Recovery measures and field management strategies after hailstone damage in upland cotton

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Research

Keywords: Hail damage, recovery strategies, fiber quality, yield, upland cotton

Posted Date: July 13th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-698130/v1

Abstract

Background

Hailstorm might damage cotton plants severely and cause heavy economic loss in field production. It hailed vehemently three times in 2015 and 2016 in Yellow River Basin Cotton Region and damaged cotton seedling and buds. The apical buds, leaves and stems were damaged as well as boll branches and few flower buds in our experiments. Serials strategies were performed to recover and rescue the cotton plants. Based on evaluating the hailstone damage, we fertilized 112.50 kg/ha Urea fertilizer (N content ≥ 46.4%) and intertilled the field timely.

Results

The recovery of plant individuals sprouted new buds and many new leaves after 12 DAH. Then the unnecessary shoots were pruned to adjust the development of fruit branches. Normally three new boll branches (NBB) in the major stem were reserved and eight subsequent emerging boll branches (EBB) in cotton plants. Five accessions with varied recovery ability and with different yield potential were sampled to compare the yield after hail damage, Sumian 20, 11–0710 and 11–0516 increased, while the other two accessions decreased relative to the normal production without hail damage. BC and RIL populations of upland cotton were used to evaluate the damage ratio of yield, which resulted in yield loss ranged 13.45%-20.27%. Fiber length, fibre elongation, fibre uniformity, and fiber elongation decreased slightly in the five accessions and in two populations.

Conclusions

The present study indicated that different accessions showed varied recovery ability for yield production, but all of them with a decreased ratio less than 20%. In addition, there was no significant effect on fiber quality in different cotton varieties. These results proved that the cotton plants can compensate by proper field managements, and remedial output could be obtained after hail damage.

Introduction

Hail causes extensive damage in field crop production in growing seasons. It is unpredictable and can cause serious physical damage for summer crops (Prabhakar et al. 2019). In China, hailstorm hazard appears occasionally and seasonally in Yellow River Basin Cotton Region and Northwest Inland Cotton Area at a high probability in the period of April to September (Wang and Yang 2001; Zhao et al. 2010). Upland cotton (*Gossypium hirsutum* L.) is the most important fiber crop and the Northwest Inland Cotton Area accounts for more than 85% of output of cultivated cotton in China (Zhang et al. 2015; Wang et al. 2017; Wang 2020). However, the growth and development of upland cotton might come across heavy hailstone damage in growing areas (Yan 2016). With the area of cotton planted expanded rapidly in Xinjiang Autonomous Region, the proportion of hail-affected areas has increased year by year, from 2.02% in 1992 to 10.05% in 2000 (Wang et al. 2002). Hails are most likely to strike in the seedling and budding stages of cotton, with the probabilities of 30.4% and 29.2%, respectively, but in bolls opening stage only 5.4%. Generally, the damage is earlier, the loss degree is heavier, and in contrast, the risk is relatively low during the maturation stage of cotton (Zhao et al. 2010).

As for the classification of hail damage, the damage degree of cotton can be divided into four classes: 1) slight damage type, less than 20% of the apical bud breakage rate and less than 30% leaves damage rate; 2) serious damage type, about 40% of the apical bud breakage rate, more than 30% the branches breaking rate with fallen and breaking leaves and buds; 3) very serious damage type, the polished stem following all of apical buds, leaves, branches and buds were destroyed but the axillary buds reserve the growth ability; and 4) destroyed damage type, the hail storm destroyed the epidermis of the stem after the whole plant damaged (Institute of Cotton Research of CAAS 2013; Singh et al. 2017). After the hail disaster, cotton is susceptible to various pathogens, the aphids and *Spodoptera litura*, which are more serious than normal condition. In addition, the growth period of cotton is delayed and the bolls are relatively set in the later stage due to the damage of the root system after the disaster, which lead to premature aging and some bolls cannot spit out in regular time (Gao et al. 2017).

Although upland cotton exhibited strong compensatory and regeneration capabilities after hail, hail damage also delayed the maturation date and reduced the number of bolls, eventually led to a decline of yield. In production practice, cotton management measures can be performed in time to recover cotton plants with the slight damage after hall disaster (Hu 2008). Generally, several managements were widely used such as intertillage, delay the time of pruning lateral branches, fertilization, and spraying ethephon (Zhou 2000). Topdressing nitrogen fertilizer on the fourth day after the disaster combined with intertillage has significant remedial effects on cotton plant growth and yield (Zhang and Chen 1992). Nitrogen application treatment, especially combined with intertillage, can significantly increase the assimilation capacity of cotton plants during the flowering and boll period by promoting the capacity of nitrogen absorption (He and Cao 1998). And it makes seed cotton increased significantly, resulting in a significant increase in bolls per unit area and the percentage of seed-cotton before frost (He and Cao 1998). The similar results also found in the research of Wang et al, nitrogen application combined with intertillage treatment will promote the fertilizer absorption on the third day after the hail damage during the bud stage, then increased the nitrogen accumulation and significantly improve the nitrogen distribution rate in the seed cotton and root system (Wang and Yang 2001).

Up to now, there has been little scientific data published on the effect of hail damage on yield and quality of upland cotton (*G. hirsutum*). In our study, two field trials for a same experiment design with two RIL populations encountered hailstone in 2015 and 2016. We performed strong continuous managements, including fertilized and intertilled the field timely to recover the plants growth and minimize the loss. We measured yield and yield components and evaluated fiber quality traits to validate whether the management is effective to recover cotton plants. Five breeding lines were used to identify the recovery potential for

hail damage, which were varied in recovery ability and resulted different yield comparing to the normal production without hail damage. Our results indicated that prompt and proper field managements can effectively minimize the loss of cotton after hail damage.

Materials And Methods

Plant materials and field design

Five upland cotton breeding lines including 11–0516 (Su et al. 2020), Sumian 20 (Su et al. 2017; Liu et al. 2018), 11-7010, 11-7027 (Su et al. 2017), 11–0514, and recombinant inbred line (RIL) and paternal backcross (BC) populations were used to investigate the morphology traits, yield and yield-components, and fiber quality traits. RIL and BC populations were developed by single seed descent method, which derived from the upland cotton hybrid 'Xinza 1' of GX1135×GX100-2 (Shang et al. 2016; Ma et al. 2017; Guo et al. 2020). The BC population was generated by backcrossing 177 RIL lines to GX100-2 (as the present male parent). All materials were planted four rows and four replications at Handan City in 2016 (2016E1). The BC field trials were carried out at Cangzhou City in 2015 (2015E2), and at E1 and E2 in 2016 (2016E1 and 2016E2). The experiment was following a randomized complete block design with two replications, respectively (Ma et al. 2017). Each BC progeny in the BC trial was inter-planted between the corresponding RIL line and GX100-2. Two-row plots spaced 80 cm and 60 cm alternately with the plot length of 3.0 m and 0.7 m pavement apart. Seeds were directly sowed. The sowing time were on April 25th (17°C-31°C) in 2015E2, and on April 30th (23°C-35°C) in 2016E1.

Hailstone disaster

Cotton plants during late seedling stage encountered heavily hailstone disaster on June 10th, 2015 at Cangzhou City (E2) after sowing for 46 days. Light and heavily hailstones happened on June 12th, 2016 (42 days after sowing) and June 28th, 2016 (early budding stage, at 58 days after sowing) at Handan City (E1), respectively. The climate and weather were normal during cotton growth season, excepting that one trial encountered hailstone.

Field managements and recovery strategies after the hailstone damage

We performed several recovery managements in time to recover the damage plants rather than re-sow or re-farm. Two days after encountering hailstone (DAH) disaster, we fertilized 112.50 kg/ha Urea fertilizer (N content ≥ 46.4%) into the field when the field was still wet, then we intertilled the field using manual intertill or machine intertill. Finally, we performed three times manual pruning to control the excessive vegetative growth and promoted the development of fruit branches. The other field managements followed the conventional standard of field practices.

Trait evaluation

After 35 days and 62 days encountering hailstone, we investigated five morphology traits for recovery plants without marginal effect at two development stages, including height of original major stem (HOS), emerging height of original major stem (EHOS), the number of original boll branch (OBB), new boll branches (NBB) in the original major stem and emerging boll branches of new emerging branches in new branches (EBB). Two development stages measured the height and the number of branches at the flowering stage on August 2^{ed}, 2016 (35 DAH) and at the late autumn bolls development stage on August 30th, 2016 (62 DAH), respectively. A total of 152, 79, 61, 63, 49 plants for 11–0516, Sumian 20, 11-7010, 11-7027 and 11–0514 were measured for morphology traits, respectively.

At maturity stage, we scored and harvested eight plants without marginal effects for seed cotton in each plot for seed-cotton yield per plant (SY, g) and boll number per plant (BNP). In order to ensure the reliability and representativeness of the experiment, twenty-five naturally opening bolls were randomly hand-harvested from the middle of plants in each plot for boll weight (BW, g) and lint percentage (LP, %). Lint yield per plant (LY, g) calculated by multiplying SY by LP. The raw data of yield and yield component traits referred to the part of Table 1 in an article in BC trials (Ma et al. 2018). The damage rate = (Mean in 2016E2 or 2017E1 - Mean in 2015E2 or 2016E1)/ Mean in 2016E2 or 2017E1 × 100%, the performance in 2016E2 and 2017E1 without hailstone damage as the control.

Table 1
Performance of plant morphology traits for five varieties or lines in two development stages after hail damage in 2016.

Line ID	Date	HOS (cm)	EHOS (cm)	OBB	NBB	EBB
Sumian 20	Aug. 2ed	41.65 ± 6.55	59.02 ± 5.83	4.2 ± 0.8	6.5 ± 3.4	6.8 ± 0.5
	Aug. 30th	41.27 ± 4.82	71.23 ± 8.77	3.4 ± 0.7	1.4 ± 0.5	8.4 ± 0.7
11-7010	Aug. 2ed	39.93 ± 3.30	62.43 ± 7.75	5.1 ± 1.4	6.8 ± 3.3	7.2 ± 1.0
	Aug. 30th	39.74 ± 3.33	68.83 ± 6.71	4.1 ± 0.6	1.4 ± 0.5	8.8 ± 0.8
11–0514	Aug. 2ed	37.55 ± 3.49	63.91 ± 8.03	3.7 ± 0.6	7.4 ± 2.6	7.4 ± 0.5
	Aug. 30th	37.56 ± 3.32	74.41 ± 8.95	3.0 ± 0.9	1.0 ± 0.0	8.9 ± 0.8
11–0516	Aug. 2ed	40.60 ± 4.28	56.11 ± 7.23	4.3 ± 0.6	4.9 ± 2.0	6.6 ± 1.0
	Aug. 30th	41.48 ± 5.44	72.93 ± 8.60	3.6 ± 0.7	1.6 ± 0.8	8.5 ± 1.1
11-7027	Aug. 2ed	40.30 ± 3.37	60.10 ± 9.19	4.0 ± 0.6	6.6 ± 2.6	7.0 ± 1.1
	Aug. 30th	39.91 ± 3.16	72.52 ± 8.17	3.0 ± 0.7	1.4 ± 0.7	9.9 ± 0.8

Notes: Trait abbreviation, HOS (cm), height of original major stem, OBB, original boll branches in the major stem, NBB, new boll branches in the major stem, EHOS (cm), emerging height of original major stem, and EBB, emerging boll branches in new branches.

Results

General description and recovery strategies after the hailstone damage

When encountering severe hailstone disaster, cotton plants were large damage during the late seedling stage on June 10th, 2015. The apical buds, leaves and stems were damaged as well as boll branches and few flower buds. The apical bud breaking rate and light stem rate of cotton reached 100% and 95% in 2015E2. Furthermore, the damage rate of apical bud and stem are 70% and 30% during the early budding stage on June 12th and June 28th, in 2016E1 (Fig. 1-A-C, Fig. S1). Though field managements performed without delay after encountering hailstone, recovery plants sprouted new buds and leaves after 12 DAH, on July 10th, 2016 (at E1 in Fig. 1D) and 12 days DAH on June 21th, 2015 (at E2 in Fig. 1E), suggesting that the fertilizer and intertillage is important to recover the damage of cotton plants.

Subsequently, we remained two to four new apical buds or one original bud when new branches of the recovery plants emerged for two times on July 11th, 2016 and on July 17th, 2016. The manual pruning controlled the excessive vegetative growth and promoted the development of remaining fruit branches. On August 7th, 2016, we removed the buds of the main stem or the new branches for preventing apical dominance (Fig. 1F). Then, we pruned manually for the third time to prevent the excessive buds on August 31th, 2016 (Fig. 1G).

Recovery developing processes of the hail damaged cotton individuals

Three types of damage plants encountered hailstone including polished stem plants with very serious damage (Fig. 2A), no apical bud plants (Fig. 2B) and plants with the apical buds (Fig. 2C). After 35 DAH, the height of original major stem (HOS) ranged from 37.55 to 41.65 cm. However, the emerging height of original major stem (EHOS) increased 56.11 to 63.91 cm on average for five varieties after 35 days. And the plants kept three to five original boll branches (OBB) in major stem. The recovery plants were at flowering or boll stages after 62 DAH in 2016 (Fig. 2D-F), and the HOS and OBB displayed no significant difference compared with 35 DAH for all of five varieties. Five accessions displayed more growth ability with 68.83 to 74.41 cm EHOS (Table 1). We retained about three new boll branches (NBB) in the major stem after 35 DAH. It attributed to the pick-off of apical buds and the pruning management. Eight to ten emerging boll branches in new branches (EBB) took shape to ensure the yield production. The results indicated that cotton plants owning strong recovery ability and the continuous field managements played efficient. In addition, the flowering and maturation time delayed about one month in order to recover the plant growth.

Yield compensation after hail damage

In order to evaluate the damage of the hailstone, we calculated the damage rate of yield and its-components and fiber quality traits in 2015E2 and 2016E1 comparing with the performance in 2016E2 or 2017E1 without hailstone damage. For five accessions, seed-cotton yield per plant (SY, g) ranged from 105.9 g to 129.6 g on average in 2016E1, and ranged 104.8 g to 127.9 g on average in 2017E1 (Table 2). The lint yield per plant (LY, g) ranged 39.8–54.7 g on average in 2016E1 and 43.3–59.1 g on average in 2017E1 (Table 2). Among the five breeding lines, the damage ratio of boll number per plant (BNP) ranged from 5.15–26.86%, and boll weight (BW, g) decreased 0.96%-18.07% in 2016E1 relative to in 2017E1 (Table 2). After hail damage, the lint percentage (LP, %) of five accessions were also decreased from 7.43–14.26% (Table 2). However, the yield components presented different varied trends for five accessions between 2016E1 and 2017E1. For example, SY of 11–0514 and 11-7027 were decreased 9.95% and 5.70% after hail damage (Table 2), and increased 1.34–10.10% for Sumian 20, 11–0710 and 11–0516, respectively.

Table 2
Yield, fiber quality traits and damage ratio of five accessions after recovery strategies in 2016E1.

Trait†	**Sumian 20**			**11–0710**			**11–0514**			**11–0516**		
	Mean (2016E1)	Mean (2017E1)	Damage ratio	Mean (2016E1)	Mean (2017E1)	Damage ratio	Mean (2016E1)	Mean (2017E1)	Damage ratio	Mean (2016E1)	Mean (2017E1)	Damage ratio
SY (g)	129.6 ± 10.2	127.9 ± 14.5	-1.34	121.9 ± 10.2	113.2 ± 8.3	-7.62	116.7 ± 30.9	129.6 ± 11.7	9.95	115.4 ± 39.4	104.8 ± 22.7	-10.10
LY (g)	54.7 ± 4.9	59.1 ± 6.1	7.47	46.7 ± 3.6	49.0 ± 2.4	4.76	48.6 ± 14.1	55.4 ± 5.4	12.36	42.8 ± 14.7	43.3 ± 9.5	1.06
BNP	15.7 ± 1.9	21.5 ± 1.6	26.86	17.9 ± 2.9	20.6 ± 4.6	13.23	16.7 ± 2.3	22.3 ± 3.7	25.19	15.4 ± 4.0	22.3 ± 1.7	31.23
BW (g)	5.18 ± 0.41	5.23 ± 0.25	0.96	4.87 ± 0.41	5.09 ± 0.25	4.32	4.76 ± 1.08	5.81 ± 0.61	18.07	5.41 ± 0.40	5.81 ± 0.30	6.88
LP (%)	42.16 ± 1.42	46.04 ± 1.80	8.43	38.34 ± 1.48	41.29 ± 1.37	7.14	41.47 ± 1.87	46.34 ± 3.29	10.51	37.12 ± 2.91	42.77 ± 1.23	13.21
FL (mm)	29.54 ± 0.52	29.54 ± 0.72	0.00	28.24 ± 1.03	28.21 ± 0.70	-0.11	29.46 ± 1.00	29.75 ± 1.16	0.97	30.32 ± 0.90	30.06 ± 0.83	-0.86
FU (%)	85.26 ± 1.18	84.35 ± 1.08	-1.08	84.57 ± 1.20	84.11 ± 0.47	-0.55	84.8 ± 1.16	84.39 ± 0.78	-0.49	85.69 ± 1.06	85.05 ± 0.61	-0.75
FS (cN/tex)	30.79 ± 1.05	28.59 ± 1.04	-7.69	30.44 ± 1.23	28.93 ± 0.83	-5.22	29.26 ± 2.08	27.89 ± 1.83	-4.91	30.10 ± 0.86	27.33 ± 1.28	-10.14
FE (%)	6.88 ± 0.06	6.67 ± 0.06	-3.15	6.86 ± 0.08	6.68 ± 0.06	-2.69	6.80 ± 0.07	6.70 ± 0.05	-1.49	6.92 ± 0.10	6.75 ± 0.08	-2.52
FM	5.21 ± 0.14	5.50 ± 0.10	5.27	4.76 ± 0.39	5.23 ± 0.22	8.99	4.78 ± 0.41	5.53 ± 0.19	13.56	5.18 ± 0.26	5.43 ± 0.10	4.60

Notes: †, SY (g), Seed-cotton yield per plant; LY (g), Lint yield per plant; BNP, Boll number per plant; BW (g), Boll weight; LP (%), Lint percentage; trait abbreviate
Fiber strength; FU (%), Fiber uniformity; FE (%), Fiber elongation; FM, Fiber micronaire. The damage ratio = (Mean in 2017E1- Mean in 2016E1)/ Mean in 2017

In BC and RIL populations, SY decreased 13.45% and 14.38%, and LY decreased 16.07–17.93% in 2015E2 (Table 3). Similarly, SY decreased 14.48% and 16.49% and LY decreased 17.45% and 20.27% in BC and RIL populations in 2016E1, respectively (Table 3). These results showed that through the recovery for field management, the cotton plants development well and damage rate less than 20.00% not only for SY but also for LY in both populations. Furthermore, the damage ratio of LP less than 4.50% both in BC and RIL populations in two different years (Table 3). We found that cotton plants encountering hailstone at seedling stage displayed the highest damage rate with 54.66 % and 56.03 % for BNP in RIL and BC populations in 2015E2, but with − 1.16 and − 2.16% for BW. However, cotton plants encountering hail damage at budding stage displayed the decrease rate with − 4.58 and − 2.59% for BNP, but with 12.40% and 11.55% for BW in 2016E1 (Table 3).

Table 3
The yield, fiber quality traits and damage ratio in BC and RIL populations.

Trait†	Env.	BC			RIL		
		Mean ± SD	C.V (%)	Damage ratio	Mean ± SD	C.V (%)	Damage ratio
SY (g)	2015E2	58.96 ± 12.10	20.53	13.45	52.56 ± 16.59	31.57	14.38
	2016E1	58.27 ± 12.35	21.19	14.48	51.27 ± 15.11	29.47	16.49
	2016E2	68.13 ± 11.86	17.41	–	61.39 ± 13.86	22.57	–
LY (g)	2015E2	22.89 ± 4.64	20.27	16.07	20.25 ± 6.35	31.36	17.93
	2016E1	22.51 ± 4.95	21.98	17.45	19.67 ± 5.88	29.87	20.27
	2016E2	27.27 ± 5.02	21.19	–	24.68 ± 5.83	23.62	–
BNP	2015E2	10.76 ± 2.10	19.49	54.66	9.92 ± 2.89	29.16	56.03
	2016E1	24.82 ± 2.99	12.03	-4.58	23.15 ± 3.70	15.97	-2.59
	2016E2	23.74 ± 2.42	10.22	–	22.56 ± 2.68	11.89	–
BW (g)	2015E2	5.49 ± 0.35	6.38	-1.16	5.25 ± 0.48	9.20	-2.16
	2016E1	4.75 ± 0.40	8.39	12.40	4.54 ± 0.48	10.60	11.55
	2016E2	5.43 ± 0.35	6.38	–	5.13 ± 0.41	8.07	–
LP (%)	2015E2	38.81 ± 1.53	3.95	2.85	38.70 ± 2.28	5.88	3.56
	2016E1	38.56 ± 1.76	4.56	3.46	38.33 ± 2.60	6.78	4.48
	2016E2	39.95 ± 1.55	3.87	–	40.13 ± 2.40	5.98	–
FL	2015E2	31.08 ± 0.69	2.21	-5.61	30.95 ± 0.95	3.07	-6.18
(mm)	2016E1	30.38 ± 0.80	2.63	-3.24	30.36 ± 1.07	3.54	-4.15
	2016E2	29.42 ± 0.78	2.64	–	29.15 ± 1.08	3.70	–
FU (%)	2015E2	86.06 ± 0.70	0.81	-0.90	85.79 ± 0.82	0.96	-0.99
	2016E1	86.28 ± 0.76	0.88	-1.16	85.99 ± 0.85	0.98	-1.22
	2016E2	85.29 ± 1.02	1.20	–	84.95 ± 1.05	1.23	–
FS	2015E2	30.63 ± 0.99	3.22	-5.21	30.80 ± 1.42	45.62	-6.09
(cN/tex)	2016E1	28.81 ± 0.94	3.25	1.03	28.99 ± 1.25	4.32	0.15
	2016E2	29.11 ± 1.02	3.50	–	29.03 ± 1.38	4.75	–
FE (%)	2015E2	6.99 ± 0.06	0.84	-3.76	6.99 ± 0.08	1.16	-4.04
	2016E1	6.81 ± 0.06	0.87	-0.99	6.80 ± 0.07	1.09	-1.18
	2016E2	6.74 ± 0.06	0.88	–	6.72 ± 0.07	1.08	–
FM	2015E2	4.76 ± 0.27	5.59	3.42	4.71 ± 0.36	7.65	5.39
	2016E1	4.81 ± 0.34	7.21	2.44	4.86 ± 0.41	8.53	2.40
	2016E2	4.93 ± 0.24	4.92	–	4.97 ± 0.37	7.45	–

Notes: The damage ratio = (Mean in 2016E2- Mean in 2015E2 or 2016E1)/ Mean in 2016E2 × 100%.

† The same as Table 2.

These results indicated that the performance of SY and LY were determined by yield components together, such as the complementary relationship between BNP and BW, and the complementary performance between BNP and BW resulting in no significant changed in yield. The varied performance attributed to the different occurrence time of hail damage, different locations and different years between 2015E2 and 2016E1.

Fiber quality affected slightly after hail damage

For five accessions, the average fibre length (FL) in 2016E1 is between 28.24 mm and 30.98 mm, this result is varied slightly from the fibre length during the normal growth conditions (2017E1). Similar with fiber length, the fiber strength (FS) ranges from 29.26 to 30.90 cN/tex in the five varieties in 2016E1, and there was no significant difference with the FS in normal condition in 2017E1 (Table 2). In addition, both the fiber uniformity (FU) and the fiber elongation (FE) were increased in the five varieties in 2016E1 relative to in 2017E1, but the increase rate is less than 3.5%. The fiber quality, include FL, FU and FE were increased both in BC and RIL populations in 2015E2 and 2016E1, but the FS was increased in two populations in 2015E2 and decreased in 2016E1 (Table 3). The micronaire values were decreased by 2.40–5.39% in BC and RIL populations in two hailstorm years, indicating the thickness of fiber declined when

encountering hail damage. It is worth noting that all of the change indices were less than 6.5%. Combining the above results, we can know that the hailstone damage affected slightly for fiber quality traits, especially for fibre elongation and uniformity.

Discussions

Hailstorms are typically localized events in crop production (Bosco et al. 2018). Corp suffer from hail damage mainly embodied in defoliation timing and severity, and lead to reductions in crop plants and loss of photosynthetic organs (Battaglia et al. 2019). Besides the loss of photosynthetic area, hailstones also bruise the stalks of larger plants, resulting in interference with the movement of assimilates, include plant hormone, nutrients and water, ultimately affect the growth and development of plants (Battaglia et al. 2019).

The dormant bud in plant is the key factor to influence the recover efficiency and to decision the yield production. The degree of hail damages depends on hailstone size, intensity and the kinetic energy (Saa et al. 2011; Yue et al. 2019). Meanwhile, the growth stage and the elasticity of the crops also important to the extent of the hailstorm damage (Petoumenou et al. 2019; Yue et al. 2019). The damage is earlier, the loss degree is heavier, and in contrast, the risk is relatively low during the maturation stage of crop (Zhao et al. 2010), and our study proved that hailstorms during the budding stage may not result in significant cotton yield reductions than the seedling stage. The cotton plants with cotyledon and apical meristem during cotyledon period are easily destroyed because the slow growth and worse in resistance after hail storm (Wan et al. 2004). In this study, we performed several appropriate, experimentally sound investigations on damage plants of upland cotton in Handan and Cangzhou City in Hebei, China. Although a terrible hailstorm occurrence during early development stage, cotton plants have latent buds after damage. So, we can avoid to re-farm again or other crops and strengthen the field managements immediately to recover cotton plants. After fertilizing, intertill and prune in time, we adjusted the plant architecture to avoid the over flourishing growth. In addition, strengthening the root system underground was critical to promote the development of dormant buds. Similar management measures were also performed to recover plant growth after hail disaster to minimize the loss to crops in other studies (Hu 2008; Bal et al. 2017).

The unfruitful buds, bolls and damage ratios differed among different varieties after hail damage (Yang et al. 2004). In present study, different accessions showed varied recovery ability for yield production. Among them, the yield loss of 11–0514 and 11-7027 showed less than 20% of damage rate, similar results in the RIL and BC populations. However, yield production of Sumian 20, 11–0710 and 11–0516 increased after recovery, this phenomenon may be attributed to the earlier maturation period and the more effective bolls. In 2015E2, another research also concluded that although cotton plants sowing at the early period experiencing hail damage, they displayed better yield performance than the upland cotton plants re-sowing at the late period, and the rate of boll forming and opening was significantly affected by different varieties (Wang 2016). However, there was no significant effect on fiber length, fiber strength, fiber uniformity and fiber elongation in different cotton varieties (Wang 2016). Similar results also found here, four fiber quality traits increased slightly in different materials.

It is worth noting that although we reduced the loss by strengthen managements after hail storm, the development period of cotton plants was delayed. It is necessary to spray ethephon to promote early-maturing of bolls at mature. In fact, the hail disaster can be prevented and limited by early warning by weather forecast, as well as planting trees on a large scale (Yan 2016). In addition, artificial hail prevention system had been constructed and destroyed the hail formation manually in Xinjiang Autonomous Region in China (Institute of Cotton Research of CAAS 2013). Moreover, if the fertility of soil is good, no or less post-disaster recovery treatment measures can be taken except for timely intertill, so that the cotton can recover naturally (Wang 2016). Otherwise, further exploring the suitable measures were taken to recovery the cotton development status by applying different nitrogen fertilizers, regulator dosages and application times, to guarantee no significant impact on cotton yield after hail damage.

Declarations

Funding

This research was supported by a grant from National Key R & D Program for Crop Breeding (Project No. 2018YFD0100303).

Conflict of interest

The authors declare no conflict of interest.

Author contributions

JPH designed the study, provided experimental platform, and revised the manuscript. HSN and YS attended field experiments, data collection, analysis and prepared the manuscript. LL, DWW, BBS and FX performed field experiments, and data collection. MHD attended bench work and discussion. All authors approved of the final manuscript.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

All data generated or analyzed in this study included in published article and additional files.

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Figures

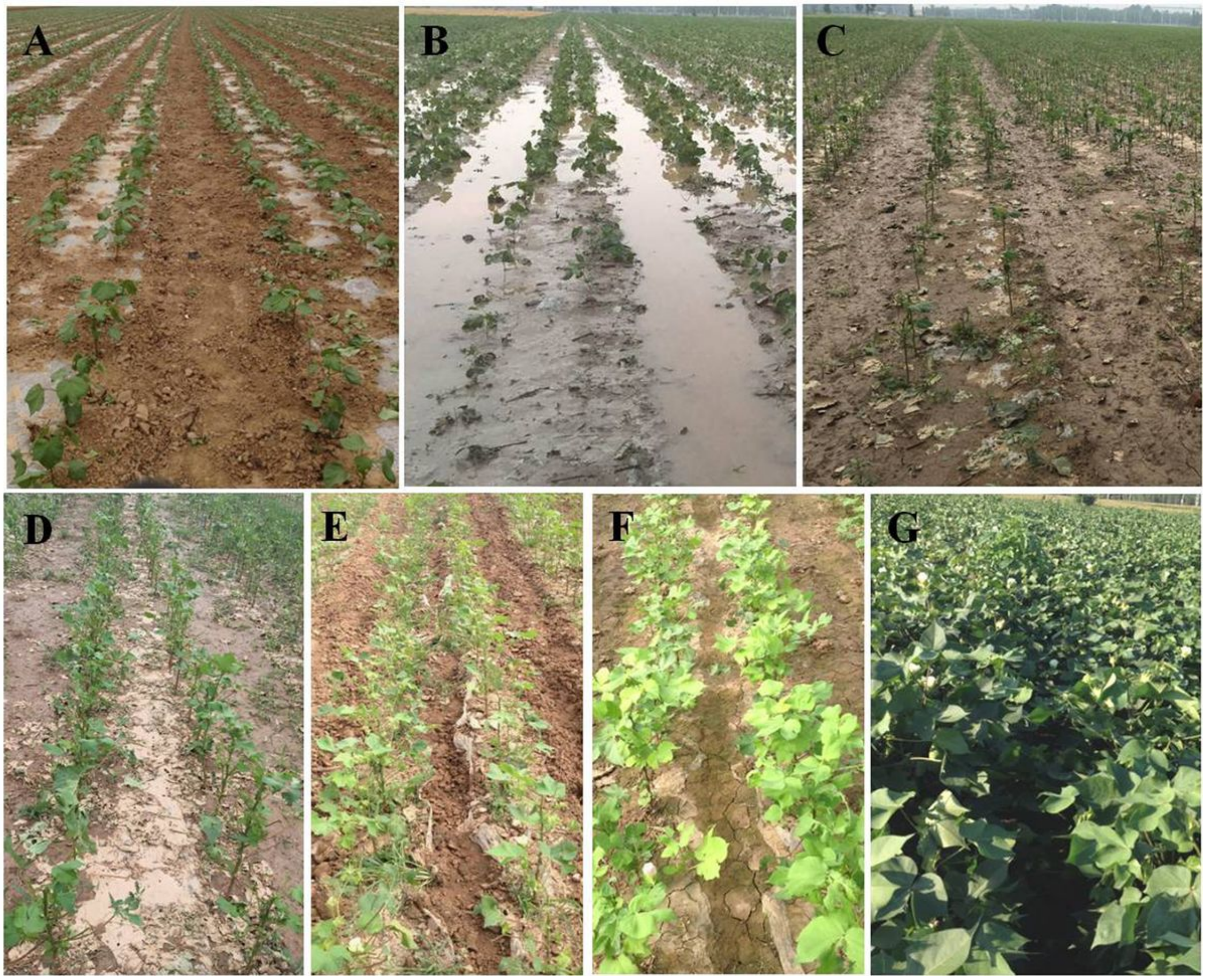

Figure 1

Plants encountered hailstone and recovery plants in the field trial in 2016E1 (Handan City, Hebei Province). A: Normal plants at seedling stage for 40 days after sowing on June 10th, 2016. B and C: The first and the second hailstone disaster on June 12th and June 28th, 2016 (E1). D and E: Plants were sprouted new buds and many new leaves after 12 DAH, on July 10th, 2016E1 (D) and on June 21th, 2015E2 (E) after fertilized and loosened the soil. F: The recovery plants for 38 DAH on August 7th, 2016E1. G: Plants growth situations for 62 DAH on August 31th, 2016E1.

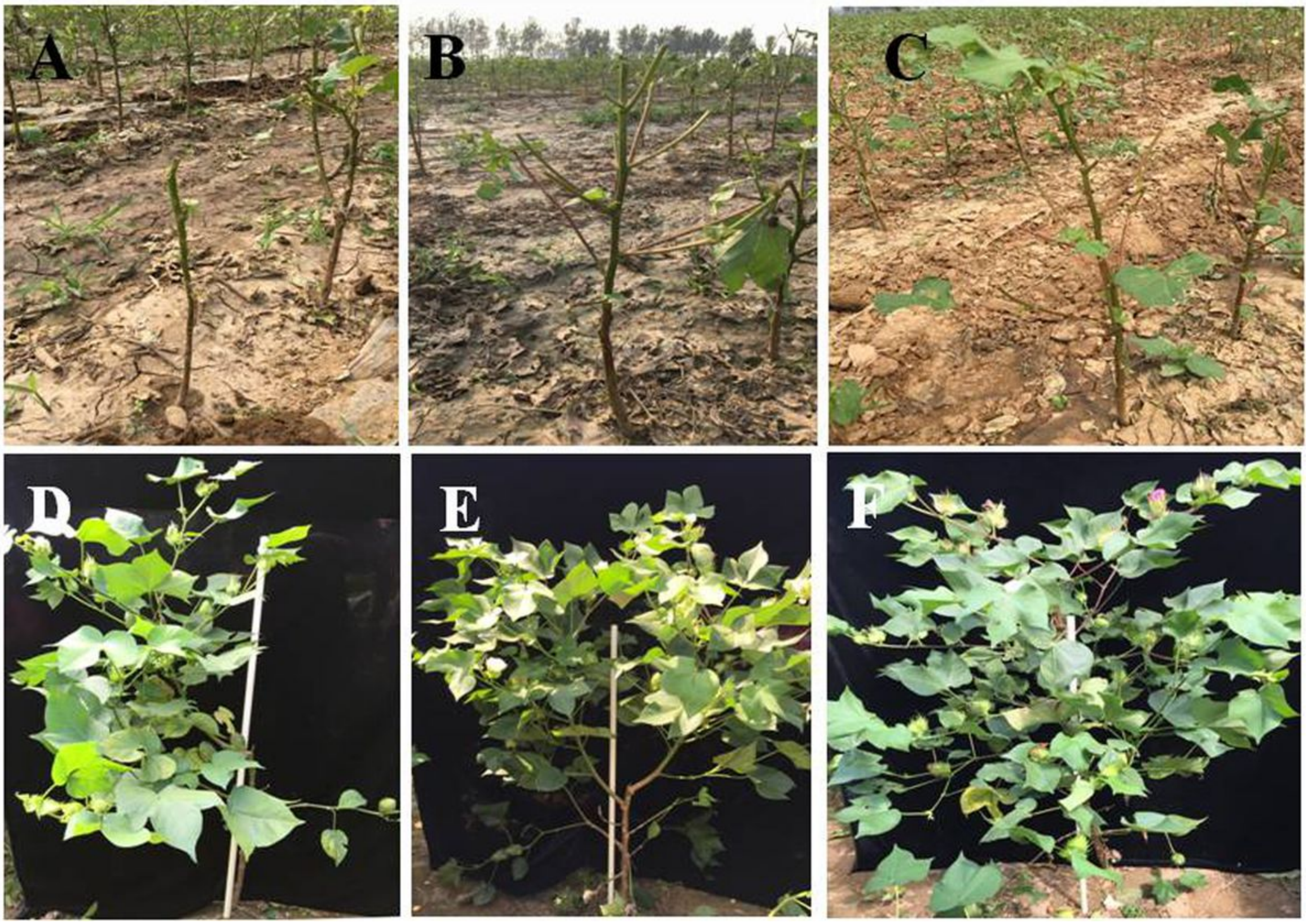

Figure 2

Three types of damage plants encountered hailstone (A-C) and their recovery plants, respectively (D-F). A, light stem, B, no apical bud in major stem, C, whole apical bud. D-F, the recovery plants corresponding to A-C for 62 DAH, the scale of the rule is 100 cm.

Supplementary Files

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- Fig.S1.jpg