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REVIEW

Exploring the Potential of Biochar and Mulched Drip Irrigation with Plastic Film on Crop Yields in Water-Stressed Regions: a Global Meta-Analysis

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Abstract

Recent years have seen several significant challenges for the agriculture industry. These challenges include population growth, resource scarcity, and climate change. To improve crop yields, conserve resources, and lessen the effects of climate change, it is necessary to find efficient and sustainable agricultural practices. Plastic film mulching and the application of biochar have drawn attention recently as potential ways to increase crop productivity and soil health. To better understand the impact of these practices on crop yields, researchers have conducted meta-analyses of multiple studies in various regions. The study examined the impact of different irrigation methods, soil textures, and soil nutrient levels on the yield of various crops such as soybeans, rice, maize, wheat, and cotton. The authors analyzed a total of 58 studies to investigate the effect of drip and sprinkler irrigation on crop yields, as well as the impact of deficit irrigation, plastic film mulching, and biochar application. The findings suggest that drip irrigation had a positive effect on crop yield in relation to the climate. The authors observed a direct relationship between crop water requirements and irrigation practice. They found that while soybean yields increased at > 400 mm, rice yields significantly increased at ≤ 400 mm. The study also revealed that sprinkler irrigation was found to increase crop yields. However, drip irrigation produced higher yields, ranging from 2716.5 to 31583.6 kg ha^{-1}. Furthermore, the study highlighted the significant impact of soil characteristics on crop yield. The effects of deficit irrigation on crops during the growing seasons were significantly influenced by the soil reaction (pH) at < 7 and at > 7, demonstrating the importance of soil nutrient levels. The significant increases in soil total nitrogen, available phosphorus, and available potassium, as well as the 25.81% decrease in soil bulk density, are likely what caused the observed trend. Additionally, the I^2 test found no heterogeneity among the studies taken into account in this meta-analysis. According to the study, drip irrigation used in conjunction with plastic film and biochar can significantly boost crop yields, particularly in semiarid rain-fed regions with subtropical climates. The study offers important insights into how various irrigation methods affect crop yields under various climatic and soil conditions. The study also highlights the significance of taking into account various elements when making farming decisions to deal with water scarcity and improve irrigation water efficiency, such as soil characteristics, climate conditions, and irrigation techniques.

Keywords Crop yield · Drought · Food security · Deficit irrigation · Meta-analysis

1 Introduction

Water scarcity is one of the most pressing issues facing agriculture in many parts of the world, especially in regions that are prone to droughts (Palazzo et al. 2019). As a result, there has been a growing interest in finding sustainable solutions that can help improve crop yields while minimizing the use of water. One promising approach that has gained attention in recent years is the use of biochar and mulched drip irrigation with plastic film. Biochar is a type of charcoal

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that is produced from organic matter, such as agricultural waste, while mulched drip irrigation involves the application of water directly to the root zone of crops through a network of tubes or pipes (Faloye et al. 2019). The use of plastic film helps to reduce water loss due to evaporation and soil erosion. This systematic review aims to summarize the findings of recent studies that have investigated the potential of biochar and mulched drip irrigation with plastic film in increasing crop yields in water-stressed regions.

Several studies have investigated the potential of biochar in improving soil fertility and crop yields. A study by Lehmann et al. (2011) showed that biochar can increase the water-holding capacity of soil and enhance plant growth. Similarly, a study by Glaser et al. (2015) found that the addition of biochar to soil improved soil fertility and crop productivity. These results were attributed to the ability of biochar to increase soil organic matter content and improve soil structure, which enhances nutrient retention and water availability to plants. Mulched drip irrigation with plastic film has also been shown to be an effective approach in reducing water use and increasing crop yields. A study by Hussain et al. (2020) reported that mulched drip irrigation with plastic film significantly improved crop yield and water use efficiency in water-stressed regions. Similarly, a study by Zhang et al. (2017) found that the use of mulched drip irrigation with plastic film increased water use efficiency and maize yield in water-limited areas.

Several recent studies have investigated the potential of combining biochar and mulched drip irrigation with plastic film in increasing crop yields in water-stressed regions. A study by Zhang et al. (2017) found that the combined use of biochar and mulched drip irrigation with plastic film significantly increased maize yield and water use efficiency in water-limited areas. The authors attributed these results to the ability of biochar to improve soil water retention and nutrient availability, and the use of plastic film to reduce water loss due to evaporation and soil erosion. Another study by Agbna et al. (2017) investigated the effects of biochar and mulched drip irrigation with plastic film on tomato yields. The study found that the combined use of biochar and mulched drip irrigation with plastic film significantly increased tomato yields by up to 34%. The authors attributed these results to the ability of biochar to increase soil water retention and nutrient availability, and the use of plastic film to reduce water loss due to evaporation and soil erosion.

Although literature suggests that the combined use of biochar and mulched drip irrigation with plastic film can be an effective approach in increasing crop yields in water-stressed regions, there is still debate over the impact of limited or deficit irrigation with biochar and plastic film mulch on crop yield. Thus, the main research questions were: (1) what is the effect of biochar and mulched drip irrigation with plastic film on crop yields in water-stressed regions? And (2) how does this effect vary across different types of crops and environmental conditions? This study hypothesized that biochar and mulched drip irrigation with plastic film will have a significant positive effect on crop yields in water-stressed regions, compared to traditional irrigation methods. Furthermore, we expected that the effect of biochar and mulched drip irrigation with plastic film on crop yields will vary depending on the type of crop and environmental conditions, such as soil type, climate, and water availability. Thus, this research examined the effect of various irrigation methods, soil textures, and soil nutrient levels on the yield of various crops, including soybeans, rice, maize, wheat, and cotton, across different regions through a global meta-analysis. The study aims to identify efficient and sustainable agricultural practices that can improve crop yields, conserve resources, and lessen the effects of climate change.

2 Materials and Methods

2.1 Data Collection and Source

The outcomes of 347 agricultural experiments between 2014 and 2023 were used as the source of the data for this study. Using Google Scholar, Scopus (Elsevier), and Science Direct, relevant literature was gathered. The search strategy was designed to identify relevant studies on the topic. The following search terms were used: "biochar", "mulched drip irrigation", "plastic film", "crop yields", "water-stressed regions", and "meta-analysis". Boolean operators such as "AND" and "OR" were used to combine these search terms. Table 1 contains a list of all the primary studies' detailed information. Using GetData Graph Digitizer, data was obtained indirectly from graphs or directly from tables (Shcherbak et al. 2014). The inclusion criterion for this study was based on the following factors: The study should be published in a peer-reviewed journal; the study should be conducted in water-stressed regions; the study should explore the use of biochar and mulched drip irrigation with plastic film to increase crop yields; and the study should report quantitative data on crop yields (Fig. 1). The exclusion criterion for this study was based on the following factors: The study was not published in a peer-reviewed journal; the study was not conducted in water-stressed regions; the study does not explore the use of biochar and mulched drip irrigation with plastic film to increase crop yields; and the study does not

Table 1 Outline of literature showing crops and study locations included in the meta-analysis

References	Country	Crops	Location	Cardinal point (N,E, m a.s.l)
Ahmed et al. 2019	China	Wheat	Hebei province	37° 41′, 116° 37′
Anapalli et al. 2022	USA	Soybean	Mississippi	33° 39′, 90° 59′, 42
Arshad et al. 2022	Pakistan	Wheat	Punjab	32° 12′, 72° 43′
Brar and Singh 2022	India	Cotton	Bathinda	30° 09´49´, 74° 55´18´
Chen et al. 2022	China	Maize	Gansu Province	37° 52´, 102° 5´, 1581
Dai et al. 2022	China	Wheat	Shaanxi Province	34° 20′, 108° 24′, 521
Drechsler and Kisekka 2022	USA	Almond	Sacramento Valley of California	38.97°, 122.07°
Gu et al. 2015	China	Wheat	Tai'an City	36° 09´, 117° 09´, 128
Guo et al. 2021	China	Maize	Wuwei	37°52´20´´, 102°50´50´´, 1 581
Han et al. 2014	China	Maize	Shaanxi	34°17´38´´, 108°4´2´´,
Hazrati et al. 2022	Iran	Salvia Officinalis L.	Tabriz	35° 84´, 51° 81´, 1215
He et al. 2022	China	Rice	Ningxia	38° 26′, 106° 03′, 1123
Hu et al. 2023	China	Maize	Nanning	22° 50′, 108° 17′
Jabeen et al. 2022	Pakistan	Wheat	Dera Ghazi Khan	30° 489′, 70.6455°
Jia et al. 2018	China	Maize	Ningxia Province	35° 79′, 106° 45′, 1800
Jouni et al. 2018	Iran	Wheat	Ardabil Province	47° 46′44″, 39°36′14″
Karges et al. 2022	Germany	Soybean	Berlin	52° 31′, 14° 07′, 62
Khaleghi et al. 2020	Iran	Sunflower	Sari	36.39°, 53.04°, 15
Kisekka et al. 2017	USA	Maize	Tribune Kansas	38.5°, 101.7°, 1086
Léllis et al. 2022	Spain	Garlic	Aguas Nuevas	38° 56' 42'', 1° 53' 58'', 695
Létourneau et al. 2015	Canada	Strawberry	Quebec City	46.90°, −70.94°
Li and Su 2017	China	Alfalfa	Wuwei	37° 52´20´´, 102° 50´50´´,1581
Li et al. 2021a	China	Wheat	Hebei Province	37° 41´, 116° 37´
Li et al. 2021b	China	Wheat	Hebei province	37° 41´, 116° 37´
Li et al. 2023a	China	Wheat	Hebei Province	37° 53′, 115° 42′, 31
Li et al. 2023b	China	Cotton	South Xinjiang	40° 53′03″, 86° 56′58″,
Liu et al. 2021	China	Wheat	Hebei Province	37.92°, 115.22°,
Matoša Kočar et al. 2023	Republic of Croatia	N/A	Osijek	45° 320, 18° 440, 90
Mengistu et al. 2018	USA	Soybean	Jackson Tennessee	35.65, 89.51
Pardo et al. 2022	Spain	N/A	Albacete	695
Parkash et al. 2021	USA	N/A	Texas	N/A
Qi et al. 2020	China	Maize	Wuwei	37° 52´20´´, 102° 50´50´´, 1581
Shang et al. 2023	China	N/A	Shandong Province	36° 12, 116° 54
Singh et al. 2023	USA	Soybean	Mississippi	33° 25'45.5", 90° 57'21.1"
Wang 2017	China	Wheat	Shandong	35° 40′, 116° 41′
Wang et al. 2022a, b, c	China	Cotton	Xinjiang	44° 18´, 86° 02´
Wang et al. 2022a	China	Maize	Cangzhou	38° 00′, 116° 40′, 11.0
Wang et al. 2022b	China	Chinese Chive	Nanjing	32.06°, 118.77°
Xiao et al. 2023	China	Cotton	Shihezi City	44° 33′, 85° 56′
Yao et al. 2023	China	Wheat	Cangzhou	37° 41′, 116° 36′
Zhai et al. 2021	China	Wheat	Hebei Province	37° 95´, 114° 71´
Zhang et al. 2016	China	Rice	Ningxia	38° 07´14´´, 106° 17´43´´,
Zhang et al. 2018	China	Rice	Ningxia	38° 07´14´´, 106° 17´43´´,
Zhao et al. 2020	China	Wheat	Hebei Province	37° 41´, 116° 36´
Zhou et al. 2017	China	Peach	Shaanxi Province	34° 17´, 108° 04´, 521
Zhou et al. 2020	China	Wheat	Henan Province	34° 43´, 113° 39´, 111.3

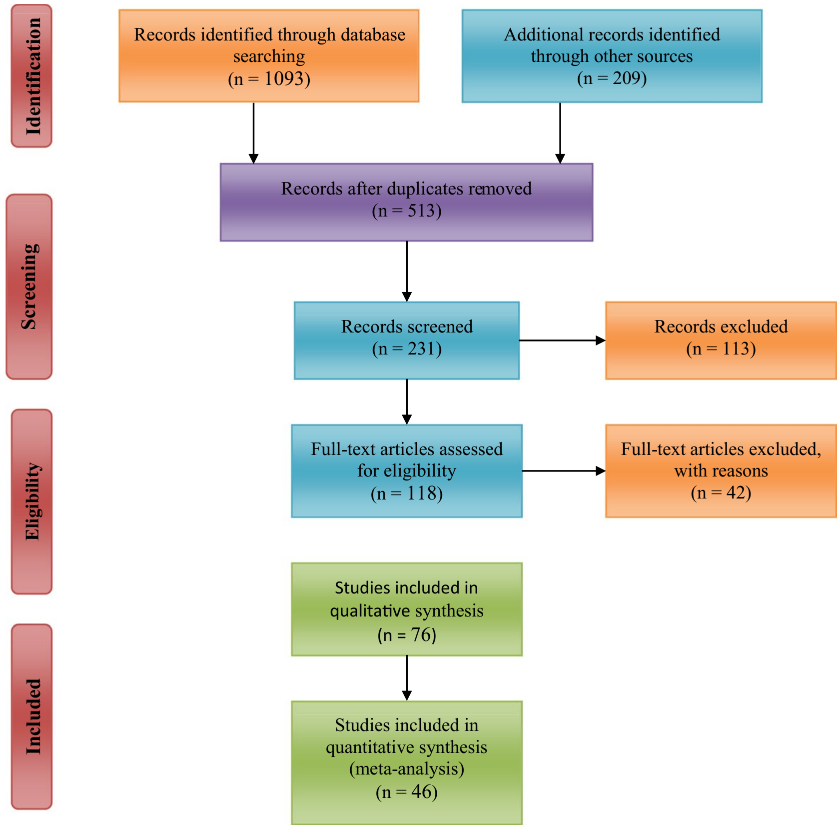

Fig. 1 Flowchart of literature identification and screening in this study. Adapted from PRISMA (Moher et al. 2009)

report quantitative data on crop yields (Fig. 1). To ensure the accuracy of this analysis, the data extracted from the selected studies included the following information: Author(s) and publication year; study location and design; sample size and crop type; methods of biochar application and mulched drip irrigation with plastic film; and results of crop yield measurements.

2.2 Variables and Descriptive Statistics

Table 1 provides a detailed definition of the study's variables, and Table 2 displays the findings of the descriptive statistics. The adoption of irrigation technologies like sprinklers and drip irrigation by farmers is referred to as irrigation water-saving technology. According to the survey, more than 85% of farm plots used water-saving irrigation technology, both in times of drought and floods and during the growing season for plants (Tables 3 and 4).

2.3 Data Analyses

The Nordic Cochrane Centre's Review Manager Software was used to conduct a meta-analysis using the response-ratio approach with a construction confidence interval analysis to quantify the effects of each input variable in relation to one another (Mak-Mensah et al. 2022). The data was analyzed using a random-effects model to calculate the overall effect size and the confidence interval. Heterogeneity was assessed using the I^2 statistic. For pairwise comparisons of normal irrigation vs. limited or deficit irrigation, we pooled studies that included side-by-side comparisons of various irrigation management practices (i.e., the treatment was the same as the control in all aspects except for the individual crop management practice). In the published paper, deficit irrigation was specifically mentioned, or it was made clear that the irrigation technology used local customary practices (Fig. 1).

Based on earlier peer-reviewed reports, other paired management practices were also categorized. The detailed method mentioned by Basche et al. (2014) as well as the natural log of the response ratio (RRs) was used to evaluate the effects of various management measures on various variables (X). The formula, [(R - 1) × 100] was used to estimate the outcomes under the treatment effects (Li et al. 2020; Marcillo and Miguez 2017). The differences were deemed important if 95% confidence intervals (CIs) did not superimpose on zero. An increase or decrease in the response variable under various management practices was indicated by a positive or negative value, respectively.

Table 2 Variation in yield of rice, cotton, soybean, maize and wheat under deficit irrigation schemes

Deficit Irrigation			*n*	Mean	Range	CV
	Drip		17	8503.02	2716.5 - 31583.6	89.27
	Sprinkler		8	6925.20	3372.75 - 8832.89	25.86
	Crops	Rice	3	4336.18	3688.5 - 5157.82	17.30
		Cotton	4	3814.48	655 - 5498	57.16
		Soybean	4	2937.67	2242.67 - 3431.67	17.00
		Maize	8	7990.02	2924 - 14587.83	52.50
		Wheat	15	7057.43	1913.33 - 19499.67	55.20
	Precipitation	≤ 400 mm	20	7923.10	1913.33 - 31583.60	88.56
		> 400 mm	18	7043.51	655 - 20535.50	73.48
	Air Temperature	< 14 ℃	12	6922.59	2242.67 - 18514	61.21
		> 14 ℃	15	8037.85	1913.33 - 20535.50	73.97
	Soil Organic Matter	≤ 10 g kg^{-1}	6	10299.68	3431.67 - 18514	55.41
		> 10 g kg^{-1}	16	5525.94	2924 - 8832.90	33.58
	Bulk Density	≤ 1.4 g cm^{-3}	11	4924.95	2540.63 - 9284.33	41.04
		> 1.4 g cm^{-3}	18	8142.42	655 - 20535.5	75.93
	pH	< 7	5	3960.96	2242.67 - 6766.12	43.77
		> 7	17	6023.08	655 - 14587.83	57.34
	Total N	≤ 1 mg kg^{-1}	14	6868.32	1913.33 - 18514	65.60
		> 1 mg kg^{-1}	11	6490.60	2540.63 - 10035.85	35.16
	Available N	< 70 %	9	6970.21	2924 - 18514	70.42
		> 70 %	7	5595.44	655 - 8832.90	45.78
	Available P	< 20 mg kg^{-1}	8	7493.88	2924 - 18514	66.70
		> 20 mg kg^{-1}	15	6346.61	655 - 14587.83	50.00
	Available K	< 140 mg kg^{-1}	13	7847.32	3012 - 18514	54.90
		> 140 mg kg^{-1}	11	5485.52	655 - 10035.85	47.18
	Soil Texture	Light	15	6832.47	655 - 20535.50	76.86
		Heavy	19	7631.36	2540.63 - 31583.60	89.93
	Countries	China	29	6808.47	2540.63 - 18514	50.67
		USA	6	7007.39	2716.5 - 20535.50	101.09
		Iran	3	10204.80	4178 - 19499.67	80.03
	Plastic film mulch		7	9754.99	3688.5 - 31583.60	106.2
	Ridge-furrow w plastic		2	7849.38	5662.90 - 10035.85	39.39
	Biochar combined w plastic film mulched drip irrigation		2	8743.25	5498 - 11988.50	52.49

3 Results

3.1 Effects of Climatic Conditions on Crops Yield

While soybean yields (2242.67 - 3431.67 kg ha^{-1}) were increased at > 400 mm with an effect size of 1227.42 [CI: 753.35, 1701.50], rice yields were significantly ($p < 0.00001$) increased at ≤ 400 mm with an effect size of 2054.54 [CI: 1585.40, 2523.69]. The test for overall effect at < 14 °C revealed a significant ($p < 0.00001$) increase in air temperature, with an effect size of 1698.82 [CI: 1074.99, 2322.65] and 1152.73 [CI: 767.32, 1538.15] at > 14 °C during the crop growing seasons. This increase in air temperature is likely the cause of the observed trend. This suggests that drip irrigation had a positive effect on crop yield in relation to the climate.

3.2 Effects of Deficit Irrigation on Soil Physical and Chemical Properties and Crop Yield

The findings demonstrated a direct relationship between crop water requirements and irrigation practice. Contrary to drip irrigation, sprinkler irrigation was found to increase crop yields. Crop yields from sprinkler irrigation ranged from 3372.75 to 8832.89 kg ha^{-1}, while drip irrigation increased yield in the range of 2716.5 to 31583.6 kg ha^{-1},

Table 3 Variation in yield of rice, cotton, soybean, maize and wheat under normal irrigation schemes

Normal Irrigation	Drip		17	9439.80	2891 - 28820.5	73.41
	Sprinkler		8	8217.85	3991 - 10133.39	24.39
	Crops	Rice	3	8824.89	7918.43 - 9959.50	11.78
		Cotton	4	4352.48	807.5 - 7111.33	65.54
		Soybean	4	3965.46	2964.5 - 4506.67	17.28
		Maize	8	10078.98	4499.5 - 16540	44.08
		Wheat	15	8659.65	1946.67 - 23411.33	53.41
	Precipitation	≤ 400 mm	20	9476.66	1946.67 - 23411.33	56.70
		> 400 mm	18	9217.89	807.5 - 28820.50	83.56
	Air Temperature	< 14 ℃	12	9270.13	2964.5 - 28586	71.35
		> 14 ℃	15	10157.02	1946.67 - 28820.50	75.83
	Soil Organic Matter	≤ 10 g kg^{-1}	6	13704.40	4506.67 - 28586	62.51
		> 10 g kg^{-1}	16	7311.89	3344.5 - 9959.50	27.83
	Bulk Density	≤ 1.4 g cm^{-3}	11	6638.59	1468.33 - 9959.50	38.10
		> 1.4 g cm^{-3}	18	10917.43	807.5 - 28820.50	77.64
	pH	< 7	5	5383.45	2964.5 - 10133.39	51.54
		> 7	17	7640.76	807.5 - 16540	54.20
	Total N	≤ 1 mg kg^{-1}	14	9555.55	1946.67 - 28586	65.20
		> 1 mg kg^{-1}	11	8050.39	1468.33 - 11919.45	34.45
	Available N	< 70 %	9	10219.68	4261 - 28586	71.69
		> 70 %	7	6259.93	807.5 - 9341.05	50.79
	Available P	< 20 mg kg^{-1}	8	11041.22	4499.5 - 28586	67.50
		> 20 mg kg^{-1}	15	7542.07	807.5 - 15211.65	44.67
	Available K	< 140 mg kg^{-1}	13	10069.22	3344.5 - 28586	62.28
		> 140 mg kg^{-1}	11	7229.30	807.5 - 11919.45	41.89
	Soil Texture	Light	15	8679.66	807.5 - 28820.50	80.68
		Heavy	19	8793.27	1468.33 - 23411.33	58.17
	Countries	China	29	8974.53	1468.33 - 28586	54.11
		USA	6	9063.70	2891 - 28820.50	110.01
		Iran	3	12093.64	4536.5 - 23411.33	82.55
	Plastic film mulch		7	10137.1	3344.5 - 19782.03	55.24
	Ridge-furrow w plastic		2	9051	6182.55 - 11919.45	44.82
	Biochar combined w plastic film mulched drip irrigation		2	11825.7	7111.33 - 16540	56.38

with an effect size of 1235.94 [CI: 390.03, 2081.86]. This may be a result of the crop growing seasons' 25.81% decrease in bulk density at ≤ 1.4 g cm^{-3} and 25.42% decrease at > 1.4 g cm^{-3}. With respective effect sizes of 1207.39 [CI: 680.55, 1734.23] and 1676.63 [CI: 1103.50, 2249.77] and a significant ($p < 0.00001$) test of overall effect, the study's soil texture included both light and heavy varieties.

The effects of deficit irrigation on crops during the growing seasons were significantly influenced by the soil reaction (pH) at < 7 with an effect size of 991.22 [CI: 695.37, 1287.07] and at > 7 with an effect size of 1481.48 [CI: 613.69, 2349.27]. Average yields of rice, soybeans, maize, and wheat were 4336.18 kg ha^{-1}, 2937.67 kg ha^{-1}, 7990.02 kg ha^{-1}, and 7057.43 kg ha^{-1}, respectively ($p < 0.00001$), while cotton yield was 3814.48 kg ha^{-1} (p = 0.51). The significant ($p < 0.00001$) increases in soil total nitrogen, available phosphorus, and available potassium, with effect sizes of 2096.89, 2405.82, and 1546.78, respectively, are likely what caused the observed trend. When soil total nitrogen was less than 1 mg kg^{-1}, yield increased between 1913.33 and 18514 kg ha^{-1}, while when it was greater than 1 mg kg^{-1}, yield increased between 2540.63 and 10035.85 kg ha^{-1}. This demonstrates that, in rain-fed conditions, deficit irrigation enhances soil physicochemical characteristics and yield.

Table 4 Heterogeneity analysis on crop yield in deficit irrigation compared with normal irrigation using random-effects models

Treatment combinations				Heterogeneity				Test for overall effect	
Limited Irrigation Vs. Normal Irrigation	Variables		*n*	Chi^2	df	*P*	I^2 %	Z	*P*
	Drip		43	665.27	16	< 0.00001	98	2.86	0.004
	Sprinkler		20	8.14	7	0.32	14	3.45	0.0006
	Crops	Rice	7	8.84	2	0.01	77	5.69	< 0.00001
		Cotton	9	235.82	3	< 0.00001	99	0.66	0.51
		Soybean	12	0.37	3	0.95	0	6.24	< 0.00001
		Maize	19	113.60	7	< 0.00001	94	4.96	< 0.00001
		Wheat	44	90.47	14	< 0.00001	85	4.84	< 0.00001
	Precipitation	≤ 400 mm	51	286.38	19	< 0.00001	93	8.58	< 0.00001
		> 400 mm	53	116.13	17	< 0.00001	85	5.08	< 0.00001
	Air Temperature	< 14 ℃	38	43.69	11	< 0.00001	75	5.34	< 0.00001
		> 14 ℃	36	129.04	14	< 0.00001	89	5.86	< 0.00001
	Soil Organic Matter	≤ 10 g kg^{-1}	18	122.77	5	< 0.00001	96	2.35	0.02
		> 10 g kg^{-1}	38	578.68	15	< 0.00001	97	4.99	< 0.00001
	Bulk Density	≤ 1.4 g cm^{-3}	26	171.36	10	< 0.00001	94	3.91	< 0.0001
		> 1.4 g cm^{-3}	49	177.29	17	< 0.00001	90	5.63	< 0.00001
	pH	< 7	13	5.17	4	0.27	23	6.57	< 0.00001
		> 7	40	855.22	16	< 0.00001	98	3.35	0.0008
	Total N	≤ 1 mg kg^{-1}	43	148.11	13	< 0.00001	91	6.36	< 0.00001
		> 1 mg kg^{-1}	24	178.17	10	< 0.00001	94	3.75	0.0002
	Available N	< 70 %	27	67.95	8	< 0.00001	88	8.65	< 0.00001
		> 70 %	16	146.65	6	< 0.00001	96	0.89	0.37
	Available P	< 20 mg kg^{-1}	26	66.01	7	< 0.00001	89	8.34	< 0.00001
		> 20 mg kg^{-1}	38	305.65	14	< 0.00001	95	2.91	0.004
	Available K	< 140 mg kg^{-1}	38	463.97	12	< 0.00001	97	2.59	0.01
		> 140 mg kg^{-1}	29	155.18	10	< 0.00001	94	5.44	< 0.00001
	Soil Texture	Light	38	167.38	14	< 0.00001	92	4.49	< 0.00001
		Heavy	50	349.46	18	< 0.00001	95	5.73	< 0.00001
	Countries	China	73	711.87	28	< 0.00001	96	6.56	< 0.00001
		USA	16	5.03	5	0.41	1	6.24	< 0.00001
		Iran	11	0.32	2	0.85	0	1.76	0.08
Plastic film mulch			16	361.91	6	< 0.00001	98	2.58	0.01
Ridge-furrow w plastic			4	0.93	1	0.33	0	1.78	0.07
Biochar combined w plastic film mulched drip irrigation			5	0.89	1	0.35	0	4.68	< 0.00001

3.3 Influence of Plastic Film Mulch, Ridge-Furrow with Plastic Film, and Biochar Combined with Plastic Film Mulched Drip Irrigation on Yield

In this meta-analysis, the yield responses to plastic film mulched treatments from 16 study observations had an average of 9754.99 kg ha^{-1} and an effect size of 248.44. In comparison to the standard irrigation treatment, the 95% confidence intervals were 59.67 to 437.22. This study found that the plastic film mulching treatment significantly increased maize, rice, and cotton yields (p = 0.01) when compared to the standard irrigation treatment. The I^2 test also revealed 98% heterogeneity between the studies taken into account for this meta-analysis.

Although it had an effect size of 1253.39, the ridge-furrow with plastic film mulched drip irrigation treatment did not significantly increase yield during the growing seasons of the crops. In four study observations, the 95% confidence intervals ranged from -126.20 to 2632.99. The study also showed that with normal irrigation as opposed to deficit irrigation, the mean yield fell from 9051 to 7849.38 kg ha^{-1}. Additionally, the I^2 test found no heterogeneity between the studies taken into account for this analysis.

In five study observations, the co-application of biochar and plastic film significantly increased the yield of cotton and maize compared to normal irrigation by 26.07% (p < 0.00001) in semi-arid regions of China. With deficit drip irrigation, mean crop yields ranged from 5498 to 11988.50 kg ha^{-1} as opposed to 7111.33 to 16540 kg ha^{-1} with regular drip irrigation. The effect size was 1651.67, and the 95% confidence intervals ranged from 959.24 to 2344.09. This suggests that drip irrigation with plastic film mulch and biochar added a positive impact on crop yield.

4 Discussion

The results of this study suggest that the use of drip irrigation had a positive effect on crop yields in relation to the climate. Specifically, soybean yields were found to be increased at precipitation levels greater than 400 mm, while rice yields were increased at precipitation levels less than or equal to 400 mm. This finding is consistent with previous research that has shown that the effectiveness of drip irrigation can vary depending on the crop type and environmental conditions (Duran-Ros et al. 2021). Furthermore, the study found that there was a significant increase in air temperature at less than 14°C during the crop-growing seasons, which is likely the cause of the observed trend. This suggests that the effectiveness of drip irrigation may be influenced by both precipitation and temperature levels, which should be taken into consideration when implementing this irrigation technique in different regions. Overall, the study provides important insights into the potential benefits of using drip irrigation for improving crop yields in different climatic conditions. This finding is consistent with other studies that have shown that drip irrigation can be an effective water-saving technique for improving crop yields under drought conditions (Özmen et al. 2015; Samui et al. 2020). By identifying the optimal conditions for using this technique, farmers and policymakers can make informed decisions about how to best manage water resources and sustainably increase food production.

The study showed that irrigation practices and soil characteristics have a significant impact on crop yields. Sprinkler irrigation was found to increase crop yields, whereas drip irrigation increased yields at a lower range. This may be due to the decrease in bulk density during crop growing seasons, which was more prominent in the light soil texture. The soil pH also had a significant effect on crop yields, with a higher effect size observed at a pH greater than 7. The increase in soil total nitrogen, available phosphorus, and available potassium was also found to have a significant effect on crop yields. When soil total nitrogen was less than 1 mg kg^{-1}, yield increased between 1913.33 and 18514 kg ha^{-1}, while when it was greater than 1 mg kg^{-1}, yield increased between 2540.63 and 10035.85 kg ha^{-1}. These results suggest that deficit irrigation can improve soil physicochemical characteristics and increase yield in rain-fed conditions. The results are supported by previous studies that have also found a positive relationship between soil characteristics, irrigation practices, and crop yield. For instance, a study by Hussain et al. (2020) found that drip irrigation significantly increased crop yield and water productivity, while sprinkler irrigation had a less significant effect. Similarly, Ali et al. (2019) found that the application of deficit irrigation in maize resulted in significant improvements in soil organic matter, available phosphorus, and potassium, which translated to increased yields. Overall, the findings suggest that proper irrigation management and soil health are essential for sustainable crop production.

The study's finding that the ridge-furrow with plastic film mulched drip irrigation treatment did not increase crop yield is consistent with previous research that has shown that the benefits of ridge-furrow systems for crop yields may vary depending on soil properties and climatic conditions (Yuan et al. 2019). Ridge-furrow systems can improve soil water conservation and reduce soil erosion, but their effectiveness in improving crop yields may be limited by factors such as soil texture, slope, and rainfall patterns (Yuan et al. 2019). Furthermore, the study's finding that the co-application of biochar and plastic film significantly increased cotton and maize yield responses by 26.07% is consistent with previous research that has shown that the application of biochar can improve soil fertility and crop productivity (Lehmann et al. 2011; Liu et al. 2021). Biochar has been found to increase soil water-holding capacity, nutrient availability, and soil organic matter content, leading to improved plant growth and yield (Mak-Mensah et al. 2023).

This study presents a comprehensive meta-analysis highlighting the potential advantages of plastic film mulching in enhancing crop yields. The findings suggest that combining plastic film mulching with practices such as biochar application can offer significant benefits. However, the study also acknowledges that the effectiveness of plastic film mulching depends on specific conditions, including soil type, properties, climate, and irrigation method. Therefore, optimizing the benefits of plastic film mulching requires site-specific management practices. This study advances the current state-of-the-art by providing a more comprehensive analysis of the effects of plastic film mulching on crop yields. The study also emphasizes the importance of considering various factors such as soil type, soil properties, and irrigation method when determining site-specific management practices. The findings of this study can aid farmers and policymakers in developing effective agricultural practices to increase crop yields and conserve resources, thus enhancing food security in the face of climate change.

5 Conclusion

This meta-analysis of 58 studies explores efficient and sustainable agricultural practices for improving crop yields, conserving resources, and mitigating climate change in water-stressed regions. The study examines various irrigation methods, soil textures, and nutrient levels for crops such as soybeans, rice, maize, wheat, and cotton. The study's findings indicate that mulched drip irrigation with biochar can significantly increase crop yields, especially in semiarid rain-fed regions with subtropical climates. The findings emphasize the importance of mulched drip irrigation with biochar and efficient irrigation and mulching strategies to improve irrigation water efficiency. The authors suggest that governments could use the study's insights to formulate specific irrigation regulations for ensuring global food security. The research also highlights the potential for gains in water-use productivity and profitability where current irrigation and mulching management strategies are not well-matched with regional agronomic and biophysical conditions.

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Data Availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Competing Interests The authors declare no competing interests.

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