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IMPROVING SOIL PROPERTIES AND PRODUCTIVITY OF COWPEA AND SUNFLOWER BY USING CERAMIC WASTE DUST AND INTERCROPPING SYSTEMS IN CALCAREOUS SOIL

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The objective of this study is to investigate how the use of ceramic waste dust (CWD) and the intercropping systems can impact the properties of soil, growth, yield and its characteristics of cowpea and sunflower under calcareous soil conditions in Ras Sudr region, Egypt, in the years 2020 and 2021. Three CWD (0, 48, and 96 Mg ha^{-1}) and five intercropping systems: sole cowpea, sole sunflower, 1:1 sunflower-cowpea, 1:2 sunflower-cowpea, and 2:1 sunflower-cowpea treatments were applied. The findings indicated that the use of CWD and the intercropping system resulted in a decrease in soil pH, electrical conductivity, bulk density, and hydraulic conductivity while increasing soil organic carbon and soil maximum water holding capacity. Moreover, the application of CWD and the intercropping systems had a significant impact on plant growth index, yield, and the characteristics of cowpea and sunflower. The highest values of plant growth, yield, and its characters were observed in plants treated with 96 Mg ha^{-1} of CWD. Also, the results indicated that the intercropping systems had a significant impact on all the traits of cowpea and sunflower. The highest yield for sunflower was observed in both pure stand and intercropping mixtures, while for cowpea, it was only achieved in a pure stand planting system. The land equivalent ratio, relative crowding coefficient, and aggressivity indices indicated that sunflower was a stronger competitor than cowpea, and sunflower was dominant, while cowpea was dominated in the intercropping systems. In conclusion, the findings indicated the critical role of CWD and intercropping systems in improving soil properties and enhancing cowpea and sunflower productivity under calcareous soil conditions.

Keywords: ceramic waste dust, planting system, soil characteristics, plant growth, seed yield

INTRODUCTION

Ceramic waste dust results from the surface leveling of the ceramic before the final polishing phase of ceramic tiles, it has been calculated that about 30% of the daily growth in the ceramic industry goes to waste (Iravanian and Saber, 2020). The ceramic products are produced from natural materials containing a high proportion of clay content (Chen and Felix, 2015). Ceramic waste dust is rich in organic and inorganic plant nutrients (Elias et al., 2014). Addition of ceramic waste in sand soil reduced maximum dry density value and increases optimum moisture content value (Sharma, 2020). Previous research has shown that the clay amendment has been recommended to be quite effective. Also, the clay amendments have a very significant effect to ameliorate the physicochemical character in sandy soil. The application of clay amendment in sandy soil increases fertility with the essential elements when the percentage of bentonite is greater than 5% in sandy soil (Karbout et al., 2015). Rajamannan et al. (2013) investigated the effect of the addition of ceramic waste to clay materials and concluded from chemical, mineralogical, and morphological analyses, that water absorption and compressive strength tests showed that ceramic waste can be added to the clay material without detrimental effect, thus enhancing the possibility of its reuse safely and sustainably.

Intercropping is an alternate technique for increasing agricultural output by maximizing the use of available land (Lithourgidis et al., 2011), it is the practice of cultivating two or more crops simultaneously in one field during the same or a part of their growing season (Zhang et al., 2020) that aims to increase the total yield per unit of land area and can significantly promote crop production due to the more efficient use of one or more resources in time and space (Zhang et al., 2007 and Wei et al., 2022). The intercropping system could play a key role in promoting the sustainable development of agriculture and the environment by improving the soil's physio-chemical properties (Chen et al., 2019). The intercropping system promotes plant growth, land equivalent ratio (LER) and crop yield (Gomaa, 2020). The intercropping of different crops at the same time and same land area can improve crop growth and production with better land management (Babar et al., 2021 and Hunegnaw et al., 2022). Liu et al. (2022) reported that intercropping system enhanced the agronomic traits of plant, such as plant height, stem diameter, branch number and increased yield of plant.

This study aims to assess and compare the impact of different levels of the ceramic waste dust and intercropping system on the properties of calcareous soil, as well as growth, yield and its characteristics of cowpea and sunflower crops. Additionally, the study aims to investigate the competitive relationships between the crops and determine the optimal level of ceramic waste dust (CWD) and intercropping system for enhancing soil properties, growth and productivity of the investigated plants.

MATERIALS AND METHODS

The research was conducted in summer of both 2020 and 2021 at Experimental Ras Sudr Station, Desert Research Centre, Egypt (29^o 60' 28" N, 32^o 68' 96" E) to study the effect of CWD and intercropping on growth and yield of both intercropped cowpea cv. Cream7 and sunflower cv. Sakha 53, as well as properties of calcareous soil. The physical and chemical analysis of the experimental soil, CWD and the chemical analysis of irrigation water are given in Table (1) according to Page et al. (1982).

Plants were irrigated with saline water (9.43 dS^{-1}), at 3 days intervals. Climate condition data of the study area is characterized by a hyper-arid. The average minimum annual temperature ranged from 22.2 to 28.7°C, while the maximum temperature ranged from 32.8 to 38.7°C, the average relative humidity ranged from 31.5 to 56% according to the metrological station of Ras Sudr, Egypt during the growing seasons from April to July, respectively. The seeds of cowpea cv. Cream7 and sunflower cv. Sakha53 were obtained from Agricultural Research Center. Seeds of cowpea or sunflower were sown at eight rows, 0.3 apart, 0.7 m width and 3 m length. Plot area was 16.8 m^2 which was separated by borders of 1.5 m in width. On April 15th cowpea and sunflower seeds were sown in hills (3-4 seeds/hill) and at 21 days after sowing plants were thinned to obtain one plant per hill in both seasons. The experimental design consisted of a split-plot layout with three replications, where the levels of ceramic waste dust were randomized in the main plots and the intercropping systems was kept in the sub-plots.

The experimental treatments included two study factors:

The first factor: CWD

- Control (without addition) - 48 Mg ha^{-1} - 96 Mg ha^{-1}

The second factor: Intercropping systems

- Sole cowpea - Sole sunflower - 1 sunflower: 1 cowpea
- 1 sunflower: 2 cowpea - 2 sunflower: 1 cowpea

CWD is a by-product of the ceramic industry, produced during the surface leveling of the ceramic before the final polishing phase of ceramic tiles; the CWD contains many mineral compounds (Table 1). CWD was obtained from a factory in 10th Ramadan City, Egypt. Treatments of CWD were applied during soil preparation. All agricultural cultivation practices were performed according to Ministry of Agriculture, Egypt recommendation.

1. Data recorded

1.1. Soil analysis

Field soil samples at depth of 0-30 cm were collected for analysis before and after the applied treatments (at harvest), air dried, passed through 2 mm sieve and analyzed for soil characteristics, particle size distribution

Table (1). Chemical and physical characteristics of the soil, CWD and irrigation water of Ras Sudr Farm.

	pH	EC ($dS\ m^{-1}$)	OC ($g\ kg^{-1}$)	Bulk Density ($Mg\ m^{-3}$)	$CaCO_3$ %	Particle size distribution: Fine sand	Coarse Sand %	Silt %	Clay %	Texture class
Soil depth (0-30 cm)	7.96	8.88	1.47	1.48	45.7	45.28	34.72	10.65	9.35	Sandy loam
CWD	7.54	1.73	29.93	1.08	5.50	1.97	1.73	27.8	68.5	Silty clay loam

Total content of some elements of CWD

	N ($g\ kg^{-1}$)	P ($g\ kg^{-1}$)	K ($g\ kg^{-1}$)	Fe ($Mg\ kg^{-1}$)	Mn ($Mg\ kg^{-1}$)	Zn ($Mg\ kg^{-1}$)	Cu ($Mg\ kg^{-1}$)
CWD	13.20	5.78	13.16	210	4.12	4.23	1.37

Chemical properties of the irrigation water

pH	EC $dS\ m^{-1}$	Cation ($mmol_c\ L^{-1}$)				Anion ($mmol_c\ L^{-1}$)				SAR
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	
8.03	9.43	23.54	24.48	40.05	0.14	nil	9.50	29.77	48.94	8.17

CWD: ceramic waste dust

was determined by the pipette method, using sodium hexametaphosphate as a dispersing agent (Kroetsch and Wang, 2007), pH and EC according to Richards (1954), organic carbon was determined by the modified Walkley and Black method (Jackson, 1973), bulk density according to Blake (1986), hydraulic conductivity was determined according to Klute (1986) and maximum water holding capacity was measured according to Stolte et al. (1992).

1.2. Plant vegetative growth traits

A random sample of five plants of each experimental plot was taken at 70 days after sowing to estimate plant height, plant branch number, plant leaf number, plant fresh and dry weight of cowpea, and at 60 days after sowing to estimate plant height, plant leaf number of sunflower.

1.3. Yield and its components

Cowpea and sunflower plants were harvested at their mature stages, ten plants were chosen randomly from each plot to estimate number of pods/plant, number of seeds/pod, average pod weight, seed yield/plant and seed yield/ha for cowpea, and head diameter, head weight, head seed weight for sunflower. Moreover, whole sunflower plants of the plot were harvested to estimate seed yields per hectare.

1.4. Sunflower seed oil content

Oil percentage of seeds was measured by extraction using Soxhlet Apparatus with hexane as a solvent, according to AOAC (2005). The oil yield was computed, as seed yield × oil percentage.

2. Competitive Relationships

2.1. Land Equivalent Ratio (LER)

It is the relative land area under sole crops that is required to achieve the same yield produced with intercropping. LER was calculated according to the equation described by Willy (1979) as follow:

$$\text{LER}= \frac{\text{Yab}}{\text{Yaa}} + \frac{\text{Yba}}{\text{Ybb}}$$

Where: Yaa = sunflower pure stand yield, Ybb = cowpea pure stand yield, Yab = sunflower yield in combination with cowpea and Yba = cowpea yield in combination with sunflower.

2.2. Relative Crowding Coefficient (RCC)

It was calculated according to equations described by Hall (1974).

In case of 1:1 ratio, the equation is as follows:

$$\text{Ka} = \frac{\text{Yab}}{\text{Yaa}-\text{Yab}} \quad \text{and} \quad \text{Kb} = \frac{\text{Yba}}{\text{Ybb}-\text{Yba}}$$

Where, ka is the relative crowding coefficient of sunflower in a mixture with cowpea, kb is the relative crowding coefficient of cowpea in a mixture with sunflower.

In case of different intercropping ratios:

$$ka = \frac{Yab \times Zba}{Yaa - Yab} \times Zab \quad \text{and} \quad kb = \frac{Yba \times Zab}{Ybb - Yba} \times Zba$$

Where, Zab is proportion of sunflower in mixture with cowpea, and Zba is the proportion of cowpea in a mixture with sunflower.

Finally: $K = \frac{Ka}{Kb}$

2.3. Aggressivity (A)

It was calculated according to equations described by McGilchrist (1965).

The equations in case of 1:1 ratio:

$$Aa = \frac{Yab}{Yaa} - \frac{Yba}{Ybb} \quad \text{and} \quad Ab = \frac{Yba}{Ybb} - \frac{Yab}{Yaa}$$

And in case of different intercropping ratios:

$$Aa = \frac{Yab}{Yaa \times Zab} - \frac{Yba}{Ybb \times Zba} \quad \text{and} \quad Ab = \frac{Yba}{Ybb \times Zba} - \frac{Yab}{Yaa \times Zab}$$

3. Statistical Analysis

All data were processed by analysis of variance according to the method described by Gomez and Gomez (1984) by using COSTAT software package. Since the homogeneity test of the two years for all soil characters was not significant, the combined analysis of variance was also done for each character over the two years. The means were compared by Duncan's multiple range test at $p \leq 0.05$ (Snedecor and Cochran 1980).

RESULTS AND DISCUSSION

1. Soil Chemical Properties

1.1. Soil pH

The results in Table (2) demonstrate that the addition of CWD significantly decreased the pH values of the soil. The lowest pH value (7.74) was obtained with 96 Mg ha^{-1} of CWD compared to the control, which gave the highest value (7.90). These results agree with those obtained by Elcossy (2022). The pH values of the soil decreased as the proportion of plants was increased because of the intercropping treatments. On the other hand, sunflower or cowpea pure stands gave the highest soil pH values (7.84 and 7.83, respectively). The pH level was the lowest (7.76) when sunflower and cowpea were intercropped as a ratio of 1:2. These results are also in agreement with Emmanuel et al. (2010) and Imran et al. (2013), who stated that intercropping decreased the soil pH when compared to sole crop conditions. The interaction between CWD and the intercropping systems had no significant effect on the soil pH values. The intercropping systems using a ratio of 1 sunflower: 2 cowpea and 96 Mg ha^{-1} of CWD resulted in the lowest soil pH values, while the highest soil pH values were obtained when sunflower or cowpea were planted in a pure stand without the addition of ceramic waste dust.

1.2. Soil EC

The soil EC responded negatively to the addition of CWD compared with the control (Table 2). The lowest value of the soil EC (7.13 dS m^{-1}) was obtained from the application of 96 Mg ha^{-1} CWD, but the highest value (9.12 dS m^{-1}) was obtained with no addition of CWD (control). The results agree with those of Elcossy (2022).

Table (2). Effect of CWD and intercropping systems on some soil chemical and physical properties at harvest in 2020 and 2021 seasons (combined over years).

Treatments		pH	EC (dS m^{-1})	OC (g kg^{-1})	Bd (Mg m^{-3})	MWHC (%)	HC (cm hr^{-1})
CWD (Mg ha^{-1})	**Intercropping systems**						
0	Sole sunflower	7.94a	9.30a	1.65m	1.59a	14.53o	19.89a
	Sole cowpea	7.92ab	9.22b	1.67l	1.58ab	14.95n	19.61b
	1S:1C	7.89bc	9.12c	1.70l	1.56bc	15.93l	19.05d
	1S:2C	7.87c	8.95e	1.70k	1.55c	16.41k	18.70e
	2S:1C	7.91b	9.02d	1.68l	1.57abc	15.38m	19.37c
	Mean	7.90a	9.12a	1.68c	1.57a	15.44a	19.32a
48	Sole sunflower	7.81d	7.56f	2.07j	1.44d	18.77j	14.95f
	Sole cowpea	7.80de	7.43g	2.22i	1.43de	19.88i	14.03g
	1S:1C	7.76f	7.16k	2.58e	1.39ghi	22.52e	12.05k
	1S:2C	7.73gh	7.02m	2.78c	1.37ijk	24.07c	10.96m
	2S:1C	7.78def	7.30i	2.39g	1.41efg	21.13g	13.07i
	Mean	7.78b	7.30b	2.40b	1.41b	21.27b	13.01b
96	Sole sunflower	7.78def	7.41h	2.28h	1.42def	20.85h	13.34h
	Sole cowpea	7.77ef	7.27j	2.44f	1.40fgh	21.98f	12.41j
	1S:1C	7.72hi	6.99n	2.83b	1.36jk	24.64b	10.46n
	1S:2C	7.70i	6.84o	3.05a	1.35k	26.29a	9.42o
	2S:1C	7.75fg	7.14l	2.63d	1.38hij	23.27d	11.46l
	Mean	7.74c	7.13c	2.64a	1.38c	23.41a	11.42c
Means of intercropping	Sole sunflower	7.84a	8.08a	2.00e	1.48a	18.05e	16.06a
	Sole cowpea	7.83a	7.97b	2.11d	1.47b	18.94d	15.35b
	1S:1C	7.79c	7.76d	2.37b	1.43d	21.03b	13.85d
	1S:2C	7.76d	7.60e	2.51a	1.42e	22.26a	13.02e
	2S:1C	7.81b	7.82c	2.23c	1.45c	19.93c	14.63c

CWD: ceramic waste dust, S: sunflower, C: cowpea, OC: organic carbon, Bd: bulk density, MWHC: maximum water holding capacity, HC: hydraulic conductivity.

The results showed that soil EC was significantly decreased with increasing sunflower or cowpea proportion in the intercropping ratio. The maximum level of soil EC (8.08 dS m^{-1}) was obtained when sunflower planted as a pure stand system, followed by sole cowpea (7.97 dS m^{-1}). While the minimum level of soil EC (7.60 dS m^{-1}) was obtained from the intercropping system ratio of 1 sunflower: 2 cowpea treatment. Regarding the interaction between CWD and the intercropping systems, it had a significant effect on soil EC. The soil EC values from the intercropping system of 1 sunflower: 2 cowpea combined with 96 Mg ha^{-1} of CWD were the lowest, whereas the greatest values were obtained from sunflower or cowpea planted as a pure stand without the addition of CWD (control).

1.3. Soil organic carbon (OC)

The data in Table (2) show the effect of CWD on soil organic carbon and it was found to be significant. The maximum soil organic carbon was 2.64 g kg^{-1} when adding 96 Mg ha^{-1} of CWD, and minimum soil organic carbon value was 1.68 g kg^{-1} in control treatment (without CWD), these differences reached to the level of significance. These results agree with those obtained by Tahir and Marschner (2016) and Elcossy (2022), who found that the soil organic carbon values increased with applying CWD.

The intercropping systems significantly affected the soil organic carbon (Table 2). Compared with monocropping, intercropping significantly increased the soil organic carbon. Intercropping sunflower with cowpea (1:2) gave the highest values of soil organic carbon followed by intercropping treatment (1:1), while the sole sunflower cropping system gave the lowest soil organic carbon values. Obtained results agree with those of Verma et al. (2014). Cong et al. (2015) found that the soil organic carbon content of the intercropping systems was significantly higher than that of cultivating the pure stand. The reason for this is that, in addition to the influence of soil particles, it is likely to be related to the ground cover condition and plant root distribution characteristics, the intercropping pattern has a significant biomass and yield advantage, and the root biomass is significantly higher than the monoculture treatment, and the residual carbon is easily imported to the soil through the root system (Brady and Weil, 2008 and Yang et al., 2010). Regarding the interaction effect between CWD and intercropping, it was found that sunflower and cowpea intercropped at a ratio of 1:2 combined with a 96 Mg ha^{-1} CWD treatment resulted in the maximum soil organic carbon value.

2. Soil Physical Properties

2.1. Bulk density (Bd)

Table (2) shows significant effect of CWD and intercropping systems on soil bulk density. There was a reduction in soil bulk density (1.41 and 1.38 mg m^{-3}) with the addition of CWD at 48 and 96 Mg ha^{-1} levels, respectively, whereas a significant increment in soil bulk density (1.57 Mg m^{-3}) was obtained at control level (without CWD). These findings concurred with those reported by Elcossy (2022), who found that the mean bulk densities were decreased with increasing application of ceramic waste dust rates.

The intercropping systems had a significant influence on soil bulk density (Table 2). In combined years, the sole crops (sunflower or cowpea) gave the highest values of soil bulk density (1.48 and 1.47 Mg m^{-3}, respectively). From intercropping treatment, the highest soil bulk density (1.45 Mg m^{-3}) was recorded in planting sunflower intercropped with cowpea by the ratio of 2:1, while the lowest value of soil bulk density (1.42 Mg m^{-3}) was obtained from intercropped sunflower with cowpea by the ratio of 1:2 (Table 2). Similar results were obtained by Xu et al. (2021a), who found that the soil bulk densities of the intercropping methods were lower than that the control. All interaction effects between CWD and intercropping systems were not significant on soil bulk density. Sunflower pure stand or cowpea pure stand without the addition of CWD gave the highest values of soil bulk density, while sunflower and cowpea intercropped at a ratio of 1:2 combined with a 96 Mg ha^{-1} CWD treatment resulted in the minimum soil bulk density value (Table 2).

2.2. Maximum water holding capacity (MWHC)

The findings in Table (2) demonstrate a significant increase in the soil's maximum water-holding capacity in the combined years following the application of CWD. In comparison to the control treatment (without CWD), the maximum increase was observed at a CWD level of 96 Mg ha^{-1}. These findings concurred with those obtained by Elcossy (2022).

The intercropping systems had a significant effect on soil maximum water-holding capacity over years (Table 2). The highest value of soil maximum water-holding capacity (22.26%) was recorded when sunflower intercropped with cowpea by 1:2 ratios, while the lowest value (18.05%) was obtained when sunflower was planted alone. These finding are also supported by Xu et al. (2021b). This may be due to intercropping, which can significantly increase soil surface cover and root distribution, making the soil surface less susceptible to wind and water erosion. It may also be caused by increased humus content, which includes organic matter and other plant residues in the soil, and increased soil water holding capacity (Ling et al., 2016). The soil maximum water-holding capacity was significantly impacted by CWD interaction with the intercropping systems. The intercropping system of 1 sunflower: 2 cowpea combined with 96 Mg ha^{-1} of CWD produced the highest soil maximum water-holding capacity values, whereas the lowest values were produced by sunflower or cowpea planted as a pure stand without the addition of CWD (control).

2.3. Saturated hydraulic conductivity (HC)

As shown in Table (2), there was a significant decrease in the saturated hydraulic conductivity (HC) in soil treated by CWD compared to control. Table (2) shows a higher decrease in HC of the soil treated by CWD at a rate of 96 Mg ha^{-1} than that treated by 48 Mg ha^{-1} in combined years. These results agree with those of Elcossy (2022), who showed that the mean saturated HC decreased with increased ceramic waste dust application rates.

The intercropping systems significantly affected HC of the soil (Table 2). Compared with sole crops, intercropping significantly decreased the soil HC. Sunflower intercropped with cowpea (1:2) results in the lowest values of soil HC which was 13.02 cm ha^{-1} compared with sole sunflower and sole cowpea which was 16.06 and 15.35 cm ha^{-1}, respectively. Soil HC was significantly impacted by the interaction between CWD and the intercropping systems. The soil HC values from the intercropping system of 1 sunflower: 2 cowpea combined with 96 Mg ha^{-1} of CWD were the lowest, whereas the highest values were obtained from a sunflower planted as a pure stand without the addition of CWD (control).

3. Cowpea Growth Characteristics

The results showed that the CWD treatments significantly affected all growth characteristics that were measured in both growing seasons (Table 3). Plants treated with 96 Mg $ha^{-1}$of CWD had the highest values of plant height, branch number, leaf number, fresh and dry weight. The least values for all these indexes were recorded with untreated plants. The improvement in plant growth might be due to a decrease in pH, EC, bulk density, and hydraulic conductivity of soil (Table 2), whereas it increased soil organic carbon and soil maximum water holding capacity when adding CWD to the soil (Table 2), which led to enhancing both absorption and transport of elements in plants, thereby, enhancing cowpea plant growth.

As regard to the effect of intercropping on cowpea plant height, branch number, leaf number, fresh and dry weight (Table 3) indicated that there were significantly differences among intercropping treatments in both seasons. The maximum values of growth indexes were noted with sole cowpea followed by the intercropping system of sunflower: cowpea (1:2). However, the intercropping system of sunflower: cowpea (2:1) produced the lowest values of growth indexes in the two investigated seasons. These results are in line with Gomaa (2020) and Liu et al. (2022). The decrease of growth of cowpea under intercropping pattern may be due to competition for light, nutrients and water which reflected on light interception and led to cowpea weak growth (Sharaiha et al., 2004). The interaction between CWD and intercropping systems on cowpea plant growth characteristics were significant different among the treatments in both seasons. Addition of 96 Mg $ha^{-1}$of CWD combined with sole cowpea followed by plants treated by 96 Mg $ha^{-1}$of CWD combined with the intercropping system of sunflower: cowpea (1:2) gave the highest values of plant growth characteristics as compared with others interaction treatments in both seasons.

4. Cowpea Yield and its Characteristics

Table (4) shows a significant increase in plant pod number, pod seed number, average pod weight, plant seed yield and seed yield per hectare with increasing of CWD levels in both seasons. The highest values of all these

Table (3). Effect of CWD and intercropping systems on cowpea plant height, branch number, leaf number, plant fresh and dry weight at 70 days after sowing seeds in 2020 and 2021 seasons.

Treatments		Plant height (cm)		Branch number		Leaf number		Plant fresh weight (g)		Plant dry weight (g)	
CWD (Mg ha^{-1})	**Intercropping systems**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
0	Sole cowpea	47.70c	49.33d	4.51e	4.65f	26.78g	31.48e	29.97f	32.92g	5.74c	5.85f
	1S:1C	37.63f	40.80g	4.23f	4.36h	22.22i	25.00g	25.36h	28.01j	5.05ef	5.22h
	1S:2C	42.22e	44.65f	4.37ef	4.51g	25.00h	28.66f	29.32f	31.16h	5.24de	5.39h
	2S:1C	35.13g	38.45h	4.05g	4.15i	21.66i	23.11h	23.56i	25.83k	4.82f	5.06i
Mean		40.66c	43.31c	4.29c	4.42c	23.91c	27.06c	27.05c	29.48c	5.21c	5.38c
48	Sole cowpea	50.28b	52.21c	5.08c	5.27cd	33.11c	35.03c	36.23c	40.72c	6.21b	6.41d
	1S:1C	42.10e	44.39f	4.50e	4.63f	27.00g	31.66e	29.58f	33.85f	5.31de	5.58g
	1S:2C	46.61c	48.10e	4.80d	5.02e	31.66d	33.89d	33.92d	38.70d	5.84c	6.22e
	2S:1C	38.59f	40.97g	4.26f	4.37h	25.00h	28.66f	26.61g	29.59i	5.09ef	5.30h
Mean		44.40b	46.42b	4.66b	4.82b	29.19b	32.31b	31.58b	35.72b	5.61b	5.88b
96	Sole cowpea	54.43a	55.78a	5.63a	5.72a	35.66a	37.00a	43.43a	45.00a	7.28a	7.51a
	1S:1C	48.51c	51.25c	5.17c	5.37c	30.03e	33.88d	37.50b	39.18d	6.26b	6.81c
	1S:2C	51.15b	53.55b	5.29b	5.61b	34.00b	36.11b	42.85a	42.40b	7.06a	7.30b
	2S:1C	44.23d	47.88e	4.87d	5.20d	27.66f	31.66e	32.74e	35.73e	5.52cd	6.13e
Mean		49.58a	52.12a	5.24a	5.47a	31.84a	34.66a	39.13a	40.58a	6.53a	6.94a
Means of intercropping	Sole cowpea	50.80a	52.44a	5.07a	5.21a	31.85a	34.50a	36.54a	39.55a	6.41a	6.59a
	1S:1C	42.75c	45.48c	4.63c	4.79c	26.42c	30.18c	30.82c	33.68c	5.54c	5.87c
	1S:2C	46.66b	48.77b	4.82b	5.04b	30.22b	32.89b	35.36b	37.42b	6.05b	6.31b
	2S:1C	39.31d	42.43d	4.39d	4.57d	24.77d	27.81d	27.64d	30.38d	5.14d	5.50d

CWD: ceramic waste dust, S: sunflower, C: cowpea

characters were recorded with 96 Mg ha^{-1} of CWD treatment. However, the plants showed the minimum response to the control treatment. In the present study, the effect of CWD on yield and its characteristics may be due to the effect of CWD on plant growth (Table 3), which is reflected on the yield and its characteristics of cowpea (Table 4).

The greatest values of plant pod number, pod seed number, average pod weight and plant seed yield were associated with sole cowpea followed by the intercropping system of sunflower: cowpea (1:2). On the contrary, the intercropping system of sunflower: cowpea (2:1) gave the lowest values in both seasons. The differences between the intercropping systems were significant in both seasons (Table 4). Regarding to the seed yield per hectare as affected by various intercropping ratios, the obtained results in Table (4) reveal that various intercropping systems significantly affected the seed yield per hectare of cowpea in both seasons. After sole cowpea, the intercropping system of sunflower: cowpea (1:2) treatment showed the highest seed yield per hectare compared to other intercropping systems. On the other hand, the lowest values of seed yield per hectare were obtained from the intercropping system of sunflower: cowpea (2:1) in the two investigated seasons. Similar results were obtained by Gomaa (2020), Hunegnaw et al. (2022) and Liu et al. (2022). This might attribute to that sunflower take up nutrients, especially N, mainly during the vegetative growth stage and associated vigorous growth may cause shading of the cowpea and thereby reduce its growth during later growth stages resulting in low yielding ability (Megawer et al., 2010). All interactions had significant positive effects and the most pronounced effect on cowpea seed yield per hectare was obtained when planted as a sole crop and treated with high levels of CWD in both seasons.

5. Sunflower Growth and Head Characteristics

According to the results presented in Table (5), plant growth characteristics of sunflower (height and leaf number) and head characteristics (diameter, weight and seed weight) were significantly increased in sunflower plants under CWD addition in both seasons. The highest values were recorded with 96 Mg ha^{-1} of CWD compared with 48 Mg ha^{-1} of CWD and control (without CWD) in the two investigated seasons. The enhanced sunflower growth and head characteristics might be attributed to the role of CWD in decreasing pH, EC, bulk density, and hydraulic conductivity of soil, whereas it increased soil organic carbon and soil maximum water holding capacity (Table 2), which led to the enhancement of both absorption and transport of elements in plants, thereby, enhancing plant growth and finally led to an improvement of sunflower head characteristics.

Intercropping sunflower with cowpea plants caused a significant increase in plant height, plant leaf number, head diameter, head weight and head seed weight of sunflower plants compared with sole sunflower plants (Table 5). Furthermore, the intercropping system of sunflower: cowpea (1:2)

Table (4). Effect of CWD and intercropping systems on cowpea plant pod number, pod seed number, average pod weight, plant seed yield and hectare seed yield at harvest in 2020 and 2021 seasons.

Treatments		Plant pod number		Pod seed number		Average pod weight (g)		Plant seed yield (g)		Seed yield (Mg ha^{-1})	
CWD (Mg ha^{-1})	**Intercropping system**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
0	Sole cowpea	7.41gh	8.13fg	4.42de	5.02f	1.30f	1.37g	9.75h	11.20hi	1.42c	1.49c
	1S:1C	6.14i	7.12h	4.18e	4.36h	1.13f	1.24h	7.06j	8.90j	0.64i	0.71i
	1S:2C	7.06h	7.94g	4.36de	4.73g	1.25f	1.32g	8.94i	10.57i	0.88f	0.96f
	2S:1C	5.58j	6.95h	3.85f	4.13i	1.13f	1.22h	6.37k	8.62j	0.44l	0.52k
Mean		6.55c	7.54c	4.20c	4.56c	1.20c	1.29c	8.03c	9.82c	0.84c	0.92c
48	Sole cowpea	8.62e	9.23e	5.01bc	5.52d	1.73cd	1.86cd	15.04e	17.22e	1.59b	1.69b
	1S:1C	7.84fg	8.34f	4.54d	5.13f	1.33f	1.53f	10.52g	12.96g	0.74h	0.84h
	1S:2C	8.31ef	9.01e	4.82c	5.35e	1.55e	1.71e	12.93f	15.84f	1.01e	1.11e
	2S:1C	7.21gh	7.90g	4.24de	4.47h	1.27f	1.46f	9.17i	11.72h	0.52k	0.62j
Mean		8.00b	8.62b	4.65b	5.12b	1.47b	1.64b	11.92b	14.43b	0.97b	1.07b
96	Sole cowpea	12.93a	14.02a	6.27a	6.54a	2.17a	2.53a	27.98a	29.75a	1.84a	1.92a
	1S:1C	10.28c	11.16c	5.24b	6.03c	1.80c	1.93c	18.73c	21.95c	0.81g	0.89g
	1S:2C	11.99b	12.40b	6.04a	6.34b	2.00b	2.34b	24.80b	28.74b	1.23d	1.30d
	2S:1C	9.62d	10.68d	4.91c	5.28e	1.61de	1.80d	15.71d	19.57d	0.57j	0.67i
Mean		11.21a	12.07a	5.62a	6.05a	1.89a	2.15a	21.80a	25.00a	1.11a	1.20a
Means of intercropping	Sole cowpea	9.66a	10.46a	5.23a	5.69a	1.73a	1.92a	17.59a	19.39a	1.62a	1.70a
	1S:1C	8.09c	8.87c	4.65c	5.17c	1.42c	1.57c	12.10c	14.60c	0.73c	0.81c
	1S:2C	9.12b	9.79b	5.07b	5.48b	1.60b	1.79b	15.56b	18.38b	1.04b	1.12b
	2S:1C	7.47d	8.51d	4.33d	4.63d	1.34d	1.49d	10.42d	13.31d	0.51d	0.60d

CWD: ceramic waste dust, S: sunflower, C: cowpea

Table (5). Effect of CWD and intercropping systems on sunflower plant height and leaf number at 60 days after sowing seeds, and head diameter, head weight, and head seed weight at harvest in 2020 and 2021 seasons.

Treatments		Plant height (cm)		Plant leaf number		Head diameter (cm)		Head weight (g)		Head seed weight (g)	
CWD (Mg ha^{-1})	**Intercropping systems**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
0	Sole sunflower	109.34i	112.68k	19.00h	17.89g	14.37i	14.65i	92.55j	94.24i	27.83k	30.01i
	1S:1C	116.57g	120.92h	20.22g	19.00f	15.14gh	15.97f	96.64h	99.58g	35.09g	35.81f
	1S:2C	119.96f	124.89f	20.89f	20.66e	15.57ef	16.23e	99.05g	102.57f	37.09e	39.01e
	2S:1C	111.34h	114.72j	19.66g	18.89f	15.05h	15.34h	95.90i	98.13h	31.81i	33.55h
Mean		114.30c	118.30c	19.94c	19.11c	15.03c	15.55c	96.04c	98.63c	32.95c	34.60c
48	Sole sunflower	115.86g	118.14i	19.89g	19.44f	15.16gh	15.54g	95.66i	98.59h	30.63j	34.94g
	1S:1C	125.86d	129.54d	22.55cd	21.44cd	15.91d	16.24e	100.45e	105.04d	39.62e	42.05d
	1S:2C	127.87c	134.96b	23.29c	22.77b	16.18c	16.74d	103.75c	107.23c	41.79d	45.56c
	2S:1C	120.56f	123.62g	21.66e	21.00de	15.39fg	16.02ef	98.60g	101.92f	36.15g	38.16e
Mean		122.54b	126.57b	21.85b	21.16b	15.66b	16.13b	99.62b	103.20b	37.05b	40.18b
96	Sole sunflower	121.86e	126.55e	22.00de	21.66cd	15.82de	16.63d	99.76f	104.32e	40.08e	42.83d
	1S:1C	130.05b	134.86b	24.00b	23.11b	17.21b	17.79b	105.87b	109.60b	49.21b	51.04b
	1S:2C	134.29a	138.88a	26.55a	24.44a	17.65a	18.31a	108.87a	111.92a	53.09a	56.30a
	2S:1C	125.15d	131.81c	22.89c	22.11c	16.27c	17.23c	102.62d	107.09c	43.96c	46.06c
Mean		127.84a	133.02a	23.86a	22.83a	16.74a	17.49a	104.28a	108.23a	46.59a	49.06a
Means of intercropping	Sole sunflower	115.69d	119.12d	20.29d	19.66d	15.12d	15.61d	95.99d	99.05d	32.85d	35.93d
	1S:1C	124.16b	128.44b	22.26b	21.18b	16.09b	16.67b	100.99b	104.74b	41.31b	42.97b
	1S:2C	127.37a	132.91a	23.58a	22.63a	16.47a	17.09a	103.89a	107.24a	43.99a	46.96a
	2S:1C	119.02c	123.38c	21.40c	20.66c	15.57c	16.20c	99.04c	102.38c	37.30c	39.26c

CWD: ceramic waste dust, S: sunflower, C: cowpea

treatment showed the highest values of plant height, plant leaf number, head diameter, head weight and head seed weight of sunflower plants in both seasons. The superiority of these traits under intercropping systems may be attributed to advantage exploitation of resource or to the cowpea effect on nutrition of sunflower or to facilitate interaction in this intercropping system (Midya et al., 2005 and Banik et al., 2006). The interaction between CWD and intercropping systems on plant growth characters (height and leaf number) and head characters (diameter, weight and seed weight) were significant in both seasons. The highest values were obtained from the intercropping system of sunflower: cowpea (1:2) treated with 96 Mg ha^{-1} of CWD in the two seasons.

6. Sunflower seed oil percentage, Seed yield and Oil yield

Table (6) revealed that CWD and intercropping systems had significant effect on seed oil percentage, seed yield and oil yield per hectare. The application of CWD enhanced seed oil percentage, seed yield and oil yield in both seasons. The maximum values of seed oil percentage, seed yield and oil yield were recorded with 96 Mg CWD ha^{-1} in both seasons. However, the plants showed the minimum response in the control treatment. The effect of CWD on sunflower seed yield and oil yield may be due to the effect of CWD on plant growth and head characteristics (Table 5) which reflected on the seed yield and oil yield of sunflower (Table 6).

The analysis of the results obtained in the present study showed that various intercropping systems significantly affected seed oil percentage, seed yield and oil yield in both seasons (Table 6). The highest values of seed oil percentage were recorded with the intercropping system of sunflower: cowpea (1:2), while the minimum values were obtained from the sole sunflower plants in the two seasons. As shown in Table (6), the seed yield and oil yield in both seasons were markedly higher in the sole sunflower crop treatment compared to other intercropping system treatments. After the sole sunflower treatment, the intercropping system of sunflower: cowpea (2:1) treatment showed the highest seed yield and oil yield per hectare, compared to other intercropping system treatments in both seasons. This agrees with Gomaa (2020) and Liu et al. (2022). This may be ascribed to the shorter height of cowpea plants than those of sunflower, which gave sunflower a relevant conditions, especially light, to grow well and increased its ability to accumulate more assimilates during seed filling period when intercropped with cowpea which reflected on sunflower seed and oil yield. These interpretations support those reported by Walker and Oingo (2003) and Banik et al. (2006). All interactions had significant positive effects and the most pronounced effect on sunflower seed yield and oil yield was obtained when planted as pure stand and treated with high levels of CWD both seasons.

Table (6). Effect of CWD and intercropping systems on seed oil percentage, seed yield and oil yield at harvest of sunflower in 2020 and 2021 seasons.

Treatments		Seed oil (%)		Yield ($Mg\ ha^{-1}$)			
				Seed		Oil	
CWD ($Mg\ ha^{-1}$)	Intercropping systems	2020	2021	2020	2021	2020	2021
0	Sole sunflower	32.33g	33.60g	1.57c	1.65c	0.506d	0.553e
	1S:1C	34.08de	35.11f	1.03g	1.12h	0.350h	0.392g
	1S:2C	34.73cd	37.06d	0.70i	0.79k	0.242j	0.293i
	2S:1C	33.85e	34.63f	1.27e	1.36f	0.431f	0.472f
Mean		33.75b	35.10c	1.14c	1.23c	0.382c	0.428c
48	Sole sunflower	32.90f	34.08g	1.76b	1.86b	0.579b	0.633b
	1S:1C	34.72cd	37.73bc	1.17f	1.27g	0.407g	0.480f
	1S:2C	35.01c	38.00b	0.73i	0.84j	0.257j	0.320h
	2S:1C	34.00de	36.97d	1.37d	1.56d	0.465e	0.576d
Mean		34.16b	36.70b	1.26b	1.38b	0.427b	0.502b
96	Sole sunflower	34.51cde	36.33e	2.04a	2.16a	0.704a	0.783a
	1S:1C	35.88b	37.92b	1.37d	1.49e	0.492d	0.565de
	1S:2C	36.53a	38.72a	0.86h	0.98i	0.314i	0.379g
	2S:1C	35.08c	37.22cd	1.54c	1.66c	0.539c	0.617c
Mean		35.50a	37.55a	1.45a	1.57a	0.512a	0.586a
Means of intercropping	Sole sunflower	33.25d	34.67d	1.79a	1.89a	0.596a	0.656a
	1S:1C	34.89b	36.92b	1.19c	1.29c	0.416c	0.479c
	1S:2C	35.42a	37.93a	0.76d	0.87d	0.271d	0.331d
	2S:1C	34.31c	36.28c	1.39b	1.53b	0.478b	0.555b

CWD: ceramic waste dust, S: sunflower, C: cowpea

7. Competitive Relationships

7.1. Land Equivalent Ratio (LER)

Results in Table (7) show that LERs for sunflower, cowpea and combined intercrop yields were not affected significantly with CWD application in both seasons. Table (7) and Fig (1) show a considerable yield advantage as a result of intercropping cowpea with sunflower in both seasons. This type of competition can be termed mutual cooperation (Willey, 1979). Land equivalent ratio (LER) values for the intercrop yields of both sunflower and cowpea were increased as their proportions were increased in the intercropping system treatments. The highest LER values for sunflower were obtained with the intercropping system of sunflower: cowpea (2:1) and that for cowpea were obtained with the intercropping system the sunflower: cowpea (1:2) in both seasons. The total LERs were in the range of 1.116 for sunflower: cowpea of 1:1 ratio to 1.069 for sunflower: cowpea of 1:2 ratio in the first season, and in the range of 1.168 for sunflower: cowpea of 2:1 ratio to 1.123 for sunflower: cowpea of 1:2 ratio in the second season, which indicated that intercropping can be increased the total productivity in the range of 12 and 7% in the first season, and 17 and 12% in the second season, respectively compared with sole planting of each crop. It was observed that all intercropping patterns resulted in LERs more than one indicating yield advantage over monocrop due to better land utilization. Similar results were found by Banik et al. (2006), Shehata et al. (2007) and Megawer et al. (2010).

7.2. Relative crowding coefficient (RCC)

Table (8) shows that the effect of CWD on relative crowding coefficient were not significant in both seasons. Relative crowding coefficients (K) revealed the superiority of 2:1 pattern of the intercropping sunflower with cowpea, followed by those of 1:1 ratio. While sunflower: cowpea of 1:2 ratio resulted in the lowest value (Table 8). This was attributed to effectual competition of sunflower, where its K coefficients were very high to those of cowpea. Resembling results were obtained by Soubeih and El Sayed (2014).

Table (7). Effect of CWD and intercropping systems on land equivalent ratio (LER) between sunflower and cowpea in 2020 and 2021 seasons.

Treatments		Partial LER for sunflower		Partial LER for cowpea		Total LER for sunflower + cowpea	
CWD (Mg ha^{-1})	Intercropping systems	2020	2021	2020	2021	2020	2021
0	1S:1C	0.656c	0.677c	0.447c	0.478c	1.103abc	1.155bcd
	1S:2C	0.446d	0.480d	0.619b	0.644b	1.065bc	1.123cd
	2S:1C	0.814a	0.829a	0.312d	0.348d	1.126a	1.176abc
Mean		0.639a	0.662a	0.459a	0.490a	1.098a	1.152a
48	1S:1C	0.667c	0.686c	0.463c	0.497c	1.131a	1.182ab
	1S:2C	0.418d	0.452d	0.635b	0.657ab	1.052c	1.109d
	2S:1C	0.777b	0.840a	0.326d	0.368d	1.103abc	1.208a
Mean		0.621a	0.659a	0.474a	0.507a	1.095a	1.167a
96	1S:1C	0.671c	0.690c	0.443c	0.465c	1.114ab	1.154bcd
	1S:2C	0.422d	0.455d	0.667a	0.681a	1.090abc	1.136bcd
	2S:1C	0.753b	0.768b	0.311d	0.350d	1.064bc	1.119d
Mean		0.616a	0.638a	0.474a	0.499a	1.089a	1.136a
Means of intercropping	1S:1C	0.665b	0.684b	0.451b	0.480b	1.116a	1.164a
	1S:2C	0.429c	0.462c	0.640a	0.660a	1.069b	1.123b
	2S:1C	0.781a	0.812a	0.316c	0.355c	1.097a	1.168a

CWD: ceramic waste dust, S: sunflower, C: cowpea

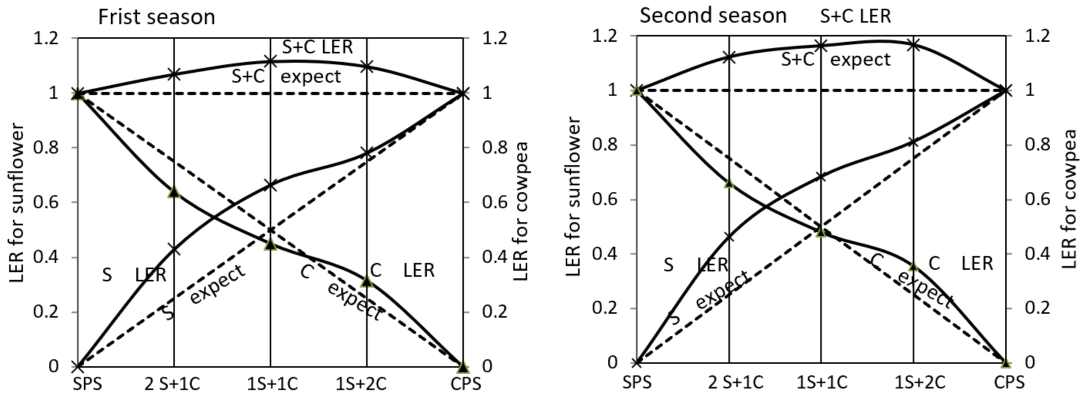

Fig. (1). Effect of intercropping between sunflower and cowpea on their actual (undotted lines) and expected (dotted lines) yield in both investigated seasons.

Table (8). Effect of CWD and intercropping systems on relative crowding coefficient (RCC) between sunflower and cowpea in 2020 and 2021 seasons.

Treatments		ka for sunflower		kb for cowpea		K= ka × kb	
CWD ($Mg\ ha^{-1}$)	**Intercropping systems**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
0	1S:1C	1.921ab	2.119ab	0.810b	0.916bc	1.559ab	1.944b
	1S:2C	1.612b	1.846b	0.812b	0.903bc	1.310b	1.668b
	2S:1C	2.282a	2.528a	0.896ab	1.068ab	2.060a	2.719a
Mean		1.938a	2.164a	0.839a	0.962a	1.643a	2.110a
48	1S:1C	2.008ab	2.184ab	0.864ab	0.988bc	1.735ab	2.157b
	1S:2C	1.438b	1.653b	0.871ab	0.960bc	1.253b	1.588b
	2S:1C	1.749ab	2.644a	0.967a	1.168a	1.687ab	3.079a
Mean		1.732a	2.160a	0.901a	1.038a	1.558a	2.274a
96	1S:1C	2.051ab	2.232ab	0.795b	0.870c	1.627ab	1.938b
	1S:2C	1.465b	1.674b	1.006a	1.071ab	1.470ab	1.789b
	2S:1C	1.528b	1.663b	0.903ab	1.080ab	1.377b	1.791b
Mean		1.681a	1.856a	0.901a	1.007a	1.491a	1.839a
Means of intercropping	1S:1C	1.993a	2.178a	0.823b	0.925b	1.640a	2.013b
	1S:2C	1.505b	1.725b	0.896a	0.978b	1.344b	1.681c
	2S:1C	1.853a	2.278a	0.922a	1.105a	1.708a	2.530a

CWD: ceramic waste dust, S: sunflower, C: cowpea, ka: relative crowding coefficient of sunflower in mixture with cowpea, kb: relative crowding coefficient of cowpea in mixture with sunflower, k: relative crowding coefficient

7.3. Aggressivity (A)

The results showed that aggressivity (A) of intercrop sunflower with cowpea were pronounced especially under 1: 1 intercropping system of sunflower with cowpea (Table 9). The aggressivity values of sunflower were positive, were as those of cowpea were negative, which indicated the prevailing effect of sunflower. Similar findings were reported by Soubeih and El Sayed (2014) and Gomaa (2020). Finally, all competition relations, i.e., land equivalent ratio (LER), relative crowding coefficient (K) and aggressivity (A) indicated that sunflower was dominant, and cowpea were dominated.

Table (9). Effect of CWD and intercropping systems on aggressivity (A) between sunflower and cowpea in 2020 and 2021 seasons.

Treatments		Aa for sunflower		Ab for cowpea	
CWD (Mg ha^{-1})	**Intercropping systems**	**2020**	**2021**	**2020**	**2021**
0	1S:1C	0.208a	0.200ab	-0.208b	-0.200bc
	1S:2C	0.004b	0.005c	-0.004a	-0.005a
	2S:1C	0.003b	0.002c	-0.003a	-0.009a
Mean		0.072a	0.069a	-0.072a	-0.065a
48	1S:1C	0.204a	0.189b	-0.204b	-0.189b
	1S:2C	0.003b	0.004c	-0.003a	-0.004a
	2S:1C	0.002b	0.002c	-0.002a	-0.002a
Mean		0.070a	0.065a	-0.070a	-0.065a
96	1S:1C	0.229a	0.225a	-0.229b	-0.225c
	1S:2C	0.003b	0.003c	-0.003a	-0.003a
	2S:1C	0.002b	0.001c	-0.002a	-0.001a
Mean		0.078a	0.076a	-0.078a	-0.076a
Means of intercropping	1S:1C	0.214a	0.204a	-0.214b	-0.204b
	1S:2C	0.003b	0.004b	-0.003a	-0.004a
	2S:1C	0.002b	0.002b	-0.002a	-0.002a

CWD: ceramic waste dust, S: sunflower, C: cowpea

CONCLUSION

The results showed significant decreases in soil pH, EC, Bd and HC due to CWD application and various intercropping systems. However, soil OC and MWHC were increased. The addition of CWD improved the growth and yield of cowpea and sunflower. Intercropping systems can increase land-use efficiency, but it may also lead to a slight decrease in the yield of the main crop due to the competition for resources. There were yield advantages for intercropping sunflower and cowpea when intercropped at 1:2 or 2:1 or 1:1 sunflower: cowpea mixture ratio under Ras Sudr conditions. Planting sunflower alone with the addition of 96 Mg CWD ha^{-1} under Ras Sudr conditions has proven to be effective for oil production.

REFERENCES

AOAC (2005). Association of official agriculture chemists. In: 'Official Methods of Analysis', 18th Ed., 2nd Version. Gaithersburg, MD: USA.

Babar, M.A., M. Arif, M. Kashif, M. Hanif, M. Hayat and M. Daud (2021). Effects of intercropping on growth and yield of radish inter cropped with turnip and spinach under clmatic conditions of quetta. Pak. J. Biotechnol., 18 (3-4): 57-61.

Banik, P., A. Midya, B.K. Sarkar and S.S. Ghose (2006). Wheat and chickpea intercropping systems in an additive series experiment: Advantages and weed smothering. Europ. J. Agron., 24: 325–332.

Blake, G.R. (1986). Bulk Density. In: 'Page, et al. (eds.)'. Methods of Soil Analysis, Part I. Physical and Mineralogical Methods, Am. Soc. Agron. Inc. Medison, WI. USA, pp. 374-390.

Brady, N.C. and R.R. Weil (2008). In: 'The Nature and Properties of Soils'. 14th Ed. Pearson Education Inc.

Chen, J.A. and I.O. Felix (2015). Effect of waste ceramic dust (WCD) on index and engineering properties of shrink-swell soils. Int. J. Eng. Mod. Technol., 1 (8): 2504-8848.

Chen, C., W. Liu, J. Wu, X. Jiang and X. Zhu (2019). Can intercropping with the cash crop help improve the soil physico-chemical properties of rubber plantations? Geoderma, 335: 149-160.

Cong, W.F., E. Hoffland, and L. Li (2015). Intercropping enhances soil carbon and nitrogen. Global Change Biol., 21: 1715-1726.

Elcossy, S.A. (2022). Comparative study between ceramic waste dust and farmyard manure for improving properties and productivity of sandy soil. Egyptian J. Desert Res., 72 (1): 89-105.

Elias, S.H., M. Mohamed, A.N. Ankur, K. Muda, M.A.H.M. Hassan, M.N. Othman and S. Chelliapan (2014). Water hyacinth bioremediation for ceramic industry wastewater treatment application of rhizofiltration system. Sains Malaysiana, 43 (9): 1397-1403.

Emmanuel, C.O., M. Ridenour, C. Ridenour and R. Smith (2010). The effect of intercropping annual ryegrass with pinto beans in mitigating iron deficiency in calcareous soils. J. Sustainable Agric., 34: 244-257.

Gomaa, S.S. (2020). Effect of Intercropping and Spraying with Amino Acids on Growth and Productivity of Sweet Corn (Zea mays L. var. Saccharata) and Sweet Potato (*Ipomoea batates* L.) under Siwa Conditions. J. Hortic. Sci. Ornam. Plants, 12 (3): 223-236.

Gomez, K.N. and A.A. Gomez (1984). In: 'Statistical Procedures for Agricultural Research'. 2nd Ed. John Wiley and Sons, New York, 68 p.

Hall, R.L. (1974). Analysis of the nature of the interference between plants of different species 1, concepts and extension of the dewitt analysis to examine effects. Aust. J. Agric. Res., 25: 739-747.

Hunegnaw, Y., G. Alemayehu, D. Ayalew and M. Kassaye (2022). Plant density of lupine (*Lupinusalbus* L.) intercropping with tef [Eragrostistef (zucc.) trotter] in additive design in the highlands of Northwest Ethiopia. Cogent Food Agric., 8 (1), doi: 10.1080/23311932.2022.2062890

Imran, A., C. Zhihui, M. Huanwen, L. Tongjin, W. Mengyi, E. Muhammad and W. Humaira (2013). Effect of pepper-garlic intercropping system on soil microbial and bio-chemical properties. Pak. J. Bot., 45 (2): 695-702.

Iravanian, A. and S. Saber (2020). Using ceramic wastes in stabilization and improving soil structures: A review study. IOP Conference Series Earth and Environmental Science, 614 (1): 012081.

Jackson A.L. (1973). In: 'Soil Chemical Analysis'. Department of Soils, Univ. of Wisc. Madison, Wisc., USA.

Karbout, N., M. Moussa, I. Gasmi1 and H. Bousnina (2015). Effect of clay amendment on physical and chemical characteristics of sandy soil in arid areas: the case of ground south - eastern Tunisian. App. Sci. Rep., 11 (2): 43-48.

Klute, A. (1986). Laboratory measurement of hydraulic conductivity of saturated soil. In: 'Page, et al. (eds.)'. Methods of Soil Analysis, Part I. Physical and Mineralogical Methods, Am. Soc. Agron. Inc. Medison, WI. USA, pp 210 -220.

Kroetsch, D. and C. Wang (2007). Particle Size Distribution. In: 'Carter, M.R. and E.G. Gregorich Eds.'. Soil Sampling and Methods of Analysis. 2nd Ed. Taylor and Francis Group, LLC. USA.

Ling, Q., X.N. Zhao and X.D. Gao (2016). Effects of inter-row economic crop planting on soil moisture in a rain-fed jujube orchard in loess hilly region, China. Chinese J. Appl. Ecol., 27: 504-510.

Lithourgidis, A.S., D.N. Vlachostergios, C.A. Dordas and C.A. Damalas (2011). Dry matter yield, nitrogen content, and competition in pea–cereal intercropping systems. Eur. J. Agron., 34 (4): 287–294.

Liu, Z., Q. Zhou, F. Ouyang, Y. Liu, G. Su, X. Wang, Z. Hou, T. Wang, Y. wang and G. Huang (2022). Border-rows effect of rape (*Brassica napus* L.) intercropping with milk vetch (*Astragalus sinicus* L.). Research on Words Agricultural Economy, 3 (1): 24-32.

McGilchrist, C.A. (1965). Analysis of competition experiments. Biometrics, 21: 975-985.

Megawer, E.A., A.N. Sharaan and A.M. El Sherif (2010). Effect of intercropping patterns on yield and its components of barley, lupin or chickpea grown in newly reclaimed soil. Egypt J. Appl. Sci., 25 (9): 437-452.

Midya, A., K. Bhattacharjee, S. S. Ghose and P. Banik (2005). Deferred seeding of blackgram (*Phaseolus mungo* L.) in rice (*Oryza sativa* L.) field on yield advantages and smothering of weeds. J. Agron. Crop. Sci., 191: 195–201.

Page, A.L., D.R. Miller, E.d. Keeney (1982). Methods of Soil Analysis, 2. In: 'Chemical and Microbiological Properties'. 2nd Ed., New York.

Rajamannan, B., G. Viruthagiri and K.S. Jawahar (2013). Effect of grog addition on the technological properties of ceramic brick. Int. J. Latest Res. Sci. Technol., 2: 81-84.

Richards, L.A. (1954). Diagnosis and Improvement of Saline and Alkali Soils. U.S. Salinity Laboratory Staff. In: 'Agriculture Hand book No. 60'. Printing office, Washington, USA.

Sharaiha, R.K, H.M. Saoub and O. Kafawin (2004). Varietal response of potato, bean and corn to intercropping. Dirasat. Agric. Sci., 31 (1): 1-11.

Sharma, R.K. (2020). Utilization of fly ash and waste ceramic in improving characteristics of clayey soil. Geotech. Geol. Eng., 38: 5327–5340.

Shehata, S.M., A.M. Safaa and S.S. Hanan (2007). Improving calcareous soil productivity by integrated effect of intercropping and fertilizer. Res. J. Agric. Biol. Sci., 3 (6): 733-739.

Snedecor, G.A. and Cochran, W.G. (1980). In: 'Statistical Methods', 7th Ed., Iowa State Univ. Press, Ames, Iowa.

Soubeih, K.A.A. and M.A.M. El Sayed (2014). Effect of biofertilizers and intercropping between garlic (*Allium sativum* L.) and potato (*Solanum tuberosum* L.) on their growth, yield and advantage, competitive relationships and microbial activity under desert conditions. Egypt J. Appl. Sci., 29 (8): 756-801.

Stolte J., G.J. Veerman and M.C.S. Wopereis (1992). In: 'Manual Soil Physical Measurements', version 2.0. Technisch Document/Technical Document 2, DLO Winand String Centre, Wageningen, The Netherlands.

Tahir, S. and P. Marschner (2016). Clay addition to sandy soil - effect of clay concentration and ped size on microbial biomass and nutrient dynamics after addition of low C/N ratio residue. J. Soil Sci. Plant Nut., 16 (4): 864-875.

Verma, R.K., A. Yadav, L.U. Rahman, A. Kalra and D.D. Patra (2014). Influence the status of soil chemical and biological properties by intercropping. Int. J. Recycl. Org. Waste Agric., 3: 46.

Walker, S. and H.O. Ogindo (2003). The water budget of rainfed maize and bean intercrop. Phys. Chem. Earth, 28: 919–926.

Wei, W., T. Liu, L. Shen, X. Wang, S. Zhang, W. Zhang (2022). Effect of Maize (*Zeal mays*) and Soybean (*Glycine max*) Intercropping on Yield and Root Development in Xinjiang, China Agric., 12: 996.

Willey, R.W. (1979). Intercropping-its importance and research needs. Part 1. Competition and yield advantages, 32 (1): 1-10.

Xu, Q., K. Xiong, Y. Chi and S. Song (2021a). Effects of crop and grass intercropping on the soil environment in the karst area. Sustainability, 13: 5484.

Xu, Q., K. Xiong and Y. Chi (2021b). Effects of intercropping on fractal dimension and physicochemical properties of soil in karst areas. Forests, 12 (10): 1422.

Yang, C.H., Q. Chai and G.B. Huang (2010). Root distribution and yield responses of wheat/maize intercropping to alternate irrigation in the arid areas of northwest China. Plant Soil Environ., 56: 253-262.

Zhang, L.Z., W. Van der Werf, S.P. Zhang, B. Li, J.H.J. Spiertz (2007). Growth, yield and quality of wheat and cotton in relay strip intercropping systems. Field Crop Res., 103: 178–188.

Zhang, D., Z. Sun, L. Feng, W. Bai, L. Zhang (2020). Maize plant density affects yield, growth and source-sink relationship of crops in maize/peanut intercropping. Field Crop. Res., 257: 107926.

تحسين خواص التربة وإنتاجية اللوبيا ودوار الشمس باستخدام بودرة مخلف السيراميك ونظم التحميل في التربة الجيرية

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أجريت هذه الدراسة تحت ظروف التربة الجيرية في محطة بحوث رأس سدر، مركز بحوث الصحراء، مصر، وذلك في موسمي الزراعة ٢٠٢٠ و٢٠٢١، وذلك لدراسة تأثير بودرة مخلف السيراميك (بدون إضافة، ٤٨، و٩٦ ميجاجرام/هكتار)، وأنظمة تحميل مختلفة لمحصولي دوار الشمس واللوبيا (دوار الشمس منفرد، اللوبيا منفردة، ١:١، ٢:١، و١:٢ على التوالي) على خصائص التربة الجيرية ونمو ومحصول دوار الشمس واللوبيا والعلاقات التنافسية بينهما. أظهرت النتائج أن إضافة بودرة مخلف السيراميك وأنظمة التحميل المختلفة أدت إلى تقليل درجة الحموضة، الملوحة، الكثافة الظاهرية، والتوصيل الهيدروليكي للتربة، في حين أدت إلى زيادة الكربون العضوي للتربة، وقدرة التربة القصوى على الاحتفاظ بالمياه. أوضحت النتائج أيضًا أن هناك تأثير معنوي لإضافة بودرة مخلف السيراميك وأنظمة التحميل المختلفة على صفات النمو والمحصول والصفات المحصولية لمحصولي اللوبيا ودوار الشمس. تم الحصول على أعلى قيم للنمو والمحصول والصفات المحصولية في اللوبيا ودوار الشمس التي عوملت بـإضافة ٩٦ ميجاجرام من بودرة مخلف السيراميك للهكتار. أظهرت النتائج المتحصل عليها أن جميع صفات اللوبيا ودوار الشمس قد تأثرت معنويًا بأنظمة التحميل المختلفة، حيث تفوقت الزراعة المنفردة لمحصول دوار الشمس وأعطت أعلى محصول تلتها الزراعة تحت نظام التحميل ٢ دوار الشمس: ١ لوبيا، بينما تفوقت اللوبيا المنفردة بنسبة كبيرة على أنظمة التحميل المختلفة في المحصول الكلى تلتها الزراعة تحت نظام التحميل ١ دوار شمس: ٢ لوبيا. بالنسبة للعلاقات التنافسية والميزة المحصولية، أظهرت النتائج المتحصل عليها لنسبة المكافئ الأرضي، ومعامل الحشد النسبي، والعدوانية أن دوار الشمس هو السائد واللوبيا هي المسود. في الختام، تشير النتائج التي تم التوصل إليها إلى الدور المهم لإضافة بودرة مخلف السيراميك وأنظمة التحميل المختلفة في تحسين خصائص التربة الجيرية وتعزيز إنتاجية كلًا من اللوبيا ودوار الشمس.