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Effectiveness of Raw Industrial Plant Residue Amendments on Soil Chemical Properties and The Growth of Three Forage Crops

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ABSTRACT

Adding organic matter is required to ensure the availability and sustainability of soil organic matter. Agricultural residues constitute an important part of overall yearly biomass output and a major source of soil organic matter. The purpose of this study was to examine how five distinct industrial plant residue supplements affected soil chemical characteristics as well as the growth of three legume forage crops. The investigation was carried out over two growing seasons in the Field Crops Department's Greenhouse at Selçuk University in Turkey. The study used a Factorial RCBD design with two factors and four replications. The first factor was composed of industrial plant leftovers, which included control (soil only), wheat bran, cottonseed oilcake, sunflower seed oilcake, rapeseed oilcake, and soybean oilcake. The second factor was fodder crop species, which included forage pea, common vetch, and Narbon vetch. The results revealed that wheat bran, cottonseed oilcake, and sunflower seed oilcake increased plant growth compared to the control. Wheat bran produced the most plant growth (across all variables) in each growing season. Rapeseed and soybean oilcake additives were shown to be phytotoxic, inhibiting plant development and causing plants to yellow, wither, and die. Three plant residue amendments (wheat bran, cottonseed oilcake, and sunflower seed oilcake) improved some soil qualities. Sunflower seed oilcake-treated soils had the highest organic matter and K_2O levels (1.35% and 10.33 kg/ha, respectively), whereas wheat bran-treated soils had the highest P_2O_5 (1.75 kg/ha).

Keywords: bran, oilcakes, organic matter, seed meal

INTRODUCTION

Soil organic matter is one of the most important factors influencing soil productivity. Soil organic matter concentration changes according to soil type, soil texture, climate, location, land position, vegetation type, soil tillage, treatment, and use (Valboa *et al*. 2015; Blanco-Moure *et al*. 2016; Geraei *et al*. 2016). The average stable organic matter concentration in soil is 5% in tropical areas and 10% in temperate or subtropical areas (Munawir 2011). However, in certain countries, such as Indonesia and Turkey, agricultural land has less than 2% organic matter (Pirngadi 2009; Gezgin 2018). Adding organic matter is critical for ensuring the availability and sustainability of organic matter. Plant residue amendment is one type of organic material that can be used to improve soil fertility. Several plant-based industrial wastes from primary food processing industries, including grain milling and oilseed processing, are widely available. These residues, such as bran and oilcakes, are significant byproducts of plant-based industries, particularly in temperate and subtropical countries. For example, wheat bran accounts for nearly 10% of the total weight of wheat-milled flour (Rosenfelder *et al*. 2013). Cottonseed oilcake is a major byproduct of cottonseed oil manufacturing, accounting for roughly 45% (Pickard *et al*. 2020). Sunflower seed processing produces roughly 44% oilcake as a byproduct (Lomascolo *et al*. 2012).

Plant-based industrial residues are currently most used for animal feeding (Mahro & Timm 2007), owing to their cost-effectiveness, availability, and nutrient density. Furthermore, these residues include a significant amount of organic matter, which can increase soil organic matter and improve soil characteristics. Aside from being an important source of organic material, plant-based industrial waste has a high potential for providing some plant nutrients. These materials will boost organic matter and plant nutritional content in soil, reducing the demand for chemical fertilizers. Using these residues to contribute organic matter to soil is another solution to the problem of organic waste management while also reducing pollution and the negative effects of chemical fertilizer residues.

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Table 1 Characteristics of the soil

Characteristics	K_2O (kg/ha)	P_2O_5 (kg/ha)	Organic matter (%)	Lime (%)	Salt (%)	pH	Saturation (%)
Amount in soil	5.49	0.71	1.13	43.92	0.018	7.74	47.30

Several studies have also revealed that wheat bran improves the growth and development of mungbean (Badar *et al*. 2014), cowpea (Badar *et al*. 2015), sunflower (Badar & Qureshi 2015), and persimmon plants (Kim *et al*. 2015). Cottonseed oilcake stimulated the growth of *Dalbergia latifolia* Roxb. (Kumar *et al*. 2014), ginger (Kadam & Jagtap 2018), and tomato plants (Parveen *et al*. 2019), but inhibited the growth of tomato plants (Radwan *et al*. 2009). Sunflower seed oilcake severely inhibited the growth of cress plants. It had no substantial effect on lettuce or Chinese cabbage plant development (Koller *et al*. 2004). Nonetheless, it considerably improved the growth of lettuce, chard, spinach, barley, ginger, and cardoon plants (Mazzoncini *et al*. 2015; Kadam & Jagtap 2018; Ronga *et al*. 2019). Canola (rapeseed oilcake) significantly inhibited cress growth (Koller *et al*. 2004), reduced blueberry fruit production (Yang *et al*. 2020), and significantly increased the growth of onion seedlings (Kowalska & Smolinska 2015), rice (Park *et al*. 2017), and blueberry plants (Wang *et al*. 2020). Soybean oilcake also inhibited wheat and hairy vetch growth (Hoagland *et al*. 2008), while increasing chickpea and persimmon plant development (Rizvi *et al*. 2012; Kim *et al*. 2015).

According to these studies, industrial plant residues have a high potential for use as soil amendments. These studies also reveal inconsistent effects of the residues on plant growth and production, certain residues have phytotoxic effects on plants, limiting their growth and development. This research will give crucial information on the application of these residues and their short- and long-term impacts on enhancing soil qualities and encouraging plant growth. The purpose of this expedrfiment was to examine how five different plant residue amendments affect some soil chemical parameters as well as the growth of three legume forage crops across two growing seasons.

METHODS

This study was carried out utilizing a controlled system in the greenhouse of the Department of Field Crops, Faculty of Agriculture, Selçuk University, Konya, Turkey. The experiment's materials included five different plant residues (wheat bran, sunflower seed oilcake, soybean oilcake, rapeseed oilcake, and cottonseed oilcake), forage pea (*Pisum arvense*) seeds, common vetch (*Vicia sativa*) seeds, Narbon vetch (*V. narbonensis*) seeds, *Rhizobium leguminosarum* inoculants, plastic crates measuring 40 cm × 60 cm × 36 cm, and polybags. The experiment used soil from the surrounding countryside near the university as a plant growing medium.

The experiment focused on three annual legume fodder crops: forage pea, common vetch, and Narbon vetch, using a Factorial Randomized Complete Block Design (RCBD) with two factors and four replications. It contained five distinct plant residue treatments and one control (no plant residue treatment). This experiment employed the following factors and their levels: plant residues, the first factor, had six levels: control (no plant residue), wheat bran, cottonseed oilcake, sunflower seed oilcake, rapeseed seed oilcake, and soybean oilcake. The second factor was the legume forage crop species, which included three kinds: forage pea, common vetch, and Narbon vetch. The investigation was carried out during two consecutive growth seasons. The industrial plant residues employed in this study were raw, with no breakdown procedures.

The experiment consisted of 72 experimental units, each of which had two observation plants, for a total of 144 observation units as samples per growing season. The data collected for the study were analyzed using variance analysis with the SAS statistical program (version 9.1) utilizing a Factorial RCBD design. The mean differences across treatments were then pooled using the least significant difference (LSD) test.

The experimental unit was a plastic crate measuring 40 cm × 60 cm × 36 cm. The growth media were prepared two weeks prior to seed sowing. Plant residues were used as raw organic materials in the same proportion, at a dose of 20 t/ha, and mixed with uniform dry soil. Soil properties were examined in the laboratory of Konya Laboratory and Warehousing at Konya Commodity Exchange. Table 1 shows some features of the soil used in this investigation. Plant waste and soil were mixed and placed in polybags. Six polybags were placed in each plastic crate. Before sowing, the seeds utilized in this experiment were infected with a peat-based *R. leguminosarum* inoculant. To keep the seeds wet, they were sprayed with a water solution (combined with sugar 1:1) before being mixed with Rhizobium culture.

The infected seeds were sown directly into the soil (growing media). The seeds were planted separately based on the treatments. Throughout the development phase, irrigation was carried out in accordance with the needs of the plants. Plant harvesting took place when at least 50−60% of the plants were in full bloom. Two plants were randomly chosen as samples to be harvested and examined. Harvesting was done one at a time and carefully, especially while extracting the roots from the dirt, to keep the roots in their natural

Table 2 Emergence rate of three forage crops with different industrial plant residue amendments

Plant Residues	First growing season				Second growing season			
	Forage pea	Common vetch	Narbon vetch	Average	Forage pea	Common vetch	Narbon vetch	Average
	---------- **Emergence rate (%)** ----------							
Control	93.06	90.28	87.50	90.28	96.67a	85.00a	73.33a	85.00A
Wheat bran	86.11	87.50	90.28	87.96	91.67a	88.33a	65.00ab	81.67A
Cottonseed oilcake	91.67	94.44	86.11	90.74	91.67a	41.67bc	78.33a	70.56A
Sunflower seed oilcake	93.06	91.67	91.67	92.13	40.28bc	18.06de	30.56cd	29.63B
Rapeseed oilcake	79.17	84.72	94.44	86.11	9.72efg	1.39g	5.56efg	5.56C
Soybean oilcake	88.89	93.06	86.11	89.35	2.78g	4.17fg	15.28def	7.41C
Average	88.66	90.28	89.35		55.47A	39.77B	44.68AB	

Remark: Numbers followed by the same lowercase letter in each interaction and capital letters in the same column or row of average values in each growing season indicate no significant difference based on the LSD test at a 5% significance level.

shape. Plantings for the second growing season began immediately following the first growing season's harvest. For the second growing season, the identical plants' seeds were planted in the same experimental units and system, but no organic materials (plant residues) were added to the growing medium. Plant maintenance and harvesting in the second season were carried out in the same method as in the first.

At each harvest, observations were made on some soil parameters and plant growth. The soil was sampled in a composite fashion, with about 1 kg extracted from each of the six polybags within each experimental unit. The soil samples were then tested in the lab for pH, organic matter concentration, K_2O, and P_2O_5. Two plants were selected at random from each experimental unit for plant sample observation. Germination rate, plant height, number of primary branches, root length, fresh and dry root and shoot weights were all measured.

RESULTS AND DISCUSSION

Emergence Rate

The variance analysis revealed that plant residues and crop species had no significant effect on plant emergence rate during the first season. Nonetheless, they had a considerable impact on the plant emergence rate during the second season. These results indicate that the plant residues did not react with the growing media during the first season because they had not yet decomposed. In contrast, in the second season, the plant remains have decomposed and interacted with the soil, resulting in diverse impacts on plant germination. According to Shahbaz *et al*. (2017), the breakdown and mineralization of plant residue-based organic matter occur rapidly within the first 2−3 weeks of incubation. In this study, the seeds of all plants were sown one week after the plant were put into the growing media. In this situation, for the first growing season, the seeds germinated with the same amount of nutrients available in the soil.

In the second growing season, plant residue treatments had a substantial effect on all plant emergence rates. Table 2 demonstrates that all wheat bran-treated plants had the same statistical emergence rate as control plants. Cottonseed oilcake-treated forage pea and Narbon vetch plants had the same emergence rate as all plants in the control treatment, however common vetch plants showed significantly lower emergence rates. Applying oilcake during the second growing season greatly inhibited plant emergence. When compared to the control, soybean oilcake reduced the emergence rate of fodder pea, common vetch, and Narbon vetch plants by 97.12%, 95.09%, and 79.16%, respectively. Rapeseed oilcake decreased the emergence rate of fodder pea, common vetch, and Narbon vetch plants by 89.95%, 98.36%, and 92.42%, respectively. Sunflower seed oilcake decreased the emergence rates of fodder pea, common vetch, and Narbon vetch plants by 58.33%, 78.75%, and 58.32%, respectively. Cottonseed oilcake slowed the establishment of common vetch plants by 50.98%. Thus, oilcakes significantly inhibited the emergence of fodder pea, common vetch, and Narbon vetch plants, with rapeseed and soybean oilcakes generally demonstrating the strongest suppressive effects.

It is thought that the decrease in plant emergence rate in the second growing season is caused by allelochemical substances emitted from plant leftovers during or after decomposition. The phytotoxicity effects of these allelochemicals in various oilcake treatments were detected three weeks after planting in the first growing season, when the organic materials (oilcake) decomposed. Plants responded to the presence of allelochemicals by yellowing as early as 20 DAP (day after planting), whereas others began to wilt and die as early as 27 DAP. It was also discovered that in the second growing season, the allelochemicals in some oilcakes continued to have a phytotoxic effect on plant emergence rate. Previous research has shown that applying oilseed cakes and residues from oilseed plants reduces plant emergence. According to Hoagland *et al*. (2008), the emergence rates of wheat, hairy vetch, and *Amaranthus retroflexus* plants in rapeseed oilcake application were 8.00%, 11.00%, and 11.00%, respectively, which were lower than the control rates of 87.10%, 15.38%, and 63.33%. The study also found that the emergence rate of wheat, hairy vetch, *Echinocloa crus-galli,* and *A. retroflexus* plants in soybean oilcake application was 12.00%, 5.00%, 16.00%, and 7.00%, respectively, which was significantly lower than the emergence rate of these plants in the control treatment, which was 90.00%, 61.53%, 42.86%, and 73.08%, respectively. Snyder *et al*. (2009) found that utilizing rapeseed oilcake for soil amendment reduced carrot plant germination rates by 32.20% and 28.13%, respectively, compared to the control. According to Khaliq *et al*. (2011), the emergence rate of rice and *Echinochloa colona* plants after applying sunflower residue was 73.33% and 61.11%, respectively, which were 15.39% and 22.54% lower than the control. In the application of combinations with sunflower residue, sorghum residue, and mustard residue, the emergence rate of rice and *E. colona* plants was found to be 63.34% and 52.22%, respectively, which were substantially lower than the control by 15.39% and 22.54%, respectively.

Plant Growth

Plants treated with oilcake yellowed, wilted, and died, or they did not survive till harvest. The harmful effects of these plant residues varied according to the type of plant residue and the treated plant species. During the first growing season, all oilcake treatments had an adverse effect on the growth of all plant species tested. However, cottonseed oilcake had a significant negative impact solely on common vetch plants. All plants treated with sunflower, rapeseed, and soybean oilcake yellowed 15 days after treatment, including cottonseed oilcake-treated common vetch plants. These plants started to wilt and die at 27 DAP (Table 3). On average, Narbon vetch plants died at 38 DAP and were more sensitive to oilcake treatment, followed by forage pea and common vetch, which died at 42 and 52 DAP. Despite the later death time, common vetch plants died in all oilcake applications. In contrast, fodder pea and Narbon vetch plants were able to withstand cottonseed oilcake application until harvest time. Soybean oilcake showed the highest toxicity when compared to other plant residues, with an average plant death time of 29 DAP. However, cottonseed oilcake was only efficient at killing common vetch plants, with death occurring at 76 DAP. Rapeseed and soybean oilcakes harmed all plant species during the second growing season, whereas cottonseed and sunflower seed oilcakes exclusively harm common vetch plants. At 20 DAP, all plant species treated with rapeseed and soybean oilcake yellowed, including common vetch plants treated with sunflower and cottonseed oilcakes. These plants began to wilt and die at 20 DAP.

Table 3 further demonstrates that common vetch plants are more sensitive to treatments in the second growing season. Common vetch plants died at an average of 29 DAP, followed by Narbon vetch and forage pea plants at 39 and 44 DAP, respectively. However, it can be shown that the typical vetch plants died in all oilcake treatments and developed sensitivity to all types of oilcake. In contrast, cottonseed and sunflower seed oilcake treatments allowed fodder pea and Narbon vetch plants to live until harvest. Soybean oilcake showed the highest toxicity when compared to other plant residues, with an average plant death time of 30 DAP. Cottonseed oilcake caused death 27 DAP, but only in common vetch plants, not forage pea or Narbon vetch. The study also found that the phytotoxicity effects of sunflower seed oilcake diminished in the second growing season, as seen by the survival of fodder pea and Narbon vetch plants until harvest time.

The surviving plants' root systems also showed phytotoxicity effects from oilcake. Cottonseed and sunflower seed oilcake additives significantly reduce plant root length compared to the control in the second season. Cottonseed oilcake reduced the plants' fresh root weight in the first season, while sunflower seed

Table 3 The death time of three forage crops with different industrial plant residue amendments

Plant residues	First growing season				Second growing season			
	Forage pea	Common vetch	Narbon vetch	Average	Forage pea	Common vetch	Narbon vetch	Average
	---------- **Death time (DAP)** ----------							
Control	-	-	-	-	-	-	-	-
Wheat bran	-	-	-	-	-	-	-	-
Cottonseed oilcake	-	76	-	76	-	38	-	38
Sunflower seed oilcake	55	50	48	51	-	27	-	27
Rapeseed oilcake	45	50	35	43	55	20	50	41
Soybean oilcake	27	30	30	29	32	30	28	30
Average	42	52	38	-	44	29	39	-

Remark: The dash (-) indicates that the plants in the treatments died (no data).

Table 4 Root length, fresh root weight, and dry root weight of three forage crops with different industrial plant residue amendments

Plant residues	First growing season				Second growing season			
	Forage pea	Common vetch	Narbon vetch	Average	Forage pea	Common vetch	Narbon vetch	Average
				---------- **Root length (cm)** -----------				
Control	44.88	57.23	53.9	52.00	27.96ef	37.03bc	52.79a	39.26A
Wheat bran	48.89	41.59	43.39	44.62	32.05cde	36.09bcd	53.44a	40.53A
Cottonseed oilcake	51.66	-	46.23	48.94	23.69f	-	41.83b	32.76B
Sunflower seed oilcake	-	-	-	-	28.75def	-	32.76cde	30.76B
Rapeseed oilcake	-	-	-	-	-	-	-	-
Soybean oilcake	-	-	-	-	-	-	-	-
Average	48.48	49.41	47.84		28.43C	36.56B	45.20A	
				----------- **Fresh root weight (g)** ----------				
Control	3.46b	1.86c	6.23a	3.85A	0.67de	0.75de	4.52b	1.98B
Wheat bran	6.18a	1.69c	3.40b	3.76A	1.50d	0.62e	6.47a	2.86A
Cottonseed oilcake	1.99c	-	3.14b	2.57B	1.03de	-	3.63bc	2.33A
Sunflower seed oilcake	-	-	-	-	1.56d	-	2.87c	2.21AB
Rapeseed oilcake	-	-	-	-	-	-	-	-
Soybean oilcake	-	-	-	-	-	-	-	-
Average	3.88A	1.77B	4.25A		1.17B	0.68C	4.37A	
				---------- **Dry root weight (g)** ----------				
Control	0.70c	0.35d	0.95b	0.67AB	0.18d	0.24d	0.99a	0.47AB
Wheat bran	1.27a	0.36d	0.69c	0.77A	0.37bcd	0.21d	1.15a	0.58A
Cottonseed oilcake	0.51cd	-	0.62c	0.56B	0.27cd	-	0.55b	0.41AB
Sunflower seed oilcake	-	-	-	-	0.30cd	-	0.45bc	0.37B
Rapeseed oilcake	-	-	-	-	-	-	-	-
Soybean oilcake	-	-	-	-	-	-	-	-
Average	0.83A	0.36B	0.75A		0.28B	0.23B	0.78A	

Remarks: Numbers followed by the same lowercase letter in each interaction and capital letters in the same column or row of average values in the growing season, and each variable indicate no significant difference based on the LSD test at a 5% significance level; The dash (-) indicates that the plants in the treatments died (no data).

oilcake reduced their dry root weight in the second season (Table 4). Plant residue application had a substantial effect on plant root length only during the second growing season. Cottonseed and sunflower seed oilcake produced considerably shorter root lengths in plants than the control and wheat bran treatments. Individually, Narbon vetch was more sensitive to the application of cottonseed and sunflower seed oilcake, with each root length much shorter than the control. The application of cottonseed oilcake had a phytotoxic effect on the fresh weight of plant roots, which was significantly lower than the control in the first growing season. However, in the second growing season, it was discovered that the phytotoxicity effects of cottonseed oilcake had diminished, as seen by the plants' fresh root weight, which was higher than in the control. Furthermore, even though the phytotoxicity effect was reduced in the second growing season, the sunflower seed oilcake treatment resulted in lower fresh root weight in Narbon vetch plants than the control group.

Table 4 further reveals that cottonseed oilcake resulted in decreased dry root weight during the first growing season, particularly in Narbon vetch plants. Similarly, in the second growth season, cottonseed and sunflower seed oilcakes reduced dry root weight in Narbon vetch plants. Based on these findings, common vetch is the plant that is most sensitive to phytotoxicity from oilcakes, as no plants developed on any of the oilcakes tested. Narbon vetch demonstrated root growth in all oilcake treatments, however it was much lower than in the control. Meanwhile, forage pea is the most tolerant plant, with root growth that is not

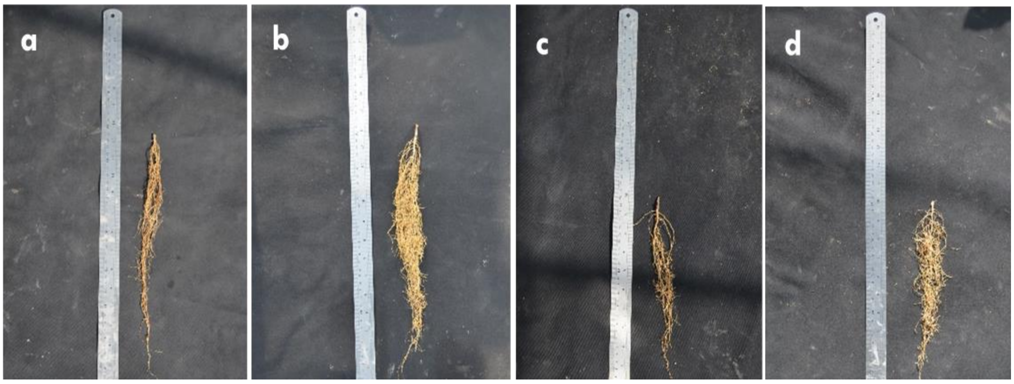

Figure 1 Roots of forage pea plants with control (a), wheat bran (b), cottonseed oilcake (c), and sunflower seed oilcake (d) amendments in the second growing season.

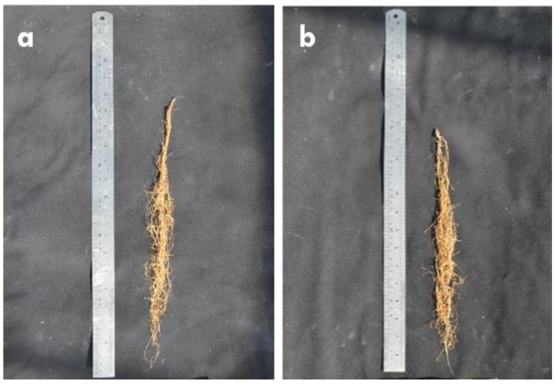

Figure 2 Roots of common vetch plants with control (a) and wheat bran (b), amendments in the second growing season.

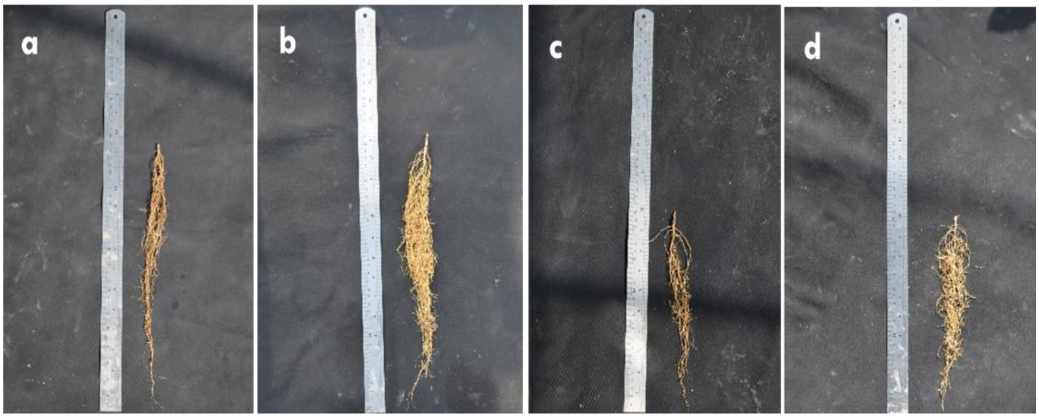

Figure 3 Roots of Narbon vetch plants with control (a), wheat bran (b), cottonseed oilcake (c), and sunflower seed oilcake (d) amendments in the second growing season.

statistically different and may even be higher than the control (Figure 1−3).

Phytotoxicity is presumably caused by the release of bioactive or allelochemicals during the decomposition of organic materials, particularly oilcakes. Several research have examined the phytotoxicity of oilcakes (Koller *et al*. 2004; Hoagland *et al.* 2008; Radwan *et al.* 2009; Pużyńska *et al*. 2019). The phytotoxicity of oilcakes was not observed in the formation of surviving plant biomass. Plants cultivated for harvest using industrial plant residue supplements showed larger fresh and dry biomass weights than plants in control treatment. In both seasons, the wheat bran treatment produced fresher biomass than the cottonseed and sunflower seed oilcake treatments, as well as the control. Cottonseed oilcake treatment in both seasons, and sunflower seed oilcake treatment in the second season, resulted in higher fresh biomass for all plants than the control (Table 5).

Several investigations have revealed that oilcake produces allelochemicals. Rapeseed or canola seed oilcake's toxicity is attributed to bioactive chemicals

Table 5 Fresh and dry shoot weights of three forage crops with different industrial plant residue amendments

Plant residues	First growing season				Second growing season			
	Forage pea	Common vetch	Narbon vetch	Average	Forage pea	Common vetch	Narbon vetch	Average
				---------- **Fresh shoot weight (g)** ----------				
Control	12.42d	5.12d	10.49d	9.34C	4.41f	5.56f	8.82ef	6.26C
Wheat bran	48.64a	26.60c	38.32b	37.86A	24.03b	13.66de	36.07a	24.59A
Cottonseed oilcake	23.01c	-	21.15c	22.08B	19.72bc	-	20.20bc	19.96B
Sunflower seed oilcake	-	-	-	-	21.29bc	-	17.22cd	19.25B
Rapeseed oilcake	-	-	-	-	-	-	-	-
Soybean oilcake	-	-	-	-	-	-	-	-
Average	28.02A	15.86C	23.32B		16.96B	9.61C	20.58A	
				----------- **Dry shoot weight (g)** ----------				
Control	2.36c	1.29c	2.00c	1.88C	0.90d	0.95d	1.47d	1.10B
Wheat bran	10.26a	7.04b	10.17a	9.15A	4.97ab	3.01bc	6.11a	4.70A
Cottonseed oilcake	5.56b	-	5.71b	5.62B	4.30bc	-	4.61ab	4.45A
Sunflower seed oilcake	-	-	-	-	4.67ab	-	4.38bc	4.53A
Rapeseed oilcake	-	-	-	-	-	-	-	-
Soybean oilcake	-	-	-	-	-	-	-	-
Average	6.05A	4.16B	5.96A		3.58A	1.98B	4.14A	

Remark: Numbers followed by the same lowercase letter in each interaction and capital letters in the same column or row of average values in the growing season, and each variable indicate no significant difference based on the LSD test at a 5% significance level; The dash (-) indicates that the plants in the treatments died (no data).

known as glucosinolates. Sunflower plants contain allelopathic chemicals such as terpenoids and flavonoids (Macias *et al*. 1998; Fernández-Luqueño *et al*. 2014). Sunflower seed oilcake and residues are also abundant in phenolics, which could hinder plant growth (Zardo *et al*. 2019). There is no thorough information on the exact chemicals in soybean oilcake that may have phytotoxic effects on plants. However, allelochemicals can be synthesized from various soybean plant sections (Yan & Yang 2008). Soybean plants have been shown to contain substances such as daidzein, coumestrol, and coumarin, which could be used as allelochemicals (Iman *et al.* 2006). Gossypol has been detected in all parts of the cotton plant, including cottonseed oilcake. Cottonseed oilcake contains gossypols in both free and bound form. Most of the toxicity could be attributed to free gossypol, which can be found in cottonseed oilcake at concentrations of up to 0.02% by mass (Maksimov *et al.* 2010).

In dry biomass production, the treatment of wheat bran and cottonseed oilcake in the first season, as well as the treatment of wheat bran, cottonseed oilcake, and sunflower seed oilcake on average, produced better results than the control (Table 5; Figure 4−6). This is assumed to be owing to the high organic content of plant residues, which can give the nutrients plants require to thrive more effectively than the control group. The soil analysis results demonstrate that the soil treated with plant residue has more organic matter, potassium, and phosphorus than control (Table 6). Wheat bran had the greatest impact on the growth of all three plants. Wheat bran decomposes easily, allowing plants to receive the nutrients it contains, contains no allelochemicals and hence does not cause toxicity. Earlier findings has shown that wheat bran application can boost the growth of faba bean and soybean plants (Abd-Alla & Omar 2001), cowpea (Badar *et al*. 2015), and tomato (Testen & Miller 2018). Cottonseed and sunflower seed oilcakes can be utilized as soil additions in the second season when their toxicity levels have diminished or vanished. These discoveries also show that cottonseed and sunflower seed oilcakes decompose during one growing season (about 2−3 months), reducing or eliminating the active chemicals and making them appropriate for soil amendment. Rapeseed and soybean oilcakes, on the other hand, take longer to decompose, typically more than two growing seasons (> 5 months).

Soil Properties

The variance analysis revealed that plant residue amendments had a significant effect on the pH, organic matter content, K_2O, and P_2O5 levels in the soil throughout both the first and second growing season. Wheat bran, cottonseed oilcake, and sunflower oilcake all decreased pH in both the first and second growing seasons, with sunflower seed oilcake decreasing pH in the second season. Wheat bran, cottonseed oilcake, and sunflower oilcake increased the organic matter, K_2O, and P_2O_5 content of the soil in both the first and

Figure 4 Performance of forage pea plants with control (a), wheat bran (b), cottonseed oilcake (c), and sunflower seed oilcake (d) amendments in the second growing season.

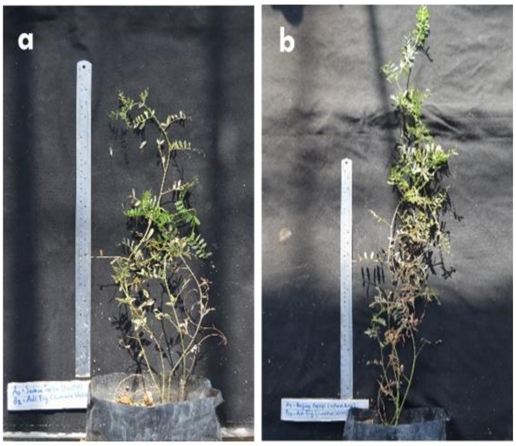

Figure 5 Performance of common vetch plants with control (a) and wheat bran (b) amendments in the second growing season.

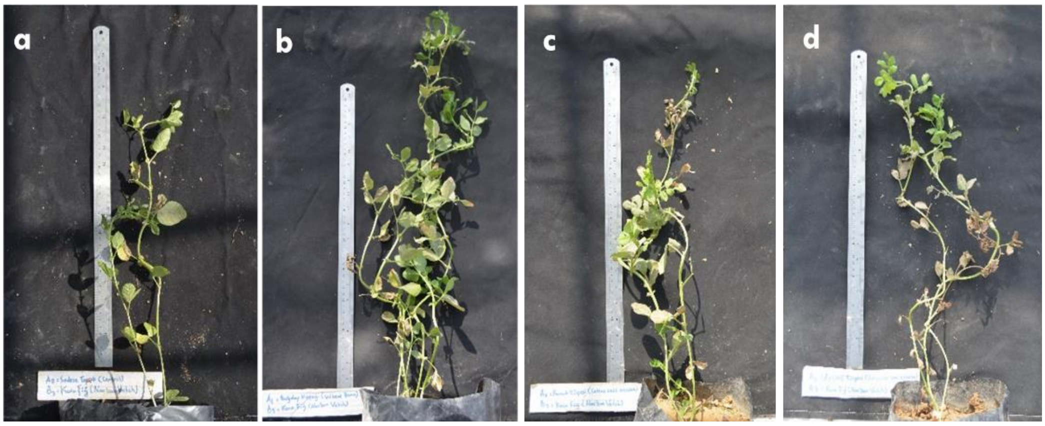

Figure 6 Performance of Narbon vetch plants with control (a), wheat bran (b), cottonseed oilcake (c), and sunflower seed oilcake (d) amendments in the second growing season.

second growth seasons, with sunflower seed oilcake doing so in the second season (Table 6).

The soil pH in control treatment tended to be alkaline (approaching 8) during the first and second growing seasons. Plant residue amendments considerably reduced soil pH due to the generation of organic acids during the organic matter's breakdown (Zhou *et al*. 2019). Plant residue additions reduced the soil pH to around 7 (normal). The high organic matter concentration linked with the nutritional content, which rose when the organic matter decomposed into simpler chemicals that plants could take as nutrients (Bashir *et al*. 2021). Previous studies reported that incorporating rice bran into the soil increased the organic matter

Table 6 pH, organic matter, K_2O, and P_2O_5 contents of the soils after being treated with different industrial plant residue amendments

Plant residues	First growing season				Second growing season			
	Forage pea	Common vetch	Narbon vetch	Average	Forage pea	Common vetch	Narbon vetch	Average
				---------- pH ----------				
Control	7.92	7.88	7.84	7.88A	7.88a	7.83a	7.84a	7.85A
Wheat bran	7.53	7.40	7.42	7.45B	7.66b	7.58b	7.42c	7.55B
Cottonseed oilcake	7.28	-	7.21	7.24C	7.25d	-	7.28d	7.26C
Sunflower seed oilcake	-	-	-	-	7.29d	-	7.31cd	7.30C
Rapeseed oilcake	-	-	-	-	-	-	-	-
Soybean oilcake	-	-	-	-	-	-	-	-
Average	7.58	7.64	7.49	7.56	7.56	7.70	7.46	7.53
				---------- Organic matter (%) ----------				
Control	0.83c	0.84c	0.81c	0.83C	1.15	1.07	0.99	1.07B
Wheat bran	1.32b	1.35b	1.62a	1.43B	1.18	1.11	1.18	1.15AB
Cottonseed oilcake	1.61a	-	1.57a	1.59A	1.32	-	1.31	1.31A
Sunflower seed oilcake	-	-	-	-	1.43	-	1.26	1.35A
Rapeseed oilcake	-	-	-	-	-	-	-	-
Soybean oilcake	-	-	-	-	-	-	-	-
Average	1.26b	1.10c	1.33a	1.25	1.27	1.09	1.19	1.20
				---------- K_2O (kg/ha) ----------				
Control	4.84	5.45	5.01	5.10B	5.21	5.18	5.05	5.15D
Wheat bran	8.26	9.66	8.82	8.91A	7.73	8.53	7.03	7.76C
Cottonseed oilcake	10.21	-	8.78	9.50A	8.83	-	8.67	8.75B
Sunflower seed oilcake	-	-	-	-	10.03	-	10.63	10.33A
Rapeseed oilcake	-	-	-	-	-	-	-	-
Soybean oilcake	-	-	-	-	-	-	-	-
Average	7.77	7.56	7.54	7.63	7.73	6.85	7.84	7.69
				---------- P_2O_5 (kg/ha) ----------				
Control	0.44	0.50	0.59	0.51C	0.68d	0.66d	0.68d	0.67C
Wheat bran	1.53	1.56	2.00	1.70A	2.04a	1.74ab	1.46bc	1.75A
Cottonseed oilcake	1.42	-	1.27	1.34B	1.24c	-	1.22c	1.23B
Sunflower seed oilcake	-	-	-	-	1.36c	-	1.27c	1.31B
Rapeseed oilcake	-	-	-	-	-	-	-	-
Soybean oilcake	-	-	-	-	-	-	-	-
Average	1.13	1.03	1.29	1.16	1.33	1.20	1.13	1.23

Remark: Numbers followed by the same lowercase letter in each interaction and capital letters in the same column or row of average values in the growing season, and each variable indicates no significant difference based on the LSD test at a 5% significance level; The dash (-) indicates that the plants in the treatments died (no data).

content of the soil by 287.50%, 75.00%, 26.98%, and 506.27% compared to the control in the cultivation of okra (Moyin-Jesu 2007), ginseng (Kim *et al*. 2010), pear (Choi *et al*. 2011), and cabbage (Moyin-Jesu 2015), and the K content was significantly increased by 6.5, 0.5, 0.6, and 65 times compared to the control. In the cultivation of the sorghum and sudangrass hybrid, Choi *et al.* (2012) reported that although the organic matter content of the soil was not significantly different from the control with the application of oilseed oilcake, the P_2O_5 content of the soil in the first and second cultivation periods was significantly increased by 14.29% and 43.10% respectively, compared to each control.

CONCLUSION

Plant residue amendment influenced the three plants' germination and growth, as well as some soil chemical qualities. Raw oilcake amendment was phytotoxic to all plants following decomposition in the soil, and this impact was initially observed at 27 DAP, causing the plants to become yellow and die. Soybean and rape seed oilcake were more harmful than cottonseed and sunflower seed oilcake, as indicated by plants dying before harvest in both the first and second growing seasons. Wheat bran was the most effective industrial plant residue, producing greater results than the control and oilcake treatments. Wheat bran, cottonseed oilcake, and sunflower seed oilcake were able to return the pH to normal while increasing organic matter, potassium, and phosphorus levels in the soil as compared to the control group. To reduce or eliminate phytotoxic effects, it is recommended that organic materials be decomposed before being used as soil amendments.

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