EFFECTS OF RESIDUAL PLASTIC FILM ON COTTON YIELD AND SOIL HEALTH IN ARID AREAS OF XINJIANG PROVINCE, CHINA

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Abstract. Xinjiang, a province characterized by its arid climate and scarce rainfall, heavily depends on mulch plastic films for agricultural practices. Plastic film mulching represents a contemporary agricultural and efficient technique for enhancing agricultural productivity. However, as its application persists over the years, the resultant accumulation of plastic film residues in the soil emerges a substantial risk to the environmental integrity of the soil and the broader ecological health. In order to understand the effect of residual plastic film on soil physicochemical properties and cotton yield, the soil parameters, including moisture content, electrical conductivity, pH, alkali hydrolyzed nitrogen, available potassium, and available phosphorus, were collected and analyzed after cotton harvest each year. It is found that the presence of film residues correlated with a decline in soil density, enhanced soil porosity, diminished soil water content, and an uptick in electrical conductivity in the uppermost 30 cm of the soil. The presence of these residues hindered root growth, which in turn affected the nutrient absorption capacity of cotton roots. Notably, there was a noticeable decline in cotton yield when the residual film quantity reached a threshold of 1000 kg/hm^2. This decline was even steeper, at 38.09%, when residues hit 4000 kg/hm^2. It suggests that excessive retention of plastic films in the soil negatively influences its physical and chemical attributes, ultimately impairing the growth of cotton. The research provides a basis for the sustainable development of agriculture and ecological security in Xinjiang.
Keywords: *plastic film residue, soil properties, cotton yield, potential ecological risks, farmland soil contamination*

Introduction

Xinjiang is the largest cotton producing area in China (Yan et al., 2014a). The oasis agricultural system in Xinjiang needs to increase soil temperature and maintain soil moisture, so it is necessary to use plastic film to cover the soil surface. Mulching with plastic film provides several benefits, including enhancing soil temperature, conserving moisture, reducing pest and disease incidence, and suppressing weed growth. This method transforms the microenvironment for crops, facilitating expanded cultivation regions. Initiated in the 1950s, the technology of using plastic films for mulching saw swift adoption in regions like Japan, Europe, and the Americas. This innovation marked a significant transformation in agricultural productivity and methodologies. Currently, agricultural plastic film ranks third among vital agricultural materials, only surpassed by chemical fertilizers and pesticides. Predominantly composed of polyethylene, this mulching film exhibits a durable molecular structure, making it resistant to

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decomposition. Statistical analysis reveals that the global application of agricultural plastic film reaches approximately 7.40 million tons annually, of which mulching film comprises 2.00 million tons, a figure that is on a rising trend (Ding et al., 2022). The low rate of recycling exacerbates the situation, leading to a significant accumulation of residual mulching film in the soil of agricultural lands. This resistance, however, has led to concerning pollution levels, posing a challenge to the green evolution of Xinjiang's cotton industry and the ecological enhancement of its farmlands.

Residual plastic film can detrimentally affect the structural integrity of the topsoil, leading to alterations in soil bulk density, modifications in porosity levels, and adversely affecting soil permeability (Li et al., 2022; Mumtaz et al., 2010). The vertical distribution of residual plastic film in soil exhibits pronounced variability, characterized by a decrement in residue concentration with increasing soil depth. Predominantly, this residue is concentrated within the top 30 cm stratum of the soil, with an approximately 60%-75% of the total residual quantity localized to the uppermost 0-10 cm layer (Piehl et al., 2018; Yan et al., 2014b; Wang et al., 2017). Climatic weathering, solar radiation, thermal decomposition, and microbial activity, residual plastic film in the soil are subject to ongoing degradation, resulting in their disintegration into diminutive fragments and micro- and nanoplastics (Zang et al., 2020; Gigault et al., 2021; Ng et al., 2018). Researches studies indicated that as the duration of plastic residue in the soil extends, the size of the plastic fragments decreases (Yin et al., 2022), facilitating their translocation to deeper soil layers and intensifying the extent of contamination therein (Ma et al., 2008). A positive correlation has been observed between the accumulation of plastic film residue in soil and a corresponding decrease in the yields of essential food and cash crops, including wheat, corn, and cotton (Chen et al., 2022; Hu et al., 2020; Gao et al., 2019). Furthermore, the presence of residual plastic film poses significant risks to the health of fauna, flora, and humans, as these materials can migrate through various environmental pathways or become integrated into the food chain (Huerta et al., 2017). The aging and degradation of residual plastic films can lead to amplified hazards through indirect cumulative ecological effects. This process may result in more severe soil pollution due to accumulation and superposition of contaminants, thereby posing escalated threat to the health of various organisms through their migration in the environment or incorporation into food chains (Luo et al., 2017).

The extensive use of plastic products has increased the annual production of plastics by more than 300 million tons worldwide since 2014 (Kaur et al., 2022). In recent years, the extent of environmental pollution and ecological damage by Microplastics pollution has increased worldwide concern. Studies have identified varying levels of Microplastics pollution in all aquatic environments worldwide, including the lakes (Dusaucy et al., 2021). The study found that the different additives of white PE film and black PE film lead to different adsorption effects of different forms of arsenic. The adsorption effect of black PE film on four forms of arsenic is stronger than that of white PE film (Tang et al., 2023). The composite effect of residual film fragments and micro/nano plastics on heavy metals is affected by film type, aging degree and residual amount. The higher the aging degree, the stronger the adsorption capacity of heavy metals (Abbasi et al., 2020). The interaction between residual film fragments and micro/nano plastics and organic pollutants in soil environment is affected by polymer composition, size, color, functional groups and aging degree (Serrano-Ruiz et al., 2021; Bhagat et al., 2021). The "plastic circle" formed by residual film fragments and micro

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nano plastics can promote the accumulation of heavy metals in soil, and pose a potential threat to farmland soil health and human health (Khalid et al., 2021).

At present, the global demand for plastics is increasing year by year, but the recovery rate is low and the disposal is improper, resulting in a large number of plastic waste entering the soil environment. There are differences in the abundance and distribution of microplastics in soils from different regions of Spain (Van-den et al., 2020). Two kinds of polymers, PS and PE, have been detected in Greenhouse Soils in South Korea, including debris, film and fiber, with a abundance of (1880 ± 1563) PCs·kg^{-1} (Kim et al., 2021), Amrutha et al. (2021) studied the current situation of microplastics pollution in the soil along the river in India and found that the abundance of microplastics in the soil along the river was 84.45·kg^{-1}, and the size and abundance of microplastics changed with soil depth, indicating that the abundance and size of microplastics in the soil were closely related to soil depth (*Table 1*).

Table 1. *Distribution and abundance of microplastics in soil in some typical regions abroad*

Countries	Soil type	Shape	Main polymer types	Abundance	Major size	Reference
Korea	Greenhouse planting	Fiber, debris, film	PE, PP, PS	1880 ± 1563	0.1~2.0	Kim et al. (2021)
India	Riverine soil	Fiber, debris, film	PE, PET, PP	84.45	0.3~5.0	Amrutha et al. (2021)
Spain	Sludge farmland	Fiber, debris	PET, PE, PP	302000 ± 83000	0.029~2.224	Edo et al. (2020)
America	Park green space	Fiber	PE, PS	334~3068	< 5	Helcoski et al. (2020)
Canada	Ordinary farmland	Fiber, debris	PP, PE, PET	25~298	0.1~1.0	Crossman et al. (2020)

Materials and methods

Overview of the test region

The study site is situated at the Anningqu Test Station in Urumqi, Xinjiang (N: 43° 95’26”, E: 87° 46’45”). This area exhibits characteristics of a temperate continental climate, recording an annual average precipitation of 265 mm and evaporation of 1250 mm. It receives sunlight for approximately 2400 to 3000 h annually. The yearly temperature fluctuations range between an average maximum of 38°C and a minimum of -20°C, with a frost-free duration spanning 169 days. The physical and chemical properties of the soil are shown in *Table 2*. Cotton (*Gossypium hirsutum* L. cv Xinluzao No. 84) was the selected crop for the study, planted in mid-April (*Figure 1a*) and Residual plastic film after cotton harvest at the end of September (*Figure 1b*).

Figure 1. *Use of plastic film and plastic film residue*

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Test design

The distribution of residual film in the 0-10 cm, 10-20 cm, and 20-30 cm depths is 38.7% ± 12.3%, 31.2% ± 11.3%, and 30.2% ± 15.8%, respectively. The majority of residual films in the soil range from 4-25 cm^2 in size, with the 0-25 cm^2 category constituting 75% (Dong et al., 2013a). Soil regions with residual film areas exceeding 25 cm^2 display reduced soil moisture and crop yield. Moreover, 80%-95% of root biomass occupies the 0-30 cm soil layer (Lin et al., 2019).

Table 2. *Soil physical and chemical properties*

Soil depth (cm)	pH	Total nitrogen (g/kg)	Total phosphorus (g/kg)	Total potassium (g/kg)	Organic matter (g/kg)	Available nitrogen (mg/kg)	Available phosphorus (mg/kg)	Available potassium (mg/kg)	Volumetric weight (g/cm^3)
0-20	8.57	0.84	0.80	18.01	14.45	54.20	6.93	211.33	1.36
20-40	8.66	0.73	0.63	18.62	12.22	46.27	4.27	178.33	1.45

The current study examined the impact of plastic film residue on cotton field soil and projected its accumulation over a span of 0-277 years based on the existing plastic film mulching techniques, using data from Xinjiang (Lin et al., 2019). Gradient treatments for plastic film residue were established at the following levels (*Table 3*). A micro area experimental design was employed, measuring 100 cm in length, 100 cm in width, and 30 cm in height. Residual film samples were collected from this micro area, with an 18 μm nylon mesh placed at the base. Plastic film fragments of both 0-25 cm^2 and > 25 cm^2 were incorporated into the 0-30 cm soil depth at a 7.5:2.5 ratio. These film fragments were uniformly dispersed across the 0-10, 10-20, and 20-30 cm layers, maintaining a residual film ratio of 4:3:3. The cotton variety utilized for testing was Xinluzao-84. The polyethylene (PE) film had a width of 1.40 m. A configuration involving one film, two pipes, and four rows was adopted. The spacing between drip irrigation belts was set at 76 cm, with emitters spaced at 30 cm apart and a flow rate of 2.1 L/h. The row spacing was determined to be 66 + 10 cm, with a plant spacing of 9 cm. Three seeds were planted per hole, with one seedling retained post-germination. Each treatment was conducted in triplicate, leading to a total of 24 micro areas. Over the growth period, irrigation totaled 5250 m^3/hm^2, distributed across nine cycles. Fertilization included the application of 600 kg/hm^2 of urea, 700 kg/hm^2 of diammonium phosphate, and 150 kg/hm^2 of potassium sulfate. All other management practices adhered to standard field protocols.

Table 3. *Different soil residual amount of processing*

Treatments	CK	A250	A500	A1000	A1500	A2000	A3000	A4000
Using film covering time (a)	0	13	31	68	104	141	209	277
Residual amount of plastic film (kg/ha)	0	250	500	1000	1500	2000	3000	4000

Measurement indexes and methods

After cotton harvest, soil samples from the 0-10 cm, 10-20 cm, and 20-30 cm layers of each micro area were transported to the laboratory for natural air drying. Subsequently, these samples were sieved based on the requirements for physical and

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chemical property tests. Another portion of the samples was transferred into sterile bags and stored at 4°C for subsequent determination of soil microbial indicators. Concurrently, in-situ soil samples were extracted using a cutting ring.

Soil organic matter was quantified using the potassium dichromate volumetric external heating method. The alkali hydrolysis diffusion method was employed to determine the available nitrogen content in the soil. Effective phosphorus was gauged through sodium bicarbonate molybdenum antimony spectrophotometry, while available potassium was extracted with neutral ammonium acetate and quantified via flame photometry. Soil conductivity was assessed using a conductivity meter. The cutting ring method facilitated the determination of soil volumetric weight and porosity. Lastly, soil moisture content was ascertained through a drying method.

Statistical analytical method

For the analysis of soil physical and chemical properties, data from three replicate experiments were processed with IBM SPSS Statistics 20. Variance analysis was employed to identify significant differences in parameters such as volumetric soil weight, soil porosity, moisture content, organic matter, available nitrogen, phosphorus, and potassium, electrical conductivity, total nitrogen, phosphorus, potassium, cotton yield, and microbial community diversity. Multiple comparisons were performed using the Duncan method with a significance level set at 0.05. Graphics were generated using the Origin software.

Results and analysis

Effect of plastic film residue on soil properties

Effect on soil volumetric weight and porosity

It was noted that an increase in plastic film residue corresponded to a decrease in soil bulk density. Specifically, in the 0-10 cm soil layer, the soil bulk density declined from 1.32 to 1.16 as the residual film quantity reached 300 kg·hm^{-2} (*Table 4*). For the 10-20 cm layer, the decrease was from 1.32 to 1.16 at 250 kg·hm^{-2}, and from 1.36 to 1.19 in the 20-30 cm layer. The reductions observed were 12.12%, 13.23%, and 12.5% for these layers, respectively.

Table 4. *Effect of residual film amount on the physical properties of cotton field soil. Different lowercase letters indicate significant differences in the amount of plastic film treatment (p < 0.05)*

Treatments	0-10 cm			10-20 cm			20-30 cm		
	Volumetric weight g cm^{-3}	Soil moisture content %	Soil porosity %	Volumetric weight g cm^{-3}	Soil moisture content %	Soil porosity %	Volumetric weight g cm^{-3}	Soil moisture content %	Soil porosity %
CK	1.32 a	6.75 bc	50.26e	1.36a	7.65a	48.76f	1.36a	8.03a	48.73d
A250	1.25 bc	6.29 b	52.78cd	1.26b	7.85a	52.46e	1.34a	8.27a	49.41d
A500	1.21 c	7.93 ab	54.35 b	1.24c	7.95a	53.38d	1.25b	8.71a	52.84c
A1000	1.23 bcd	7.24 abc	53.35 bcd	1.21de	7.92a	54.37bc	1.21c	7.80a	54.23b
A1500	1.26 b	7.47 abc	52.37 d	1.20ef	8.40a	54.89ab	1.19cd	8.13a	54.87ab
A2000	1.23 cd	8.50 a	53.74 bc	1.23cd	8.55a	53.55cd	1.21cd	8.08a	54.46ab
A3000	1.17 e	8.36 a	55.93 a	1.21cde	8.76a	54.18bce	1.18d	7.98a	55.37a
A4000	1.16e	8.42 a	56.04 a	1.18f	8.71a	55.45a	1.19cd	7.96a	54.77ab

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Table 4 indicates a rise in soil porosity in tandem with an increase in plastic film residue. In the 0-10 cm layer, there was an 11.50% increment in soil porosity (from 50.26 to 56.04). Notably, the soil porosity corresponding to a 4000 kg·hm^{-2} residual film significantly outstripped other treatments. Within the 10-20 cm layer, the soil porosity augmented by 13.72% (shifting from 48.76 to 55.45). In the 20-30 cm stratum, the soil porosity markedly amplified once the residual surpassed 500 kg·hm^{-2} and stabilized with further residue increases, showing a 12.40% increase from 48.73 to 54.77.

Residual film impedes the retrograde motion of soil water. In the 10-20 and 20-30 cm layers, the soil moisture content peaked with lesser residual amounts and values exceeding 500 kg·hm^{-2}, respectively. These residual fragments disrupt soil pore continuity, obstructing gravity water infiltration. An elevated residual film quantity leads to increased water interception in superficial soil layers. Generally, in the 0-10 cm layer, soil moisture content escalated. An augmentation was significantly noted when residuals exceeded 2000 kg·hm^{-2}, marking a 24.74% rise (from 6.75 to 8.42). In the 10-20 cm layer, the moisture content trajectory echoed that of the topsoil. Attaining a residual amount of 3000 kg·hm^{-2} saw peak soil moisture content, with negligible variation among treatments. The increase was from 7.65 to 8.71, amounting to 13.85%. Due to the influence of the downward movement of residual film on moisture, the peak soil moisture in the 20-30 cm layer was observed at 500 kg·hm^{-2}. Subsequent increases in residual film led to a decrease in soil moisture from 8.03 to 7.96, marking a 0.87% decline.

Effect of plastic film residue on soil salinity

As illustrated in *Figure 2a,* the results showed that the soil pH value with a residual film of 4000 kg hm^{-2} was the smallest, and there was no significant difference among other treatments. In the 0-10 and 10-20 cm soil layers, the 1500 kg·hm^{-2} treatment was the most influential, inducing a reduction in pH from 8.25 to 7.90, equivalent to a 4.24% decrease. For the 20-30 cm soil layer, the 2000 kg·hm^{-2} treatment emerged as the most efficacious, reducing the pH by 6.49% (from 8.47 to 7.92).

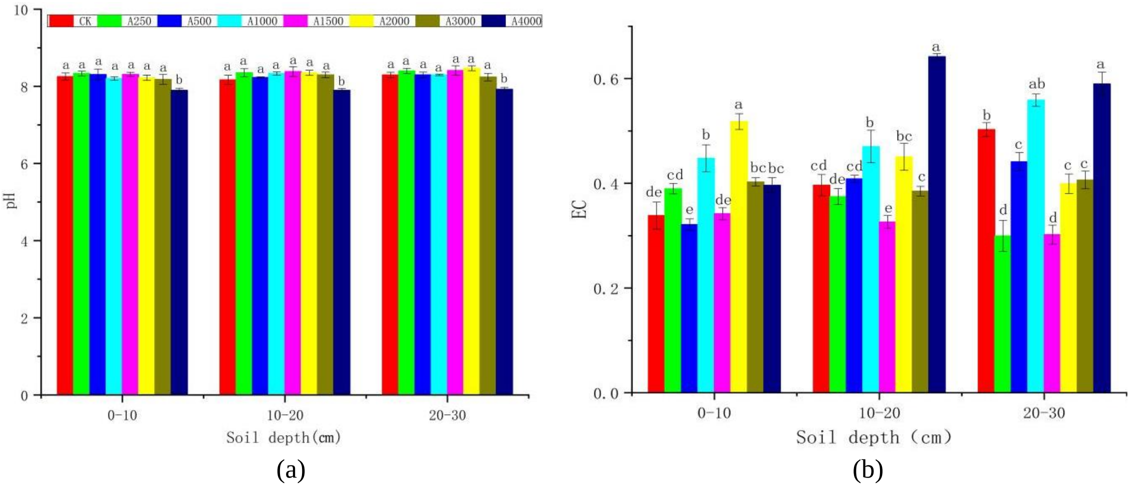

Figure 2. *Effect of plastic film residue on soil nutrients. Different lowercase letters indicate significant differences in the amount of plastic film treatment ($p < 0.05$). Bars denote standard error*

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As depicted in *Figure 2b*, an elevation in soil conductivity was correlated with higher plastic film residue content. In the 0-10 cm soil layer, the conductivity associated with a residual film of 2000 kg·hm^{-2} significantly exceeded other treatments, rising from 0.33 to 0.52, marking a 57.58% increment. In both the 10-20 and 20-30 cm layers, the 4000 kg·hm^{-2} treatment notably surpassed other treatments in terms of residual film content.

Effect of plastic film residue on soil nutrients

Figure 3a demonstrates a decrease in available nitrogen with increasing soil depth. Between different soil layers, the higher the residual amount of plastic film, the greater the effective nitrogen value. Within the 0-10 cm soil layer, a significant elevation in available nitrogen was observed when the residual film was ≥ 2000 kg·hm^{-2}. In the 10-20 and 20-30 cm layers, the 4000 kg·hm^{-2} treatment surpassed 0 kg·hm^{-2} treatment with increases of 26.79% and 29.95%.

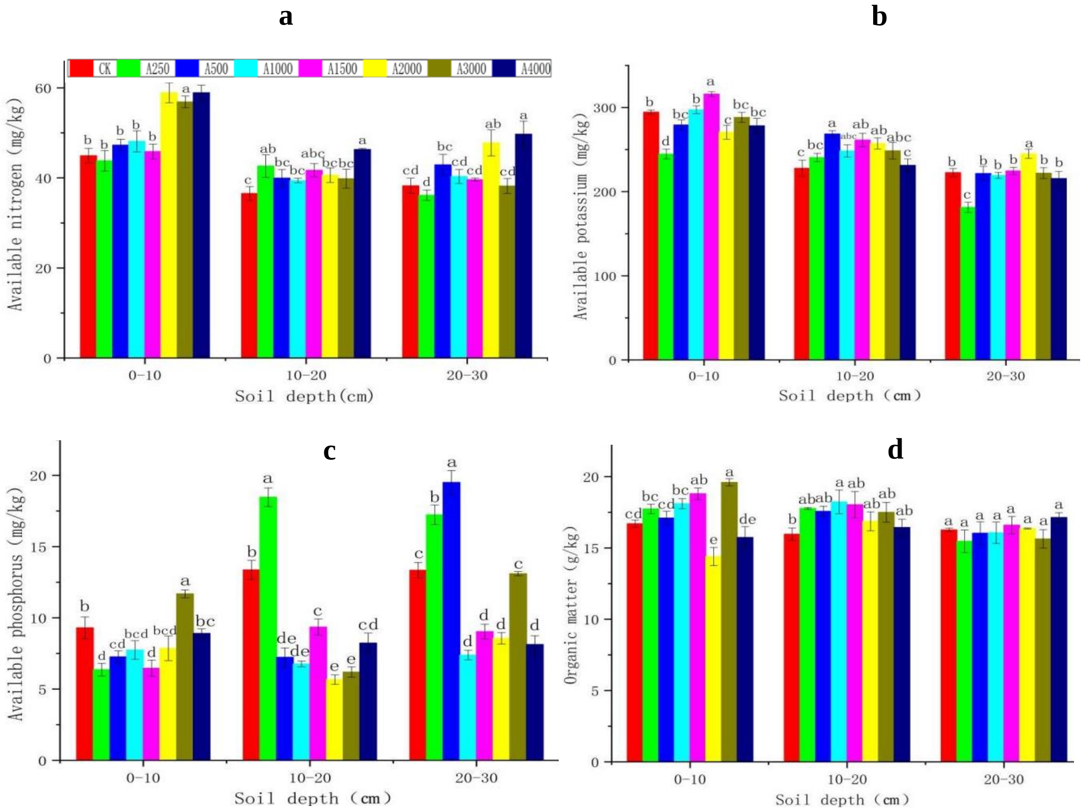

Figure 3. *Effect of plastic film residue on soil nutrients. Different lowercase letters indicate significant differences in the amount of plastic film treatment ($p < 0.05$). Bars denote standard error*

Furthermore, it could be found from *Figure 3b* that the trends of available potassium and available nitrogen were congruent as soil depth increased. Within the 0-10, 10-20, and 20-30 cm soil layers, the highest rapidly available potassium levels were observed at residual film amounts of 1500 (7.28% above CK), 500, and 4000 kg·hm^{-2}, with the latter two showing increases of 16.14% and 13.59% over the 4000 kg·hm^{-2} treatment, respectively.

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In *Figure 3c,* available phosphorus displayed a decline with increasing plastic film residue. In the 0-10 cm soil layer, significant variations between treatments were evident. The 3000 kg·hm^{-2} treatment contained the peak available phosphorus, a value 25.48% above CK. In the 10-20 and 20-30 cm layers, the treatments with residual film amounts of 250 and 500 kg·hm^{-2} revealed effective phosphorus contents of 124% and 142%, markedly higher than the 4000 kg·hm^{-2} treatment, respectively.

Figure 3d shows that the trend of organic matter with depth mirrored that of available nitrogen. In the 0-10 cm layer, differences between treatments were minimal. Organic matter peaked at a residual film of 2000 kg·hm^{-2} but then declined with increasing residual film amounts, 8.07% above the 4000 kg·hm^{-2} treatment. For the 10-20 cm layer, the zenith of organic matter was observed at a residual film of 2000 kg·hm^{-2}, a value 12.27% higher than the 4000 kg·hm^{-2} treatment. No significant variations were detected among treatments in the 20-30 cm layer, with CK organic matter exhibiting the highest content, 4.12% above the 4000 kg·hm^{-2} treatment.

Effect of plastic film residue on dry matter accumulation and cotton yield

An elevation in plastic film residue negatively impacted the cotton biomass as depicted in *Table 5*. Maximum biomass for cotton roots, stems, and hulls was observed at a residual film quantity of approximately 250 kg·hm^{-2}. In the case of the 4000 kg·hm^{-2} treatment, there was a decrease of 59.28%, 20.46%, and 11.93% in the respective biomasses.

Table 5. *The effect of plastic film residue on the dry matter weight of cotton. Different lowercase letters indicate significant differences in the amount of plastic film treatment ($p < 0.05$)*

Treatments	Residual amount of plastic film (kg/ha)	Dry matter weight of cotton roots (g)	Cotton stem dry matter weight (g)	Weight of cotton shell dry matter (g)
CK	0	56.4 ± 1.94b	100.1 ± 1.27b	78.83 ± 1.68a
A250	250	63.76 ± 1.18a	114.23 ± 1.86a	80.36 ± 2.06a
A500	500	49.13 ± 1.58c	93.46 ± 2.53b	62.83 ± 2.98c
A1000	1000	46.36 ± 1.18c	98.26 ± 1.54b	64.73 ± 2.51c
A1500	1500	59.00 ± 2.13ab	100.80 ± 2.81b	61.43 ± 2.64c
A2000	2000	33.83 ± 2.01e	83.90 ± 2.05c	42.46 ± 1.33e
A3000	3000	44.5 ± 1.62cd	96.83 ± 2.64b	75.93 ± 2.42ab
A4000	4000	40.03 ± 1.20d	94.83 ± 2.90b	71.80 ± 1.70b

Figure 4 demonstrates a consistent total nitrogen content in cotton roots across treatments. The apex nutrient content was registered when the plastic film residue amounted to 2000 kg·hm^{-2}. Conversely, a 13.58% decline was noted at 4000 kg·hm^{-2}. Remarkably, the CK treatment exhibited a total nitrogen content in the cotton stems that outperformed 4000 kg·hm^{-2} treatments. For instance, the 4000 kg·hm^{-2} treatment displayed a reduction by 35.24% in comparison to the CK treatment, and was 35.91% inferior to the 2000 kg·hm^{-2} treatment.

The total potassium content (*Fig. 5a*) in cotton tissues exhibited the most noticeable response to a residual film quantity of 500 kg·hm^{-2}. Furthermore, about 35.23% reduction was observed with the 4000 kg·hm^{-2} treatment. The CK treatment manifested the highest total potassium content in cotton stems, which was 9.14% higher than the 1500 kg·hm^{-2} treatment. Interestingly, when the plastic film residue was 1000 kg·hm^{-2}, the total potassium content in the cotton shell surpassed 4000 kg·hm^{-2} treatments, which is 9.21% higher than that at 4000 kg·hm^{-2}.

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Figure 5b elucidates the effect of residual plastic film quantity on total phosphorus content in cotton organs. The zenith of total phosphorus content in cotton roots was witnessed at 500 kg·hm^{-2}, with the 4000 kg·hm^{-2} level plummeting by 104%. In the stems, the peak phosphorus content occurred at 500 kg·hm^{-2}, diminishing by 38.37% at 4000 kg·hm^{-2}. For cotton hulls, 2000 kg·hm^{-2} marked the pinnacle for total phosphorus content, which waned by 48.95% with the 4000 kg·hm^{-2} treatment.

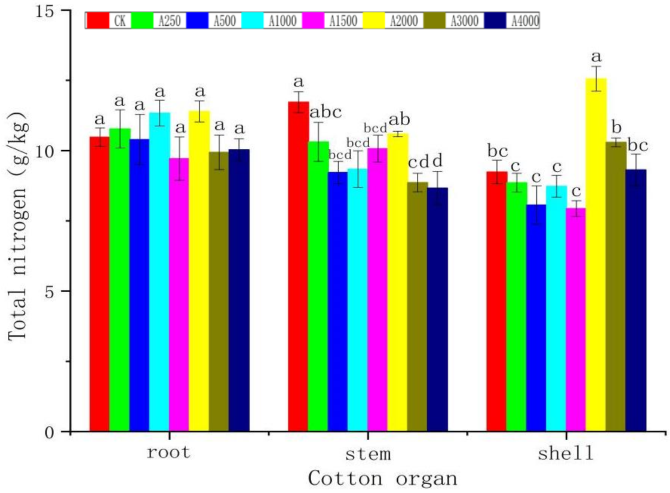

Figure 4. *The effect of plastic film residue on the total nitrogen content of cotton plants. Different lowercase letters indicate significant differences in the amount of plastic film treatment (p < 0.05). Bars denote standard error*

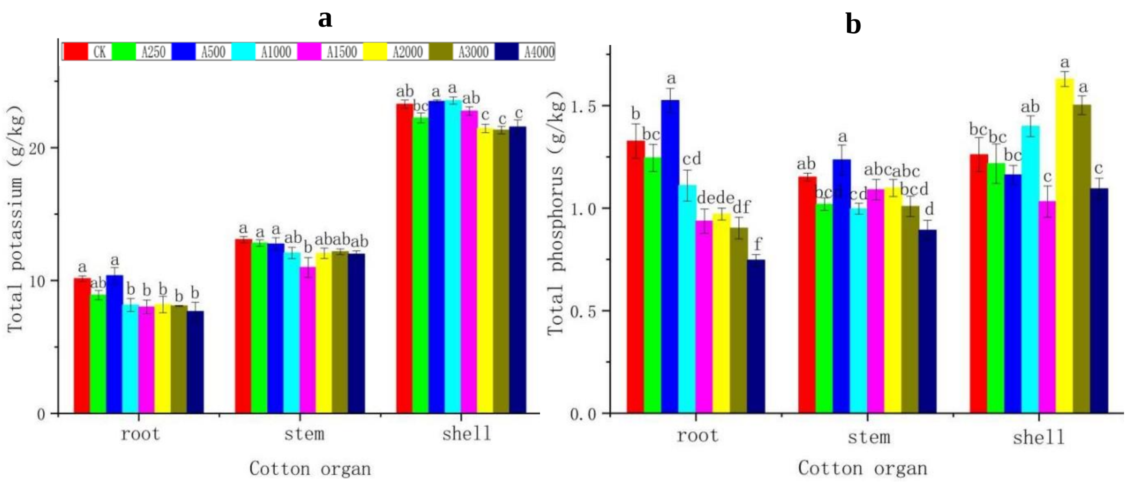

Figure 5. *Effects of plastic film residues on nutrients of cotton plants. Different lowercase letters indicate significant differences in the amount of plastic film treatment (p < 0.05). Bars denote standard error*

It could be found from *Figures 4* and *5* that there is a decline in cotton yield corresponding to an increment in plastic film residue. At a residual film quantity of 1000 kg·hm^{-2}, the cotton yield remained unaffected. The peak cotton yield stood at 370.71 kg/666.67 m^2, showing a gradual reduction with escalating residual film amounts. The yield at a residue of 4000 kg·hm^{-2} was 38.09% less than the CK (*Fig. 6*).

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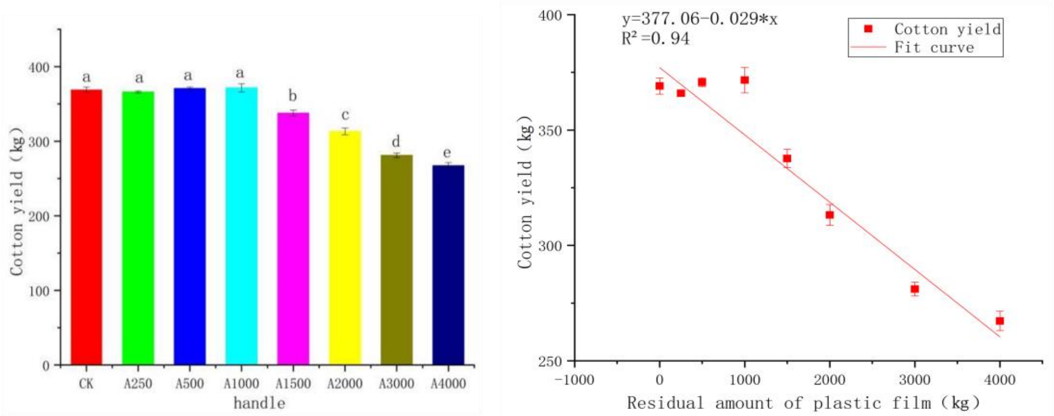

Figure 6. *Effect of plastic film residue on cotton yield. Different lowercase letters indicate significant differences in the amount of plastic film treatment ($p < 0.05$). Bars denote standard error*

Discussion

Plastic film mulching technology offers prominent advantages, such as enhancing temperature, conserving moisture, mitigating salt effects, and inhibiting weed growth. In arid and semi-arid regions, this technology results in yield increases of 20%–35% for grain crops and 20%-60% for cash crops (Liu et al., 2014). Recent studies indicate that 80%-95% of root biomass is distributed within the 0-30 cm soil layer. This layer exhibits pronounced alterations in soil water distribution and cotton root configuration due to the residual plastic film (Lin et al., 2019). Such residual films compromise soil aggregate structure, create structural impediments, degrade nutrient content, hinder the mobility of soil water and salts, and degrade both soil and microbial environments (Zhang et al., 2017; Yang et al., 2020). This research focused on the impact of plastic film residue within the 0-30 cm soil depth on cotton soil properties. Through this analysis, valuable data was obtained to enable early warnings of plastic film pollution risk, guiding the development of pertinent prevention and control technologies.

Effect of residual film on soil physical and chemical properties

Liu et al. (2010) demonstrated that residual film can influence certain physical properties of the soil, including its structure and porosity. Soil porosity is inherently associated with soil structure, humus content, and soil compaction. It plays a pivotal role in regulating the availability and movement of water, fertilizers, gases, heat, and other essential soil fertility determinants, making it an indispensable metric for assessing soil physical properties in agricultural contexts (Jiang et al., 2017). Observations indicated that as the residual film content in the soil rose, the volumetric weight of the soil declined, while its porosity experienced a corresponding increase. Such variations might be attributed to disturbances within the sampled soil during the experimental setup.

The utilized film was composed of polyethylene, which possesses a lower density compared to soil particles. Incorporation of this film led to soil loosening, a decrease in density, and a reduction in volumetric soil weight. A lower volumetric soil weight typically indicates that the soil is more porous and loosely structured. Hence, as the amount of residual film increased, soil porosity also exhibited an upward trend. Factors

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such as the volumetric weight of soil, soil porosity, and related parameters play a pivotal role in determining soil water conductivity, retention capacity, and air permeability.

Residual film augmented soil porosity but concurrently impeded the downward migration of water. The inconsistent distribution of residual plastic film contributes to non-uniform pore distribution in the soil, facilitating either a predominant water flow or a water-retention effect within the soil profile (Lin et al., 2017). Such dynamics lead to a marked reduction in the water content of the soil's deeper layers (Liu et al., 2021). In the soil strata of 0-10, 10-20, and 20-30 cm, the moisture content peaked under treatments of 2000, 3000, and 5000 kg·hm^{-2}, respectively. Analysis suggests that in cotton field soils with substantial residual film presence, water predominantly accumulates in the 0-20 cm layer, causing a significant decline in moisture content within the 20-30 cm layer.

Research indicates that an increase in the amount of residual film curtails the migration distance of wetting in drip irrigation. Moreover, the salt-washing rate in the absence of residual film surpasses that observed under residual film treatment (Liu et al. 2010, 2021). The presence of residual film influences both the movement and distribution of soil water, subsequently impacting the movement and distribution of salts and notably impeding the salt's downward migration (Li et al., 2021). These findings align with the anticipated patterns in soil moisture content. The conductivity within the 10-20 cm soil layer was notably higher than in other layers. Accumulation of salt in the 10-30 cm layer poses challenges to its discharge. Conductivity measurements in the 0-10 cm layer showed significant differences across various treatments, peaking at 0.52. For the 10-20 cm and 20-30 cm soil layers, the conductivity observed with a 4000 kg·hm^{-2} film residue was significantly elevated compared to other treatments.

Dong et al. (2013b) noted an increase in soil pH value with the elevation of residual film quantity. Concurrently, there was a reduction in organic matter, hydrolyzed nitrogen, available phosphorus, and available potassium, which translated to diminished soil fertility. Furthermore, mulching film residue markedly decreased the soil pH, alkali hydrolysable nitrogen, available phosphorus, and available potassium content. A plausible explanation might be the alteration of soil physical properties by the residue film, such as its porosity, which then modifies soil permeability, impacts microbial concentration and activity, and curtails colloidal adsorption capability (Xin et al., 2021).

The residual film affects the distribution of water and nutrients, thereby impeding the growth and development of crop roots and reducing the contribution of soil organic matter. Additionally, as the amount of residual film increases, it compromises the soil's heat transfer capacity, elevates the soil temperature, and augments the water content of the plough layer due to the barrier effect of the residual film. This also accelerates the mineralization and decomposition rates of soil organic matter (Zumilaiti et al., 2017). As a result, an inverse relationship is observed between the residual amount of soil film and the soil organic matter content.

This investigation determined that, owing to the obstructive impact of the residual film on water, the levels of soil organic matter, hydrolysable alkali nitrogen, and available potassium are most pronounced in the surface soil. There is a decreasing trend in these components in the 0-30 cm soil layer as the residual film increases. Although the mobility of available phosphorus with water is limited, it increases in the 0-30 cm soil layer. For different soil layers, both available nitrogen and potassium initially rise with the amount of residual film but eventually decline. The fluctuations in alkali

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hydrolysable nitrogen and available phosphorus correlate closely with water movement patterns. Primarily, effective phosphorus diffuses through the soil and relies more on colloidal adsorption capacity compared to alkali-hydrolyzed nitrogen and available potassium. Hence, both colloidal adsorption capacity and effective phosphorus decrease with an increase in film residue.

Effect of residual film on cotton yield

Residual mulching film impedes the infiltration of natural and capillary soil water, leading to secondary soil salinization and a reduction in soil porosity. This, in turn, diminishes permeability, microbial activity, and soil fertility. Such conditions precipitate the deterioration of soil tillage and engender an impermeable, entropy-free layer within the soil tillage stratum (Yang et al., 2021). An increase in film residue disrupts the flow of soil water and nutrients, compromising the supply of soil water, fertilizer, air, heat, and other essential factors to crops. This altered distribution of crop roots curtails the comprehensive absorption of soil water and nutrients by cotton roots, subsequently reducing both the quantity and quality of bolls per plant and culminating in a cotton yield reduction ranging from 1% to 23% (Li et al., 2017).

In a separate study, demonstrated that the influence of residual film on cotton yield became significant when it reached 210 $kg·hm^{-2}$, registering a yield decline between 16.9% and 21.6%. In the present study, it was discerned that with an escalation in residual film, the biomasses of cotton root, stem, and shell diminished. The dry matter weight of cotton began to wane when the residual film amount was 250 $kg·hm^{-2}$, aligning with prior research findings. A pronounced decline in cotton yield was noted when the residual film quantity attained 1500 $kg·hm^{-2}$, plummeting by 38.09% upon reaching 4000 $kg·hm^{-2}$.

Conclusion

The conclusions arrived at from this research are itemized as follows:

(1) Plastic film residue exerts a substantial influence on soil aeration, water permeability, and nutrient status. Within the 0-30 cm soil depth, there is an inverse relationship between the volumetric soil weight and film residue: as film residue escalates, the volumetric soil weight diminishes, whereas soil porosity augments. For plastic film residue levels at or below 500 $kg·hm^{-2}$, there is a positive correlation between soil moisture content and soil layer thickness. In contrast, for residue levels exceeding 500 $kg·hm^{-2}$, soil moisture content recedes as soil thickness proliferates. This research posits that plastic film residue modifies the movement of soil water and colloidal adsorption, subsequently impacting the movement and distribution of salt and water-soluble nutrients. Additionally, as residual film quantities elevate, there is an uptick in salinity within the cultivated layer. The conductivity observed in samples with residual film levels of ≥ 1000 $kg·hm^{-2}$ markedly surpassed those with levels of < 1000 $kg·hm^{-2}$. Concurrently, organic matter and available nitrogen displayed an uptrend with rising film residue, whereas available potassium and phosphorus exhibited an initial increase followed by a downturn.

(2) Plastic film residue impedes the absorption of water and nutrients by cotton, leading to a decline in cotton yield. An increase in plastic film residue is correlated with a reduction in the dry matter weight of cotton tissues. Furthermore, this residue compromises the root's nutrient uptake. Specifically, when the residual film

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accumulates to 2000 kg·hm^{-2}, plant nitrogen content diminishes. In treatments devoid of residual film, plant potassium peaked but showed a subsequent decline with rising levels of the residual film. Plant phosphorus content registered a pronounced drop upon reaching residual film levels of 500 kg·hm^{-2}. A significant downturn in cotton yield was observed when residual film levels touched 1000 kg·hm^{-2}, with a stark reduction of 38.09% at 4000 kg·hm^{-2}.

In conclusion, plastic film mulching practices promote soil water conservation and elevate soil temperature. These measures address water scarcity, mitigate frost-free periods, and decrease accumulated temperatures in temperate continental climate regions. Consequently, these changes create an optimal environment for cotton, enhancing its yield. Nonetheless, due to the extensive remnants of plastic film in the soil, alterations in the soil's physical and chemical, which adversely affects cotton growth.

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