms of cumulative respiration in sandy soil alone, but at addition of 10 % clay subsoil, antagonism occurred in two residue mixtures, and at 30 % clay addition synergism occurred in one of the mixtures. It can be concluded that clay soil addition to sandy soil does not only alter decomposition rate but also interactions in residue mixtures.

In Mediterranean climate such as in South Australia long periods of dry and hot weather are interrupted by occasional rainfall or irrigation. Although the effect of drying and rewetting (DRW) has been studied extensively, the factors determining the respiration flush upon rewetting and total cumulative respiration are not fully understood. A sandy soil amended with different proportion of clay subsoil (0, 5, 10, 20, 30, and 40 %) was exposed to a single DRW event. Expressed per g soil, cumulative respiration in the constantly moist control (CM) decreased with increasing clay soil addition rate, but cumulative respiration in the DRW treatment did not vary among clay soil treatments. However, when expressed per g total organic C (TOC), cumulative respiration in the DRW treatment increased with increasing clay subsoil addition rate. Addition of clay subsoil increased water retention capacity during drying, thus microbial activity. The respiration flush one day after rewetting was greater than the respiration rate in CM only in treatments with 20-40 % clay addition rate.

The response of respiration to DRW may be influenced by land management due to its effect on the soil organic C pool and differ between soil size fractions. An incubation experiment was conducted with soils collected from two plots with a long history of different management (wheat-fallow rotation and permanent pasture). The soils were sieved to 4-10 mm and <2 mm to obtain two size factions. There were five moisture treatments with the same length (48 days). The CM treatment was maintained at 50 % of maximum water-holding capacity (WHC) throughout. In the DRW treatments, the number of dry and moist days was equal but the number of DRW events ranged from one to four (1 to 4DRW). Cumulative respiration per g TOC at the end of the experiment was greater in the <2 mm than in the 4-10 mm fraction in both soils and was highest in CM and 1DRW. In wheat soil, cumulative respiration decreased from 1DRW to 3DRW, whereas it decreased only between 2 to 3DRW in pasture soil. Cumulative respiration in the second moist period was greater in 3DRW than in 2DRW (8 and 12 prior moist days) whereas cumulative respiration in the third moist period was greater in 4DRW than in 3DRW (12 and 16 prior moist days). It can be concluded that the response of respiration to drying and rewetting is more strongly influenced by management than size fraction. Cumulative respiration upon rewetting is influenced not only by the number of DRW cycles but also the number of moist days prior to rewetting.

Three incubation experiments were carried out to assess the relationship between cumulative respiration per g TOC and the number of moist or dry days with the two soils used in the previous experiment. In the first experiment, the CM and DRW treatments had the same total length (10 days) with different proportions of moist and dry days in the DRW treatments. The second and third experiment had DRW cycles of dry and moist period of equal length with one cycle in Experiment 2 and two cycles in Experiment 3. Soil in the CM was maintained at 50 % of WHC throughout for all experiments. Total cumulative respiration per g TOC was greater in wheat than in pasture soil which can be explained by the greater proportion of particulate organic matter in the former. In the first experiment, cumulative respiration in the dry period was not influenced by the number of dry days, but cumulative respiration in moist period increased with number of moist days. Total cumulative respiration in the DRW cycle was negatively correlated with the number of dry days and positively correlated with the number of moist days. Cumulative respiration in DRW treatments was lower than in CM when the proportion of moist days was less than 50 % of the total length with the difference becoming greater with decreasing proportion of moist days. In both the second and the third experiment, total cumulative respiration increased with increasing number of days with a greater increase in CM than in DRW treatments. When subjected to two DRW cycles in the third experiment, total cumulative respiration in each DRW cycle was also positively correlated with the number of moist days with the slope greater in first than in the second DRW cycle. In conclusion, cumulative respiration in DRW cycles is mainly a function of the number or proportion of moist days and little influenced by soil management.

An incubation experiment was conducted with the soil from the wheat-fallow rotation to determine the influence of number of dry and moist days and their distribution in two DRW cycles on respiration rate and cumulative respiration in each DRW cycle. The number of moist and dry days ranged in either the first or second DRW cycle between 10 and 35. The constantly moist treatments were maintained at 70 % of WHC throughout. Cumulative respiration in CM was greater than that in DRW treatments with the difference greater in treatments with varying number of dry days than those with varying number of moist days. Cumulative respiration in the dry period differed little among DRW treatments. The flush of respiration upon rewetting increased with number of prior dry days. Respiration rates in the moist period of the first cycle were higher than in the second cycle only up to 17 days, indicating that the effect of prior substrate utilisation in 5 moist days in the first cycle is limited to first 17 days in the moist period of second cycle. Cumulative respiration in the moist period increased with the number of prior dry or moist days with the increase greater in treatments varying in number of moist days than those varying in number of dry days. Cumulative respiration was greater when the number of moist or dry days varied in the first than in the second cycle. It is concluded that the number of dry days influences the size of the respiration flush after rewetting, while the number and distribution of moist days affect cumulative respiration.

To summarise, the studies described in this thesis showed:

- Cumulative respiration in residue mixtures relative to that of the individual residues depends on residue type and soil clay content.
- Removal of WEOC from residues reduces initial respiration rates but not always cumulative respiration.
- Addition of clay to sandy soil not only reduces cumulative respiration but also alters respiration in dry and moist periods of DRW cycles.
- Cumulative respiration in DRW treatments is mainly influenced by the length of the moist period: (i) total length of the moist period determines total cumulative respiration at the end of the DRW treatments, and (ii) number of prior moist days influences respiration in the subsequent cycles.

Declaration

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Andong Shi (Signature)

Date

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