Effectiveness of direct application of top dressing with spent coffee grounds for soil improvement and weed control in wheat-soybean double cropping system

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**ABSTRACT**

With increasing annual global coffee consumption, the amount of spent coffee grounds (SCGs) increases. Direct application of SCGs in large agricultural fields can potentially improve soil and control weeds in an environmentally safe manner. However, except for composting, the use of SCGs during cropping has not been implemented thus far because of inhibitory effects on crop growth observed in pot-based studies. We evaluated the effect of a top dressing approach to direct SCG application on crop biomass, soil improvement, and weed control, through double cropping field experiments using wheat and soybean. The field experiments were conducted over six successive cropping seasons in an upland field converted from paddy, and crop and weed biomass as well as soil total carbon and nitrogen were investigated. To avoid growth inhibition, the SCGs were surface broadcasted after crop germination to mimic living mulch. The soil total carbon and nitrogen contents increased significantly under an SCG concentration of 5 kg m\(^{-2}\) or more, approximately 20 months after the first application, whereas SCG application did not significantly affect crop yield except for the first cropping of wheat. In addition, the 10 kg m\(^{-2}\) SCG application reduced the weed biomass by 50% or more during cropping, except for the wheat cropping in the second year. We concluded that top dressing with SCGs after crop germination is an efficient method for sustainable agricultural production, although further detailed studies of SCGs’ effect on the crop growth and soil characteristics are required.
Introduction

Coffee is one of the world’s most popular beverages and the second most traded commodity after petroleum (Murthy & Naidu, 2012a). In 2017 and 2018, for example, approximately 175.6 million 60-kg bags were produced globally (International Coffee Organization, 2021). Such high production generates more than two million tons of coffee residues, such as coffee pulp, husk, and grounds annually (Zabaniotou & Kamaterou, 2019). Particularly, disposal of spent coffee grounds (SCGs) is problematic because of the high oxygen demand during decomposition and the potential release of residual caffeine, tannin, and polyphenol contaminants, resulting in environmental pollution (Kovalcik et al., 2018). On average, approximately 1 kg of soluble coffee can produce 2 kg of wet SCGs (Tsai, 2017). Several studies have evaluated the recycling potential of SCGs, and low-cost and effective strategies for SCG recycling have gained importance (Atabani et al., 2018). For instance, SCGs can be used as fuel because of their high calorific value compared to other residues (Haile et al., 2013). In addition, SCGs have functional properties including water-holding capacity, oil-holding capacity, emulsion activity and stability, and antioxidant potential, which facilitate their reutilization in different biotechnological processes (Ballesteros et al., 2014; Campos-Vega et al., 2015).

Attempts have already been made to use SCGs for agricultural purposes. Some studies have indicated that SCGs contain nitrogen (1.2%–2.3%), phosphorus (0.02%–0.5%), and potassium (0.35%) (Cruz et al., 2012; Mussatto et al., 2011). The concentrations of nitrogen and potassium are higher than those in general agricultural organic waste products used for composting, such as cattle manure (Kasongo et al., 2011). SCGs affected the soil carbon and nitrogen content, but did not affect soil phosphorus and potassium content (Liu & Price, 2011). Yamane et al. (2014) have reported that the soil amendment effects of SCGs, particularly soil carbon and nitrogen enrichment, are substantially greater compared to the effects of horse manure. Wakasawa et al. (1998) reported that the NO$_3^-$-N content of soil incorporated with SCGs gradually increased after four months of application. These results imply that SCGs have the potential to improve soil fertility.

The application of SCGs to soil is known to affect plant growth. Kito and Yoshida (1997) have reported that high concentrations of SCGs inhibit plant growth, and Pandey et al. (2000) attributed plant growth inhibition to the chlorogenic acid contained in SCGs. Particularly, SCGs inhibit plant germination (Ciesielczuk et al., 2018). These findings indicate that SCGs could be effective agricultural materials for weed control, and the weed control potential of SCG application has been demonstrated (e.g., Kito & Yoshida, 1997). In addition, Yamane et al. (2014) have reported that top dressing with SCGs at more than 10 kg m$^{-2}$ facilitates weed control in fields for six months. These results suggest that the use of SCGs may be effective for weed management during crop cultivation; however, there are no studies on the impact of SCGs on weed control in cultivated crop fields.

Thus far, the use of SCGs in crop cultivation has not been proposed, because of the potential inhibitory effects of SCG application on crop growth. Direct application of SCGs to soils has been found to be detrimental to cultivated crops because of the high phenol content, acidity, and carbon/nitrogen ratio (Hardgrove & Livesley, 2016). However, top dressing with SCGs may decrease the inhibitory effect on cultivated crops. Another inhibitory effect of SCG application is an associated reduction in mineral nitrogen content in the soil (Wakasawa et al., 1998), and these authors suggest the necessity of nitrogen fertilization when SCGs are applied. Although Yamane et al. (2014) conducted field experiments, they were not in the cropping field. Despite all the research conducted on SCG application in cropping, no long-term field crops research has been conducted to evaluate the effects of continuous SCG application and the synergistic effect of the addition of chemical fertilizer. Therefore, evaluating the effect of SCGs in the long-term cropping field experiment is required for practical use.

Given that soil nutrient management is essential for sustainable productivity in the double cropping system of soybean and wheat (Behera et al., 2007), this study aimed to evaluate the effects of top dressing with SCGs on crop biomass, soil improvement, and weed control by conducting wheat and soybean double cropping field experiments, where the soil surface was covered with SCGs after crop germination to mimic living mulch application. We hypothesized that a top dressing application of SCGs after crop germination minimizes the inhibitory effect on crop growth and positively impacts weed control.

Materials and methods

Study site

Field experiments were conducted from 2017 to 2020 in an upland field converted from paddy on a farm in Nara, western Japan (latitude 34º67´ N, longitude 135º75´ E,
175 m a.s.l.). In 2017, during the wet summer (from June to July) and the hot summer after the wet season (from August to October), the experimental site was cultivated with crotalaria, Guinea grass, and sunflower as green manure crops. Compound chemical fertilizer (N: P₂O₅: K₂O = 60: 60: 60: kg ha⁻¹) was applied before sowing, and the green manure crops were mixed-seeded in the fields and harvested before ear emergence. The experimental site soil, just prior to experimentation, was classified as a sandy clay loam (sand: silt: clay = 72.7: 17.3: 10) with 1.97 g total C kg⁻¹, 0.19 g total N kg⁻¹, 6.46 mg available P kg⁻¹, and 0.95 cmol K kg⁻¹. The monthly temperature and rainfall recorded during the experiment are presented in Figure 1.

**Experimental design**

We used wheat and soybean as our experimental crops, particularly *Triticum aestivum* ‘Norin 61’ and *Glycine max* ‘Sachiyutaka’ in 2018 or ‘Fukuyutaka’ in 2019 and 2020, as these are recommended cultivars for western Japan. The experimental crops were grown for six successive cropping seasons from November 2017 to November 2020. Wheat was cultivated in the first, third, and fifth cropping seasons (winter seasons), and soybean in the second, fourth and sixth cropping seasons (summer seasons). A week before each sowing, the fields were prepared and leveled using a rotary plow, to a depth of 15 cm. Seeds of the wheat cultivar were sown in rows at a rate of 80 kg ha⁻¹ with 30 cm row spacing on November 21st, 28th, and 27th, in 2017, 2018, and 2019, respectively. Three seeds of the soybean cultivars were manually sown at each planting point on July 27th, 8th, and 29th in 2018, 2019, and 2020, respectively. The relatively late sowing of soybean in both 2018 and 2020 was due to heavy rainfall during the wet season. The row and intra-row spaces were 0.7 and 0.25 m, respectively. After plant emergence and establishment, thinning and complementary planting were conducted to adjust the planting density to 5.71 plants m⁻². No pest management was implemented, and irrigation was occasionally conducted during the dry spells (from early August to early September). This was done to avoid the negative effects of prolonged drought stress on soybean growth. To enhance the weed control function, weeding was performed manually before the soil surface was top dressed with SCGs to mimic living mulch.

Nine treatments (three SCG treatments × three chemical fertilizer treatments) were arranged in a completely randomized block design with six replications. The size of each plot was 2.8 m × 1.5 m. The same treatments continued at the same plots. Three quantities of SCGs were set: control (0 kg m⁻²), low (5 kg m⁻²), and high (10 kg m⁻²). The SCGs

Figure 1. Monthly average air temperature (°C) and precipitation (mm) at the field experiment site in Nara, western Japan. The data were obtained from the Japan Meteorological Agency website (https://www.data.jma.go.jp/obd/stats/etrn/index.php).
were surface broadcasted to the low and high concentration plots at 64, 24, 68, 22, 65, and 27 days after sowing during the six cropping seasons, respectively. The wet granule SCGs after the extraction were provided by UCC Ueshima Coffee Co., Ltd. (Kobe, Japan). The chemical characteristics of SCGs are shown in Table 1. The total carbon and nitrogen contents of the SCGs were 249 g kg⁻¹ and 22 g kg⁻¹, respectively, and the water content was 58.3 ± 0.3%. Phenolic acids, caffeic acid and chlorogenic acid, induce crop growth inhibitory effect (Nishino et al., (2020)), and the contents of SCGs in the present study are 22 mg kg⁻¹ and 408 mg kg⁻¹, respectively. Three chemical fertilizer treatments were set: none, one dose for wheat, and double doses (one dose for each of wheat and soybean); the unit dose contained 24 kg ha⁻¹ each of N, P₂O₅, and K₂O. The fertilizer application dates for wheat were 132 days, 127 days, and 118 days after sowing, in 2018, 2019 and 2020, respectively. The application dates for soybean were 39, 40 and 41 days after sowing, respectively.

**Measurements**

The wheat and soybean crops were harvested after the plants matured. Sampling areas of 0.9 m² (1 m x 0.9 m) and 1.05 m² (1.4 m x 0.75 m) in each wheat plot and soybean plot were harvested, respectively. Wheat was harvested on June 1st, May 30th, and May 22nd, in 2018, 2019, and 2020, respectively, and all above-ground plant parts and panicles within the sampling sub-plots were harvested. The harvested panicles were air-dried for more than three weeks. Soybean was harvested on October 31st, October 30th, and November 8th, in 2018, 2019, and 2020, respectively. The harvested seed weight was adjusted to a 15% moisture content. The above-ground dry weight of both crops was measured after oven drying at 80°C for 72 h.

Soil samples were collected from the top soil (0–20 cm deep) at the time of soybean harvesting. All soil samples were air-dried and ground to pass through a 2-mm sieve before analysis. The total nitrogen (N) content in the soil was measured using the indophenol method after digest-dial digestion (Selmer-Olsen, 1971), and the total carbon (C) content in the soil was measured using the Tyurin method (Kalembasa & Jenkinson, 1973).

**Table 1. The chemical characteristics of spent coffee grounds.**

| Compound       | Unit     | Value |
|----------------|----------|-------|
| Total C        | g kg⁻¹   | 249   |
| Total N        | g kg⁻¹   | 22    |
| Caffeine       | mg kg⁻¹  | 647   |
| Caffeic acid   | mg kg⁻¹  | 22    |
| Chlorogenic acid| mg kg⁻¹ | 408   |

The dominant weed species in the sub-plots were recorded during crop harvesting. The dominant weed species were identified by sight, and the above-ground biomass of these and other weed species was harvested separately from the crop plants during all harvests except for the wheat harvest in the first year. The dry weight of the above-ground biomass was measured after oven drying for 72 h at 80°C.

The effects of the concentrations of SCG and chemical fertilizer applications of each crop were analyzed using two-way ANOVA. For all multiple comparisons, Fisher’s LSD test was performed at the 0.05 probability level. All statistical analyses were performed using Excel Statistics Version 2015 software (Social Survey Research Information Co., Ltd. Tokyo, Japan).

**Results**

**Table 2** shows the mean values and ANOVA results for wheat and soybean productivity in response to the SCG and fertilizer applications. In the first year, the total biomass of both crops and the panicle weight of wheat were significantly lower in the plots that were top dressed with SCGs. Although not significantly different, the soybean seed weight was lower in the SCG plots. The effects of additional fertilizer on the productivity of both crops were not significant (Table 2 (a)). In the second year, the effects of SCGs on the panicle weight, seed weight, and total biomass of both crops were not significant (Table 2 (b)). The interaction effect between SCG and the fertilizer treatments was significant for wheat (Table 2 (b)), where the panicle weight was higher in the fertilizer plots that received the greatest quantity of SCGs. In the third year, neither the effects of SCGs nor the fertilizer on the panicle weight, seed weight, and total biomass of both crops were significant (Table 2 (c)). However, the interaction effect between SCG and the fertilizer treatments was significant, as indicated by a higher total soybean biomass in the non-fertilized plots that were top dressed with SCGs.

**Table 3** shows the mean value and ANOVA results for the total C and total N contents, and the C/N ratio of the soil after soybean cropping. In the first year, neither the application of SCGs nor the fertilizer had a significant effect on soil total C and total N contents (Table 3 (a)). In contrast, in the second and third years, top dressing with SCGs resulted in significantly higher amounts of total C and N in the soil (Table 3 (b), (c)). Whereas the C/N ratio was not significantly different in the first and second years, it showed the highest value in the plots top dressed with 5 kg of SCGs in the third year.
Table 2. Mean values and ANOVA results of total wheat and soybean biomass, wheat panicle weight, and soybean seed weight from a double cropping field experiment using a combination of spent coffee grounds and fertilizer applications.

|                | Wheat                  | Soybean                |
|----------------|------------------------|------------------------|
|                | Panicle weight (g m⁻²) | Panicle weight (g m⁻²) |
|                | Total biomass (g m⁻²)  | Total biomass (g m⁻²)  |
|                | Seed weight (g m⁻²)    | Seed weight (g m⁻²)    |
|                | Total biomass (g m⁻²)  | Total biomass (g m⁻²)  |
|                |                        |                        |
| (a) 2017/2018 |                        |                        |
| SCGs (kg m⁻²) |                        |                        |
| 0              | 244.6                  | 552.4                  |
| S              | 211.6                  | 439.8                  |
| 10             | 216.3                  | 457.7                  |
| Fertilizer     |                        |                        |
| None           | 217.1                  | 464.3                  |
| Single dose    | 227.6                  | 497.5                  |
| Double dose    | 227.4                  | 488.0                  |
| ANOVA          | 0.030*                 | 0.027*                 |
| Fertilizer (F) | 0.657                  | 0.731                  |
| S × F          | 0.066                  | 0.566                  |
| P value        |                        |                        |
| (b) 2018/2019 |                        |                        |
| SCGs (kg m⁻²) |                        |                        |
| 0              | 259.8                  | 523.1                  |
| S              | 268.7                  | 506.8                  |
| 10             | 247.1                  | 488.4                  |
| Fertilizer     |                        |                        |
| None           | 232.2                  | 450.7                  |
| Single dose    | 260.0                  | 515.8                  |
| Double dose    | 283.4                  | 551.9                  |
| ANOVA          | 0.628                  | 0.609                  |
| S × F          | 0.065                  | 0.098                  |
| Fertilizer (F) | 0.024*                 | 0.054                  |
| P value        |                        |                        |
| (c) 2019/2020 |                        |                        |
| SCGs (kg m⁻²) |                        |                        |
| 0              | 248.2                  | 476.7                  |
| S              | 221.0                  | 426.4                  |
| 10             | 258.0                  | 491.7                  |
| Fertilizer     |                        |                        |
| None           | 234.8                  | 441.5                  |
| Single dose    | 249.8                  | 488.3                  |
| Double dose    | 242.6                  | 465.0                  |
| ANOVA          | 0.323                  | 0.430                  |
| S × F          | 0.032                  | 0.041                  |
| Fertilizer (F) | 0.083                  | 0.071                  |

SCGs: spent coffee grounds. Fertilizer: the number of additional fertilizer applications. None: no fertilizer; Single dose: fertilizer applied only to the wheat crop; Double dose: fertilizer applied to each of the wheat and soybean crops. * and ** indicate significant effects at 0.05 and 0.01 probability levels, respectively. Means followed by different lowercase letters within columns are significantly different as per Fisher’s LSD test at P < 0.05.

Over the three years of the experiment there were consistently one, and two, dominant weed species associated with the wheat and soybean crops, respectively, as follows: first year: *Lolium multiflorum* (wheat) and *Amaranthus viridis* and *Ludwigia decurrens* (soybean); second year: *Poa annua* (wheat) and *Ludwigia decurrens* and *Digitaria violascens* (soybean); and third year: *Lolium multiflorum* (wheat) and *Digitaria violascens* and *Ludwigia decurrens* (soybean). Table 4 shows the dry weight of weeds at the maturing stage of wheat and soybean. In the first year, weed biomass was significantly lower in the plots top dressed with more than 5 kg of SCGs, and the biomass of all weed species, including the most dominant ones, was approximately twice as high in the plots without SCGs. Fertilizer effect and the interaction effect between SCGs and the fertilizer treatment were not significant in the first year (Table 4 (a)). In the second year of wheat cropping, the effect of SCGs on weed dry weight was not significant (Table 4 (b)). This may have been because most of the weeds were *Poa annua* and, consequently, there was no reduction in the number of weed species in response to SCG application. In contrast, the effect of top dressing with SCGs on the weed biomass was significant in soybean cropping. In the third year, the inhibitory effect of top dressing with SCGs on weed biomass was significant at the 1% level in both wheat and soybean cropping. In soybean cropping, the interaction effect between SCGs and the fertilizer treatment on the two dominant species was significant (Table 4 (c)).

Discussion

The extensive and intensive use of herbicides has resulted in the evolution and spread of herbicide-resistant weeds in many crop production systems (Nakka et al., 2019). Therefore, devising non-chemical and organic weed control methods for application in field cropping is imperative (Farooq et al., 2011). Allelopathy, for example, offers an innovative and attractive option for weed control in organic farming systems (Arif et al., 2015). The use of allelopathy for weed control has been extensively studied and many allelopathic compounds have been identified (Jabran et al., 2015); however, the effective use of organic materials for weed control has rarely been studied. With increasing global population and the associated decrease in available agricultural resources, effective weed management is critical for improving work efficiency and agricultural productivity, especially in upland fields. Yamane et al. (2014) have speculated that SCGs may be useful as an organic material for weed control due to their inhibitory effects on plant growth. Evaluating the effect of SCGs on the weed control in the long-term cropping field experiment is required for practical use. We found that the application of 10 kg m⁻² of SCGs as top dressing to our experimental field plots reduced the total weed biomass by 50% or more during cropping, except for the wheat crop in the second year (Table 4). These findings suggest that top dressing with SCGs after crop germination, in quantities above 10 kg m⁻² facilitates weed control during cropping. Therefore, this application method may
Table 3. Mean values and ANOVA results of soil total carbon, total nitrogen, and C/N ratio from a double cropping field experiment using a combination of spent coffee grounds and fertilizer applications.

|          | Total carbon (g kg⁻¹) | Total nitrogen (g kg⁻¹) | C/N ratio |
|----------|-----------------------|-------------------------|-----------|
| (a) 2017/2018 SCGs (kg m⁻²) |                       |                         |           |
| 0        | 23.2                  | 2.2                     | 10.8      |
| 5        | 24.9                  | 2.2                     | 11.9      |
| 10       | 23.7                  | 2.0                     | 11.9      |
| Fertilizer |                       |                         |           |
| None     | 27.9                  | 2.1                     | 11.6      |
| Single dose | 28.0                | 2.0                     | 11.8      |
| Double dose | 28.8                 | 2.2                     | 11.1      |
| ANOVA P value |                 |                         |           |
| SCGs (S) | 0.498                 | 0.402                   | 0.133     |
| Fertilizer (F) | 0.743             | 0.171                   | 0.559     |
| S x F   | 0.373                 | 0.011                   | 0.289     |
| (b) 2018/2019 SCGs (kg m⁻²) |                       |                         |           |
| 0        | 23.2b                 | 1.9b                    | 12.4      |
| 5        | 29.6ab                | 2.2ab                   | 14.0      |
| 10       | 31.8a                 | 2.5a                    | 12.7      |
| Fertilizer |                       |                         |           |
| None     | 29.8                  | 2.4                     | 12.4      |
| Single dose | 27.5                | 2.1                     | 13.1      |
| Double dose | 28.6                 | 2.1                     | 13.6      |
| ANOVA P value |                 |                         |           |
| SCGs (S) | 0.004**               | 0.000**                 | 0.295     |
| Fertilizer (F) | 0.929             | 0.147                   | 0.527     |
| S x F   | 0.857                 | 0.032                   | 0.875     |
| (c) 2019/2020 SCGs (kg m⁻²) |                       |                         |           |
| 0        | 20.5b                 | 1.9c                    | 11.0ab    |
| 5        | 28.7a                 | 2.3b                    | 12.4a     |
| 10       | 26.3a                 | 2.6a                    | 10.2b     |
| Fertilizer |                       |                         |           |
| None     | 26.0                  | 2.4                     | 11.3      |
| Single dose | 25.3                | 2.3                     | 11.2      |
| Double dose | 24.2                 | 2.2                     | 11.1      |
| ANOVA P value |                 |                         |           |
| SCGs (S) | 0.000**               | 0.000**                 | 0.030*    |
| Fertilizer (F) | 0.643             | 0.403                   | 0.989     |
| S x F   | 0.484                 | 0.211                   | 0.345     |

SCGs: spent coffee grounds. Fertilizer: the number of additional fertilizer applications. None: no fertilizer; Single dose: fertilizer applied only to the wheat crop; Double dose: fertilizer applied to each of the wheat and soybean crops. * and ** indicate significant effects at 0.05 and 0.01 probability levels, respectively. Means followed by different lowercase letters within columns are significantly different as per Fisher’s LSD test at P < 0.05.

The inhibitory effects of SCGs on crop growth have been investigated in several previous studies (e.g. Hirooka et al., 2021; Kito & Yoshida, 1997). However, these studies were all pot-based, and used soils containing SCGs. In the present study, the effect of continuous application of SCGs on crop growth was evaluated in cultivated fields using a top dressing approach. In the first year, both the wheat and soybean crops showed negative responses to SCG mulching, suggesting that the crop growth inhibition associated with the SCGs mulch could be due to inhibitory effects of the SCGs top dressing during the first year of application. Kito and Yoshida (1997) have reported that legumes such as azuki bean and soybean grow well in soils containing low concentrations of SCGs. Yamane et al. (2014) suggested that the relative tolerance of legumes to SCGs could be due to biological N₂ fixation, and that it is productive to grow legume species in soil incorporated with SCGs. We found that the seed weight of soybean was not affected by SCGs, even in the first year. During the second and third years, the effect of SCG application on the soybean crop biomass was not significant. Yamane et al. (2014) reported that the application of SCGs enhanced the growth of some green manure crops one year after application. Enhancement effects of SCGs on crop growth were not observed during the current experiment, suggesting the possibility of competition between the enhancement and inhibitory effects of SCGs when the SCGs were continuously applied as top dressing.

Because the application of SCGs to soil is known to induce N starvation in plants (Wakasawa et al., 1998), combining SCG application with chemical N fertilization is considered efficient for crop growth. Rochester et al. (1993) have shown that the addition and incorporation of crop residues slightly reduces the mineral nitrogen content in the soil by facilitating biological immobilization. Thus, it is presumed that the incorporation of SCGs into soil induces nitrogen starvation. However, application of the SCGs as top dressing in our study may explain absence of nitrogen starvation, and the insignificant interaction between SCGs and the fertilizer treatment on soybean seed weight. This finding may also be linked to a sufficiently high soil fertility to support soybean growth at the study site. In contrast to the soybean crop, the interaction effect between SCGs and the fertilizer treatment on the panicle weight of wheat was significant, and further studies for determining the optimum amounts of SCGs and chemical fertilizers are required. Applying SCGs together with chemical fertilizers may be efficient under low soil fertility conditions.

improve weed control efficiency. However, during soybean cropping, fertilizer treatment decreased the inhibitory effect on the weed growth (Supplemental Figure). In addition, the absence of SCGs induced reduction in the amount of Poa annua in the wheat crop in 2018/2019, and the species might be tolerant to the germination inhibitory effect of SCGs. The relatively cold tolerant characteristics of Poa annua may enable germination prior to SCGs application. Further studies of variation in plant species sensitivity to SCGs is required for efficient application and weed control.
Table 4. Mean values and ANOVA results of weed dry weight from a double cropping field experiment using a combination of spent coffee grounds and fertilizer applications.

(a) 2017/2018

|              | Wheat | Soybean |
|--------------|-------|---------|
|              | Total | Amaranthus | Ludwigia | Others |
|              | (g m⁻²) | (g m⁻²) | (g m⁻²) | (g m⁻²) |
| SCGs (kg m⁻²) |       |       |       |       |
| 0            | 21.4a | 52.4a | 27.0a | 11.8 | 13.6a |
| 5            | 11.1b | 28.3b | 15.5b | 6.5  | 6.3b  |
| 10           | 6.6b  | 27.8b | 16.3b | 5.2  | 6.3b  |
| Fertilizer   |       |       |       |       |
| None         | 7.6   | 28.7  | 15.2  | 6.3  | 7.2   |
| Single dose  | 14.8  | 38.7  | 20.3  | 9.7  | 8.7   |
| Double dose  | 16.7  | 41.1  | 23.4  | 7.5  | 10.2  |

ANOVA

|              | P value |
|--------------|---------|
| SCGs (S)     | 0.001** |
| Fertilizer (F) | 0.055  |
| S × F        | 0.525   |

(b) 2018/2019

|              | Wheat | Soybean |
|--------------|-------|---------|
|              | Total | Poa | Others |
|              | (g m⁻²) | (g m⁻²) | (g m⁻²) |
| SCGs (kg m⁻²) |       |     |       |
| 0            | 24.3  | 21.2 | 3.1   |
| 5            | 25.2  | 23.8 | 1.4   |
| 10           | 18.6  | 17.4 | 1.1   |
| Fertilizer   |       |     |       |
| None         | 21.1  | 19.8 | 1.2   |
| Single dose  | 19.1  | 18.1 | 1.0   |
| Double dose  | 27.9  | 24.5 | 3.4   |

ANOVA

|              | P value |
|--------------|---------|
| SCGs (S)     | 0.470  |
| Fertilizer (F) | 0.295  |
| S × F        | 0.167  |

(c) 2019/2020

|              | Wheat | Soybean |
|--------------|-------|---------|
|              | Total | Lollum | Others |
|              | (g m⁻²) | (g m⁻²) | (g m⁻²) |
| SCGs (kg m⁻²) |       |      |       |
| 0            | 148.3c| 93.7b | 54.6b |
| 5            | 100.9b| 65.4a | 35.5a |
| 10           | 62.0a | 41.7a | 20.4a |
| Fertilizer   |       |      |       |
| None         | 77.0a | 44.3a | 32.7  |
| Single dose  | 113.3b| 76.1b | 37.2  |
| Double dose  | 121.0b| 80.4b | 40.6  |

ANOVA

|              | P value |
|--------------|---------|
| SCGs (S)     | 0.000** |
| Fertilizer (F) | 0.002** |
| S × F        | 0.131   |

SCGs: spent coffee grounds. Fertilizer: the number of additional fertilizer applications. None: no fertilizer; Single dose: fertilizer applied only to the wheat crop; Double dose: fertilizer applied to each of the wheat and soybean crops. * and ** indicate significant effects at 0.05 and 0.01 probability levels, respectively. Means followed by different lowercase letters within columns are significantly different as per Fisher’s LSD test at P < 0.05.
Soil organic carbon enrichment is an agricultural keyword toward climate change (Lehmann et al., 2020). The soil organic carbon let many microorganisms develop the rhizosphere, and the plant grows robustly. In the present study, continuous SCGs application significantly enhanced soil C content 2 years after the first application. In addition, the SCGs application significantly enhanced the soil N content. Thus, the continuous SCGs application in double cropping field maintained C/N ratio, although the application of organic materials tends to increase C/N ratio. Intertillage is a normal practice in the study area controlling lodging and weeds (Matsuo et al., 2013). Therefore, we suggested applying SCGs with intertillage, especially in soybean planting, which is economically efficient, time- and labor-saving.

Toxic substances in SCGs can be extracted using organic solvent treatments (Bravo et al., 2013), and a 20-min treatment with hot water is effective for extracting polyphenols from SCGs (Conde & Mussatto, 2016). Hydrothermal carbonization of SCGs by hot water washing generates hydrochars with chemical and physicochemical properties different from those of the original SCGs (Cervera-Mata et al., 2021). In addition, Hirooka et al. (2021) reported that SCGs, artificially treated using water and UV to simulate the effects of rainfall and sunshine, improve soybean growth. These findings suggest that treated SCGs could be effectively used for soil improvement and weed control without negative effects on the cultivated crops, even soon after application.

Conclusion
In the present field-based study, we found that top dressing the entire soil surface with SCGs after crop germination minimizes the inhibitory effect of SCGs on the crop productivity during the wheat-soybean double cropping. Top dressing with SCGs after crop germination inhibits crop productivity only during the first cropping season. Further, this approach can substantially reduce weed biomass if a sufficient quantity of SCGs is used, and can enrich the soil C and N in the long term. We found that top dressing with SCGs after crop germination is efficient for sustainable agricultural production, although detailed further studies of the effect on the soil characteristics and crop growth are required.

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Disclosure statement
No potential conflict of interest was reported by the author(s).

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