Title: Effect of crop residue addition on soil organic carbon priming influenced by temperature and soil properties

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Abstract

Priming of soil organic carbon (SOC) is a crucial factor in ecosystem carbon balance. Despite its increasing importance in the changing global climate, the extent of influence of temperature and soil properties on the priming effect remains unclear. Here, soil priming was investigated using ^{13}C labeled wheat residues in two cultivated subtropical soils of Australia (Vertisol and Luvisol) at four incubation temperatures (13, 23, 33 and 43°C). The priming effect was computed from respired CO_2 and associated $\delta^{13}C$, which were measured periodically over the 52-day incubation period. Wheat residue addition resulted in greater priming effect in the Luvisol (1.17 to 2.37% of SOC) than the Vertisol (0.02 to 1.56 % of SOC). The priming of SOC was the highest at 23°C in the Luvisol, and at 43°C in the Vertsiol, which indicates a variable positive priming effect of temperature in different soil types. Wheat residue addition significantly increased the temperature sensitivity (Q_{10}) of SOC mineralization in the Vertisol at temperature ranges below 33°C (i.e., 13-23 and 23-33°C) and had no significant effect in the Luvisol. A negative correlation was observed between temperature and the Q_{10} values. Across soils, the Q_{10} of residue C was lower than SOC suggesting that soil C is more vulnerable to climatic warming. This work demonstrates that the magnitude of SOC priming by wheat residue and Q_{10} of SOC mineralization varied significantly with soil type (Luvsiol > Vertisol) and incubation conditions (temperature and time). Given the current trend towards increasing atmospheric temperatures, future studies should evaluate temperature effects on the priming of different pools of SOC induced by crop residue in different agro-ecosystems.

Key words: SOC priming, Q_{10}, ^{13}C, Wheat residue, SOC mineralization, Temperature

1. Introduction

Understanding the potential impact of crop residue on soil organic carbon (SOC) storage is a key focus to understand the magnitude of current and future global changes in temperature (Fang et al., 2017; Lal, 2004; Thiessen et al., 2013). This is because crop residue is a significant source of external carbon (C) input, while concurrently impacting native SOC mineralization (Fang et al., 2018). Moreover, crop residue retention and application to soil is an integral component of sustainable and conservation agriculture worldwide (Campbell et al., 2001; Corsi et al., 2012; Lal and Kimble, 1997; Lenka et al., 2015)) with numerous benefits to soil properties, functioning and processes (Chen et al., 2014; Fang et al., 2018; Sarker et al., 2018; Singh et al., 2014). Directly, residues are the sources of energy and nutrients to the soil microbiome which may consequently affect SOC and residue C mineralization (Shahbaz et al., 2017a). Therefore, crop residue addition can either increase or decrease the mineralization of native SOC, termed the priming effect (Kuzyakov et al., 2000; Shahbaz et al., 2017b; Zhang et al., 2013). The priming effect of crop residue is hypothesized to be a function of abiotic factors including temperature and soil type (Blagodatskaya and Kuzyakov, 2011). While increasing the temperature can increase the mineralization of SOC in residue treated soil, the effect depends on the soil condition and properties (Fang et al., 2018).

Multiple studies have elucidated the effect of residue C on SOC mineralization rate using crop residues derived from various species (Guenet et al., 2010a; Liu et al., 2015; Mazzilli et al., 2014; Nottingham et al., 2009; Shahbaz et al., 2017b; Wang et al., 2015; Zhang et al., 2013) . However, SOC priming by crop residue as a function of temperature in different soils is still poorly understood. Crop residue input has been observed to result in both positive and negative priming effects. For example, negative priming could be the result of preferential residue C utilization over

65 SOC by the microbes that results in less SOC mineralization (Guenet et al., 2010a; Liu et al., 2015;

66 Wang et al., 2015). Nevertheless, crop residue input generally results in positive priming of native

67 SOC mineralization (Fang et al., 2018; Sarker et al., 2018; Shahbaz et al., 2017a; Wang et al.,

68 2015; Zhang et al., 2013). The possible mechanisms for positive SOC priming suggested by

69 previous studies include co-metabolism (Guenet et al., 2010b), preferential substrate utilization

70 (Gontikaki et al., 2013), soil nutrient mining (Fang et al, 2018), shifts in microbial community

71 structure that enhance native SOC mineralization (Fang et al., 2015), stimulation of microbial

72 biomass and activity (Liang et al., 2017; Thiessen et al., 2013; Xiao et al., 2015), microbial

73 necromass as a soil primer (Shahbaz et al., 2017b), and changes in production of extracellular

74 enzymes (Blagodatskaya and Kuzyakov, 2008; Rousk et al., 2015).

75   The extent and direction of SOC priming have been shown to be controlled by temperature

76 (Thiessen et al., 2013; Zhang et al., 2013; Fang et al., 2015). Generally, temperature changes the

77 rates of enzyme reactions through influencing activation energy (Davidson and Janssens, 2006).

78 Concurrently, temperature can directly affect microbial soil respiration (Curiel Yuste et al., 2007)

79 or change microbial community structure (Biasi et al., 2005) through influencing microbial

80 activity. Furthermore, temperature can affect microbial utilization of substrate C (Manzoni et al.,

81 2012), and thus to influence SOC priming. Critical to improving our understanding is assessing

82 the relationship of temperature on priming effects, an area where data is still scarce and

83 consequently difficult to generalise (Zhang et al., 2013). For example, in a long-term incubation

84 study, the addition of fresh plant materials increased the rate of SOC mineralization, with higher

85 temperatures resulting in a similar effect (Thiessen et al., 2013). In another study, addition of ^{13}C-

86 labeled glucose induced stronger priming at 25°C than at 15°C (Li et al., 2017). The potential

87 effects of temperature on priming are likely to depend on substrate quality as well as soil type.

88   The extent and direction of priming by crop residue input have been shown to be influenced by

89   variations in physical, chemical and/or biological properties of different soils, such as soil texture

90   (Krull et al., 2001; Mtambanengwe et al., 2004; Razafimbelo et al., 2013; Xu et al., 2016), SOC

91   content (Guenet et al., 2010b; Zhang et al., 2013), C:N ratio (Wang et al., 2016; Xu et al., 2016)

92   and nutrient availability (Wang et al., 2016; Zhang et al., 2007). Mineralization of SOC and crop

93   residue is generally slower in fine than in coarse textured soils (Hassink, 1992; Mtambanengwe et

94   al., 2004; Sarker et al., 2018; Xu et al., 2016; Yadvinder-Singh et al., 2005), because clay can

95   physically protect organic C in soil and may limit its microbial access (Hassink, 1992; Xu et al.,

96   2016). Therefore, soil texture may attenuate the SOC and residue C mineralization in soils with

97   high clay content. This concept contradicts the view of greater contribution of SOC content and

98   C:N ratio on higher SOC priming (Wang et al., 2016; Zhang et al., 2013;). In fact, most previous

99   studies have examined the priming effect of crop residues in one soil (Liu et al., 2015; Mazzilli et

100   al., 2014; Shahbaz et al., 2017a; Thiessen et al., 2013; Wang et al., 2015; Zhang et al., 2013), thus

101   making it difficult to compare the effect in different soils, particularly at different temperatures

102   (Fang et al., 2018). Therefore, in this study, two contrasting cultivated soils (Vertisol and Luvisol)

103   originating from subtropical (Vertisol) and semi-arid (Luvisol) regions were used to co-investigate

104   the effect of crop residue in different soil types and at different temperatures on the priming of

105   SOC.

106   Crop residue quality also influences temperature sensitivity (Q_{10}) of SOC mineralization (Dai

107   et al., 2017; Karhu, 2010; Stewart et al., 2015). The temperature sensitivity of SOC mineralization

108   is referred to as Q_{10} and is defined as the rate of change in soil respiration as measured by soil CO_2

109   emission with a 10°C increase in temperature (Karhu, 2010; Kirschbaum, 1995). Application of

110   crop residues to the soil increased Q_{10} of SOC mineralization in some studies (Benbi and Khosa,

111   2014; Dai et al., 2017; Thiessen et al., 2013; Wetterstedt et al., 2010) and reduced it in others

112   (Guixiang et al., 2016; Wang et al., 2016; Zhang et al., 2013), potentially reflecting preferential

113   substrate C utilization during mineralization (Fierer et al., 2005; Hartley and Ineson, 2008; Leifeld

114   and Fuhrer, 2005). Because quality and quantity of substrate C dictates the activation energy

115   requirement of the decomposers and influences the Q_{10} of SOC mineralization (Davidson and

116   Janssens, 2006; Thiessen et al., 2013). It is apparent that the interactions of residue C with

117   incubation conditions like temperature and soil properties affect Q_{10} of SOC mineralization.

118   Incubation of soils under controlled conditions using ^{13}C labeled substrate is the most widely used

119   method for partitioning of the total respired CO_2 into C derived from crop residue and SOC

120   (Thiessen et al., 2013). In this study, we hypothesized that (1) the higher temperature will

121   accelerate positive priming of SOC by wheat residue, relative to lower temperatures, (2) the

122   priming would be higher in a clay- and C-rich Vertisol compared to a clay- and C-poor Luvisol,

123   and (3) the wheat residue application will increase the temperature sensitivity of SOC

124   mineralization.

125

2. Materials and methods

To test whether crop residue addition in soil can affect priming on SOC at different temperatures and how these responses are modulated by soil types, we used a laboratory based soil incubation approach. In this study, we incorporated a ^{13}C labeled wheat residue with two contrasting soils (see below) from two separate long-term experiments in Australia (Sarker et al., 2018; Trivedi et al., 2017) at four temperatures (13, 23, 33 and 43°C). These temperatures were selected because aboveground mean annual maximum and minimum surface temperatures may reach above 30°C and below 15°C in sub-tropical and semi-arid regions during different crop growing seasons (Zimmermann et al., 2012). We partitioned different C sources in the CO_2 derived from the added wheat residue C and native SOC using a two-pool C isotopic model (Balesdent and Mariotti, 1996).

2.1. Study site and soil sample preparation

The soils used for the incubation study were from a Luvisol and a Vertisol of Australia. The Vertisol (clayey soil) was collected in November 2014 from a 46-year-old field trial conventional tillage, stubble retained and nitrogen fertilized (90 kg N ha^{-1} yr^{-1}) under a continuous wheat cropping system at the Hermitage Research Station (28°12'S, 152°06'E), Queensland (QLD). The native vegetation in this soil type before the cropping system trial was a predominately C_4 grass vegetation, while C_3 vegetation, mostly wheat crops, has contributed to SOC at this site, resulting in a mixed C_3–C_4 value of SOC, i.e. -19.05‰ (Table 1). A detailed description of the Hermitage trial site is given in Dalal et al. (2011). The Luvisol (sandy clay loam soil) was collected in April 2015 from a long-term conservation agriculture cropping system experiment established in 2007 at the Cunderdin College of Agriculture (117 °14'E, 31°38'S) in Western Australia. The site has predominately C_3 vegetation under a Mediterranean-type environment with a 20-year average rainfall of 300 mm. The Luvisol at the selected experimental plots received high C inputs

149   (continuous cereals; no-tillage disc seeder) (Trivedi et al., 2017). A corer was used to randomly

150   sample the soil (0-10 cm depth) from three replicated plots under a wheat rotation treatment. The

151   three field replicates were taken as three replicated samples in the laboratory incubation

152   experiment. Fresh soils were immediately transported to the laboratory. All visible roots and wheat

153   residue materials were removed from the collected soil, and the samples were passed through a 2-

154   mm sieve to remove larger wheat residue fragments and particles. Soils were stored at 4°C until

155   further analysis. The concentration of C and N in the initial bulk soil and wheat residue was

156   determined by an elemental analyzer (LECO TruMac CN-analyzer, Leco Corporation, USA). The

157   $\delta^{13}C$ signatures of SOC and wheat residue were determined using a stable isotope ratio mass

158   spectrometer (IRMS; Delta V, ThermoFinnigan). The physicochemical properties of the two soils

159   and wheat residue are given in Table 1.

160   *2.2.Production of ^{13}C-labeled wheat residue*

161   The procedure for isotopically labelling wheat residue is outlined in Fang et al. (2016). Briefly,

162   wheat was grown in a 2-hactare experimental plot located ~10 km east of Condobolin, New South

163   Wales, Australia. At the heading growth stage (September 2015), a smaller micro-plot (1.8-m

164   length $\times$ 2.0-m width; 8 wheat rows) was covered with a transparent chamber, constructed with 25

165   mm thick PVC tubing and 200 µm thick clear high density polyethylene sheet (Gro-tuff HDPE,

166   89% light transmission, Cheltenham, Victoria, Australia). The extra HDPE sheet was buried inside

167   soil ditches (10-cm deep) and covered with moist soil to ensure good sealing of the chamber. The

168   wheat plants inside the chamber were then pulse labelled with 10.0 l $^{13}CO_2$ (99.0 atom% ^{13}C,

169   Cambridge Isotope Laboratories, Andover, MA, USA) (with ~ 300 to 3,000 µmol photons m^{-2} s^{-1}

170   of maximum photosynthetic active radiation). The ^{13}C-labelled CO_2 was injected into the sealed

171   chamber through a flow meter (S325-15-170-F/M CO$_2$, Influx Duff and Macintosh, Gascon

172 Systems, Sydney) at 300 to 500 cm^3 min^{-1}. The chamber air was circulated by two battery operated

173 mini-fans. The chamber CO_2 concentration was monitored using a portable CO_2 probe (Vaisala

174 GMP 343, Helsinki, Finland), which temporarily reached ~700-800 ppm and then decreased. Air

175 temperature inside the chamber increased from 22.0 to 38.0°C within a few hours after the chamber

176 closure and started to decrease after 4 pm. After injection of ^{13}C-labelled CO_2 at ~ 2 pm, the

177 chambers were kept sealed for ~ 20 h to maximize uptake of overnight respired $^{13}CO_2$, and were

178 opened after the night-accumulated CO_2 in the chamber decreased to < 200 ppm (~ 10 am). The

179 wheat plants continued to grow in the field until they were harvested 50 days after pulse labelling.

180 The plants were dried at 60°C. The wheat stem portion after removal of leaves was then separated

181 from the whole plant and ground to <2 mm prior to incubation in the soils (Fang et al. 2016). Total

182 C, total N, δ^{13}C, and C:N ratio in the wheat stem are 46±0.071%, 0.54 ±0.001%, 583.58±15.054‰

183 and 85±0.099, respectively.

184 *2.3. Incubation and sampling*

185 The wheat residue (<2 mm) was thoroughly mixed with each of the two soils (<2 mm) and

186 homogenized prior to incubation. Briefly, the treatment consisted of: (a) 20 g of each of two soils

187 (dry weight basis) treated with 4.55 mg g^{-1} soil ^{13}C labelled ground wheat stem residue corresponding

188 to 5 t/ha residue in 470 ml glass jars; and (b) 20 g soil (dry weight basis) without wheat stem residue

189 (control). A blank glass jar without soil and residue was included for C isotopic mass correction and

190 accounting for the atmospheric CO_2 concentration present in the headspace of the incubation jars.

191 All treatments were replicated three times and incubated at four different temperatures, that is, 13,

192 23, 33 and 43°C. Soil moisture was adjusted to field capacity moisture content (-33 kPa pressure)

193 at the start of the incubation and was maintained periodically throughout the experiment by

194 weighing the jars and adding water to replace water lost to evaporation. After gas sampling, all

195   bottles were opened for 20 min to refresh headspace oxygen and CO_2 and then resealed with the

196   caps. Headspace gases were sampled at regular interval on fixed days (1, 3, 6, 9, 13, 17, 24, 31, 38,

197   45, and 52 days of incubation). The gas samples were drawn from the incubation jars using a syringe

198   and immediately transferred to an evacuated gas vial. The unequal interval was designed to capture

199   the asymptotic decrease commonly observed in incubation experiments (Townsend et al., 1997).

200   Concentration of total headspace CO_2 was measured via gas chromatography (Agilent Technologies

201   model 7890A). The C mineralization rate was calculated as the change in headspace CO_2

202   concentrations (μg C) per gram soil (dry wt. equivalent) per unit incubation time (day). Relative

203   abundances of $^{13/12}CO_2$ were determined via Cavity Ring-down Spectrometry (CRDS) using a

204   PICARRO G2201-*i* analyser with accuracy to $\pm$ 0.05% for CO_2 and 0.1‰ for ^{13}C-isotopic

205   composition of CO_2.

206   *2.4. Partitioning of CO_2-C from soil and wheat residue*

207   The isotopic composition of control soil and residue treated soil was calculated using the

208   chemical and isotopic mass balance equation (Mary et al., 1992) as given below:

209   *Control soil*

210   The respired CO_2 from the control soil jar without residue constitutes CO_2 originating from SOC

211   mineralization and the blank atmospheric CO_2. The isotopic composition of the control soil δ_{cs} can

212   be calculated as:

213    $Q_{cs} = Q_{ts} - Q_{blank}$ (1)

214    $\delta_{cs} = \dfrac{Q_{ts} \times \delta_{ts} - Q_{blank} \times \delta_{blank}}{Q_{cs}}$ (2)

215   where, Q_{cs} is the amount of CO_2-C derived from the soil and δ_{cs} is its isotopic composition; Q_{ts} is

216   the total amount of CO_2-C in the soil and δ_{ts} is its isotopic composition; and Q_{blank} is the amount of

217   CO_2-C in the blank jar, and δ_{blank} is its isotopic composition.

218   *Residue treated soil*

219   The respired CO_2 from the residue treated soil jar (Q_{rs}) constitutes CO_2 originating from

220   mineralization of both SOC and residues and the blank atmospheric CO_2.

221    $Q_{rs} = Q_{trs} - Q_{blank}$ (3)

222   The isotopic composition of residue-treated soil (δ_{rs}) can be calculated as:

223    $\delta_{rs} = \dfrac{Q_{trs} \times \delta_{trs} - Q_{blank} \times \delta_{blank}}{Q_{rs}}$ (4)

224   where, Q_{rs} is the amount of CO_2-C derived from residue plus soil (after subtraction of the amount

225   of CO_2-C in the blank jar) and δ_{rs} is its isotopic composition; and Q_{trs} is the total amount of CO_2-

226   C from the soil plus residue, and δ_{trs} is its isotopic composition.

227   The proportion of residue derived CO_2-C (F_r) in the total CO_2-C evolved was determined using a

228   two pool model as described by Balesdent and Mariotti (1996):

229    $F_r = \dfrac{\delta_{rs} - \delta_{cs}}{\delta_r - \delta_{cs}}$ (5)

230    $F_s = 1 - F_r$ (6)

231    $Q_{res} = F_r \times Q_{rs}$ (7)

232    $Q_{soil\text{-}r} = F_s \times Q_{rs}$ or $Q_{rs} - Q_{res}$ (8)

233   where, F_s is the proportion of soil derived CO_2-C, Q_{res} is C mineralized from residue in the soil,

234   and $Q_{soil\text{-}r}$ is C mineralized from the soil treated with residue.

235   *Priming effect*

236   The priming of SOC induced by wheat residue (Q_{Pr}) was calculated as (Kuzyakov and Bol, 2006):

237   Q_{Pr} (Primed SOC by residue) $= Q_{soil\text{-}r} - Q_{cs}$ (9)

238   where, $Q_{soil\text{-}r}$ is C mineralized from native soil after residue application and Q_{cs} is C mineralized

239   from native soil without residue application.

240

241   *2.5. Temperature sensitivity of mineralization rate (Q$_{10}$)*

242   The temperature sensitivity of soil respiration (denoted as Q$_{10}$) represents the difference in

243   respiration over a 10°C interval measured during the incubation period for both temperatures. A

244   time series of Q$_{10}$ values for instantaneous mineralization rates of residue and soil C were

245   determined by the following Q$_{10}$ model (Kirschbaum, 1995):

246    $$Q_{10} = \frac{R_{tT2}}{R_{tT1}}^{(\frac{10}{T2-T1})}$$ (10)

247   where, R$_t$ is the C mineralization rate at incubation time t; and T$_1$ and T$_2$ are two different

248   incubation temperatures.

249   *2.6. Statistical analysis*

250   All data were tested for normality and homogeneity of variance. Log-transformation was applied,

251   if the transformation improved the normality and variance substantially. The data were statistically

252   analyzed using SPSS software (version 21.0, SPSS Inc., Chicago, IL, USA); the significance level

253   was set at P = 0.01. Repeated measures ANOVA was employed to determine the effects of

254   sampling time, temperature and their interaction on observed properties viz., respiration rates, Q$_{10}$

255   and cumulative respiration. Tukey's HSD multiple comparison method was used to compare the

256   means. A two-way analysis of variance was performed for comparing the means of observed data

257   among treatments. Pearson correlation was performed to test the relationship between priming and

258   incubation temperature, temperature and Q$_{10}$ of SOC mineralization.

3. Results

3.1. Soil and residue C mineralization

The SOC mineralization was significantly influenced by the interactive effects of residue, temperature, soil and time (Table S1). The cumulative SOC mineralization increased exponentially and levelled off as the incubation proceeded (Fig. S1). The cumulative native SOC and residue C mineralization (Fig. S1) increased in both soils as the incubation temperatures were increased. Wheat residue addition triggered the mineralization of native SOC to CO_2 in both soils, which was significantly greater at higher (43°C) than lower temperatures (13°C) (Fig. S1). However, residue addition at lower incubation temperatures (13 and 23°C) had no significant effect on mineralization of SOC in the Vertisol. The mineralization of residue C significantly ($p<0.01$) increased with incubation temperature (Fig. S1e and f) in each soil. The total residue C mineralization ranged from 754.1 to 1264.3 μg-CO_2-C g^{-1} soil in the Vertisol and 780.1 to 1274.2 μg-CO_2-C g^{-1} soil in the Luvisol. There was no difference in total residue C mineralization between the Vertsiol and the Luvisol.

The two soils differed in their C content therefore SOC mineralization was normalized by initial SOC content of the soils (Fig. 1a, b, c and d). For the control Vertisol, 1.3, 2.7, 3.6, 5.0 % of initial SOC was mineralized during the incubation at 13, 23, 33 and 43°C, respectively. The corresponding values for the Luvisol were 1.9, 4.9, 8.4 and 11.2 % (Fig. 1c and a). Residue addition caused a significant ($p<0.05$) increase in the total amount of mineralized CO_2-C from both soils, and the increase was higher for the Luvisol than the Vertisol. Similar to SOC, residue C mineralization was normalized by residue C (Fig. 1e and f). The soil had no significant effect on the proportion of cumulative residue C mineralization at all temperatures (Fig. 1e and f). The

281 cumulative mineralization of residue C increased with increasing incubation temperatures till 43°C

282 for the Luvisol, and remained constant after 33°C for the Vertisol.

283 *3.2. Priming of SOC*

284 Wheat residue addition significantly ($p<0.05$) primed mineralization of SOC in both soils at all

285 incubation temperatures; however, the direction and magnitude of SOC priming changed over time

286 (Fig. 2a and b). Though all soils experienced positive priming initially, negative priming was also

287 observed (as reflected by a dip in the cumulative priming curve). Nevertheless, the net result was

288 positive priming at all incubation temperatures. The shift from negative to positive priming

289 occurred early at higher temperatures and later at lower temperatures. The magnitude of primed

290 SOC during the incubation period was very low at 13°C (*cf.* 33 and 43°C), particularly for the

291 Vertisol (Fig. 2). The total priming over the incubation period ranged from 112.9 to 229.6 µg C g^{-1}

292 ^{1} soil in the Luvisol, and from 4.1 to 316.6 µg C g^{-1} soil in the Vertisol. Like SOC mineralization,

293 the cumulative primed soil CO_2-C was normalized by initial SOC and was expressed as percent of

294 SOC primed which ranged from 0.02 to 2.4% across soils and temperatures (Fig. 2c). Wheat

295 residue addition primed SOC mineralization, however the effect was different for the two soils.

296 The normalized priming was greater for the Luvisol than the Vertisol, especially at the two lower

297 temperatures (Fig. 2c). A significantly positive correlation ($p<0.01$) was observed between

298 temperature and priming for the Vertisol, but no trend was observed for the Luvisol (Fig. 2c).

299 3.3. *Temperature sensitivity of SOC and wheat residue C mineralization (Q_{10})*

300 The main effects of temperature, soil type and the interaction effect of time, temperature

301 and soil were significant on the Q_{10} of SOC mineralization in the control soils (Table S2). The

302 average Q_{10} values of SOC mineralization ranged from 1.42 to 2.21 for the Luvisol and 1.41 to

303 1.75 for the Vertisol (Table 2). For the wheat residue treated soils, the Q_{10} of SOC mineralization

304 was significantly influenced by temperature, soil, time of incubation and their interactive effect

305 (Table S2). The average Q_{10} values of SOC mineralization in the residue treated soil ranged from

306 1.47 to 2.33 for the Luvisol and 1.44 to 2.41 for the Vertisol (Table 2). Residue application

307 significantly increased the average Q_{10} values of SOC mineralization for the Vertisol at the 13-23

308 and 23-33°C ranges. However, the effect of residue was insignificant on the Q_{10} of SOC

309 mineralization at 33-43°C for the Vertisol and for the Luvisol at all temperature ranges (Table S2).

310 The Q_{10} values of SOC mineralization for the control and residue treated soil significantly

311 decreased with increase in temperature from 13 to 43°C in both soils.

312 The Q_{10} of wheat residue C was significantly affected by the main and interactive effects

313 of temperature, soil and incubation time (Table S2). The Q_{10} values of the wheat residue C

314 mineralization were greater for the low temperature range (13-23°C) than the high temperature

315 range (33-43°C). The average Q_{10} values ranged from 0.81 to 1.13 at 13-23°C and 1.53 to 1.66 at

316 33-43°C. The Q_{10} values of wheat residue C were significantly higher for the Luvisol than the

317 Vertisol at 13-23 and 23-33°C. However, at 33-43°C, the Q_{10} values of wheat residue C

318 mineralization was significantly greater for the Vertisol than the Luvisol. These results indicated

319 that there was a negative correlation between temperature and Q_{10} of SOC mineralization and

320 residue C mineralization.

321 The Q_{10} dynamics of SOC mineralization in the control Vertisol decreased from the first

322 day of incubation to the 17th day and increased afterwards until the end of incubation at the 13–

323 23°C temperature range (Fig. 3). However, at 23–33 and 33–43°C, the Q_{10} values increased from

324 the first day of incubation and decreased after the 13th and 6th day at 23–33 and 33–43°C,

325 respectively. Similar variation of Q_{10} with incubation time was observed for the Luvisol.

326 Temperature had significant effects on the Q_{10} values of SOC mineralization in the control and

327 residue treated soils, and of residue-C mineralization at different time points of incubation. The

328 Q_{10} variability of residue-C mineralization decreased with increasing incubation time.

329 **4. Discussion**

330 *4.1. Soil organic C priming and mineralization*

331   Our first hypothesis that wheat residue addition will accelerate positive priming of SOC at

332 higher compared to lower temperatures was true for the Vertisol only. By contrast, for the Luvisol,

333 the magnitude of positive priming decreased with increase in temperature above 23°C. It is known

334 that the input of crop residues would likely to increase substrate availability, microbial growth and

335 extracellular enzyme activities in both soils (Thiessen et al., 2013; Blagodatsky et al., 2010; Fang

336 et al., 2018; Shahbaz et al., 2017b; Wutzler et al., 2008). However, the increased residue-induced

337 positive priming from 13 to 43°C for the Vertsiol may be attributed to greater microbial growth

338 and activity (Fang et al., 2018) and higher SOC content in the Vertisol than Luvisol (Table 1). This

339 may have caused constant microbial accessibility and decomposability of relatively stable

340 (resistant) SOC fractions induced by the residue input after the depletion of labile SOC in the

341 Vertisol. A similar mechanism was also proposed by Kuzyakov (2010), who predicted that

342 incubation temperature may mediate SOC priming, for example, increasing temperature can

343 accelerate most enzyme activities, thus increasing SOC mineralization (Thiessen et al., 2013).

344 Furthermore, low temperatures could retard soil microbial activity, as evident from the

345 significantly lower cumulative CO_2-C mineralization at 13°C relative to the higher temperatures

346 in both soils (Fig. S1). This suggests that due to the retarded microbial activity at low temperatures,

347 soil microbes may not be able to decompose resistant SOC fractions, such as in the Vertisol, thus

348 decreasing positive SOC priming (Kuzyakov, 2010; Thiessen et al., 2013). On the other hand, for

349 the Luvisol, the decrease in positive priming with increasing temperature was possibly due to high

16

350 cumulative SOC mineralization in both control (without residue) and residue treated Luvisol for

351 the temperatures >23°C (Fig. S1). This indicates an equivalent accessibility and decomposability

352 of stable SOC fractions in the Luvisol induced by the increasing temperatures with or without the

353 input of residues. A similar observation of higher priming effect below 20°C than above 20°C was

354 reported by Zhang et al. (2013) and Kuzyakov (2010). Another potential explanation could be a

355 quick loss of labile C above 23°C during the first day of incubation (Fig. 1). The first 1 % of initial

356 SOC is assumed to be labile C across all incubation temperatures (Conant et al., 2008). At

357 temperature >23 °C, the loss of labile SOC during the initial phase of residue mineralization could

358 have changed the soil microbial biomass stoichiometry (C:N), because residue retention is known

359 to increase microbial N content *via* the residue induced microbial N immobilization (Wang et al.,

360 2018). It seems that all these above mentioned soil microbial processes may have occurred rapidly

361 in the Luvisol (*cf.* Vertisol). Thus, we assume that preferential microbial substrate utilization

362 (Blagodatskaya and Kuzyakov, 2011; Shahbaz et al., 2017b; Thiessen et al., 2013) and changes in

363 microbial community structure (Anderson et al., 2011) may have decreased SOC priming by the

364 residues at temperature above 23°C in the Luvisol. The microbial enzyme activities may also shift

365 to degrade relatively resistant C (Zimmermann et al., 2012). Such potential shifts in microbial

366 communities and their enzymes to degrade the relatively resistant SOC may have contributed to

367 the change in the magnitude of native SOC priming by wheat residue with increasing temperature.

368 In this study, we observed a switch from positive to negative priming and then again positive

369 across incubation temperatures in both soils. The initial positive priming may be attributed to

370 growth of r-strategists that respond quickly to newly available C sources (Kuzyakov et al., 2000;

371 Kuzyakov, 2010; Fang et al., 2018), while mineralizing labile pools of residue C and SOC. The

372 switch from positive to negative priming observed in some treatments during the intensive phase

373 of residue mineralization could be ascribed to preferential utilization of easily available residue-

374 derived C compared to native SOC (Blagodatsky et al., 2010; Thiessen et al., 2013; Shahbaz et al.,

375 2017a). Further, in later stages, K-strategists may predominate, and are likely to co-metabolize

376 resistant SOC fractions (Wu et al., 1993; Kuzyakov, 2010). The decline in microbial biomass after

377 the initial phase of rapid residue mineralization results in accumulation of microbial necromass

378 which would act as a soil primer to induce native SOC mineralization (Kallenbach et al., 2016;

379 Rousk et al., 2015; Shahbaz et al., 2017b).

380 To study the effect of different soil properties on priming, our second hypothesis was that

381 priming would be higher in the Vertisol compared to the Luvisol because the Vertsiol has higher

382 SOC and clay content than the Luvisol. However, our results differed from our hypothesis because

383 the priming was higher for the Luvisol than the Vertisol. According to Zhang et al. (2013), the

384 difference in properties of the two soils, for example, the nature of organic-clay mineral

385 complexation, texture, clay content and C:N ratio could be the probable reason for the different

386 magnitude of SOC priming. Previous studies have suggested that higher stabilization of SOC

387 through organo-mineral associations in a smectite clay-rich soil would limit the accessibility of

388 SOC to microorganisms (von Lützow and Kögel-Knabner, 2009; Fang et al., 2014). This can be a

389 more important mechanism for lowering the residue induced priming of SOC for the Vertisol than

390 Luvisol. This corresponds to observations of Fang et al. (2015) where a biochar treated Inceptisol

391 (sandy soil) had higher positive priming than a biochar treated Vertisol under similar temperatures.

392 Therefore, our finding strongly indicates that the magnitude and direction of priming depends on

393 incubation temperature and soil types.

394 *4.2. Q_{10}*

395 In this study, wheat residue addition significantly ($p<0.01$) increased the Q_{10} of SOC

396 mineralization in the Vertisol, thus supporting our third hypothesis, although there was no

397 difference in the Q_{10} between the control and residue treated Luvisol. This indicates that the Q_{10}

398 of SOC mineralization in the residue treated soil was influenced by soil type, as reported previously

399 (Dai et al., 2017; Wang et al., 2016). This different response may be attributed to differences in

400 physico-chemical properties between the two soils, for example, C:N ratio, texture and pH (Table

401 1). The results from the Vertisol agree with observations of previous studies that suggested that

402 the addition of a C substrate increased Q_{10} (Benbi and Khosa, 2014; Dai et al., 2017; Davidson and

403 Janssens, 2006; Gershenson et al., 2009; Sandeep et al., 2016; von Lützow and Kögel-Knabner,

404 2009; Zhu and Cheng, 2011).

405 In the current study, addition of wheat residue increased SOC mineralization (Fig. S1) and

406 this process may have enhanced the growth and activity of microbes and consequently

407 immobilization of N (Giardina and Ryan, 2000; Wang et al., 2016). Furthermore, the increase in

408 Michaelis-Menten parameter (Km) with a decrease in soil available nitrogen and immobilization

409 (Eberwein et al., 2017) could have increased the Q_{10} values (German et al., 2012) for SOC

410 mineralization in the residue treated Vertisol. Another probable mechanism could relate to the

411 addition of low quality wheat residue (C:N = 85:1), which may increase the activation energy

412 requirement for SOC mineralization with a corresponding increase for the Q_{10} values (Gershenson

413 et al., 2009; Thiessen et al., 2013). However, our findings contradict the reports that addition of

414 external organic inputs decreased Q_{10} of SOC mineralization (Wang et al., 2016).

415 In the control soil without residue addition, higher Q_{10} was observed in the Luvisol than

416 Vertisol at temperature below 33°C. The Q_{10} of the control Vertisol was lower despite having

417 higher SOC content and C:N ratio than the control Luvisol (Table 1). This could be probably due

418   to higher SOC mineralization in the clay-poor Luvisol than the clay-rich Vertisol (Fig. S1). Soil

419   texture is the primary driver for mineralization of SOC (Mtambanengwe et al., 2004; Xu et al.,

420   2016). This could be because the higher specific surface area of clay minerals in the clay-rich

421   Vertisol may physically and chemically protect SOC from microbial and enzymatic mineralization

422   *via* organo-mineral interactions (Six et al., 2002; Xu et al., 2016).

423   The Q_{10} of SOC mineralization is significantly affected by temperature in both treated and

424   control soils. A negative correlation was observed between Q_{10} and temperature. The greater

425   temperature sensitivity of SOC mineralization at lower temperature range (13-23°C) than the

426   higher temperature range (23-33 and 33-43°C) in our study is consistent with other studies (Bao

427   et al., 2016; Benbi and Khosa, 2014; Gutinas et al., 2013; Karhu, 2010; Kirschbaum, 1995; Suseela

428   et al., 2012). The decline in the Q_{10} of SOC mineralization with increase in temperature suggests

429   that the stimulation effect of warming on SOC mineralization will be lower and can partly reduce

430   C losses in these soils (Del Grosso et al., 2005). Therefore, this will result in a less positive

431   feedback to climate change than previously expected for subtropical or semi-arid cultivated soils.

432   The Q_{10} values of control soils observed in our study, ranging from 2.57 to 1.29 (Luvisol)

433   and 2.05 to 1.34 (Vertisol), agree with Q_{10} values reported by Fang et al. (2014) for similar soils

434   in these regions. In the current study, a significant increase in Q_{10} with time was found at the lowest

435   temperature range (13-23°C) in the residue treated and control soils. Our results partly agree with

436   a previous incubation study that observed an increase in Q_{10} with time at both cold and warm

437   temperatures (Thiessen et al., 2013). In the current study, the increase of Q_{10} values with time at

438   low temperature could be the result of slow depletion of labile SOC and subsequent mineralization

439   of resistant SOC fraction with higher activation energy and Q_{10} values at the later phase of

440   incubation. Whereas, for temperatures above 23°C in the residue treated and control soils, the Q_{10}

20

441 dynamics either decreased or remained constant. Therefore, the trend of changes in Q_{10} dynamics

442 seems to be influenced by incubation temperature and substrate quality (Curiel Yuste et al., 2007;

443 Thiessen et al., 2013).

444 **5. Summary**

445   In conclusion, wheat residue addition increased the priming of SOC in two cultivated,

446 subtropical or semi-arid, soils with contrasting organic C and clay contents. The magnitude of

447 priming was higher for the low-C and clay-poor Luvisol than the high-C and clay-rich Vertisol at

448 all temperatures, indicating that the Vertisol is more resistant to priming. On the other hand, the

449 priming of SOC mineralization caused by wheat residue increased with temperature for the

450 Vertisol but decreased with temperature for the Luvisol, which may be linked to the timing of

451 microbial accessible resistant SOC fractions in the soils. Wheat residue addition significantly

452 increased the Q_{10} of SOC mineralization at lower temperature ranges (13-23 and 23-33°C) for the

453 Vertisol only. The significant negative correlation between Q_{10} and temperature for SOC and

454 residue-C mineralization means a lower positive feedback response to climate change in high-C,

455 smectite-rich soils relative to low-C kaolinitic soils.

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