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Effect of Particulates (Dust) on Cotton Growth, Photosynthesis, and Respiration[1]

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ABSTRACT

Wind erosion suspends large quantities of dust in the atmosphere that settle back to the earth's surface and are deposited on plant leaves when wind velocities decrease. The object of this research was to determine the effect of wind-erodible size dust particles on upland cotton [*Gossypium hirsutum* (L.) 'Dunn 120'] growth and physiology. Dust (< 0.106 mm) at concentrations of 0, 10.8, 15.2, 16.5, 22.1, 28.6, 38.5, and 51.1 μg m^{-2} was settled onto leaves of 22-day-old growth-chamber-grown cotton plants in a dust chamber. Net photosynthesis, dark respiration, dust concentration, leaf area, and dry weight were measured 1, 3, 7, and 14 days after dust was applied. Applied dust (> 15.2 μg m^{-2}) resulted in reduced dry weight at 3, 7, and 14 days after application, but dry weight accumulation was not reduced by increasing dust concentration after day 3. The dry weight reduction was due to reduced photosynthesis, 1 and 3 days after dust application, and increased dark respiration, 1, 3, and 7 days after application when dust application rates exceeded 28.6 μg m^{-2}. This study indicates that particulate deposits can alter cotton growth without physical damage to the plant and without toxic materials present in the dust. However, rapid removal of particulates by wind and rain and low natural deposition rates (1.5 μg m^{-2} day^{-1}) indicate that dust deposits on leaves should not be a major problem in cotton production.

Additional index words: **Wind erosion, Dust storms, Air pollution, *Gossypium hirsutum* L., Dust concentration.**

Wind erosion events in western Kansas and eastern Colorado injected approximately 5455 Mg of dust per vertical kilometer into the atmosphere during 1954 and 1955 (3). The average storm lasted 6.6 h and had a median dust concentration of 4.85 mg m^{-3} (9). An estimated 224 × 10^6 Mg of dust was suspended annually in the 1950's (10). Any dust injected into the atmosphere by dust storms, man's activities, or natural disasters will be deposited elsewhere. Dust deposition measured from 1964 to 1966 in the Great Plains averaged 17 to 459 kg ha^{-1} month^{-1} (16). Cement-kiln dust deposits have been reported as high as 3.8 g m^{-2} day^{-1} (6), and the volcanic explosion of Mt. St. Helens deposited a maximum of 300 Mg ha^{-1} on agricultural crops (4).

The effect of gaseous air pollutants such as ozone, SO_2, nitrogen oxides, and fluorides on plant metabolism has received much attention, but the effect of particulates has not been examined extensively, except in those cases where plant damage has been noted.

Hand dusting cement-kiln dust at rates of 0.5 to 3.0 g m^{-2} on green bean [*Phaseolus vulgaris* (L.)] leaves reduced photosynthesis up to 73% (6). Coal dust inhibited photosynthesis at low and medium light levels with Scotch pine [*Pinus sylvestris* (L.)] and poplar (*Populus euramericana*) leaves but not at high levels of illumination because of absorption of light by the coal dust (1). A 1-mm ash coating reduced apple [*Pyrus malus* (L.)] leaf photosynthesis 90%, whereas lighter coatings temporarily reduced photosynthesis 25 to 33% and increased photorespiration by 25 to 50% (4).

Dust coatings increased leaf temperatures 2 to 4°C (7), increased the number of bacteria and fungi on the leaves (14), and increased transpiration (8). Water loss increased with increased concentration and decreased particle size of applied dust.

The objective of this study was to determine the effect of particulate coatings of wind erodible dust on the growth, photosynthesis, and respiration of cotton [*Gossypium hirsutum* (L.)].

MATERIALS AND METHODS

'Dunn 120' cotton was planted in plastic pots with 0.18-m diam and filled with 4 kg of masonry sand sieved to remove all particles larger than 3.35 mm. Plants were grown in a growth chamber at 30°C during a 16-h day and at 25°C during the night. Photon flux was 1400 μmol photon m^{-2} sec^{-1} (400–700 ηm) at the top of canopy. Plants were watered daily with 0.2-strength Hoagland nutrient solution.

Twenty-two days after emergence, plant leaves were coated with dust by sedimentation of known amounts of a mixture of particles < 0.106 mm in diam from Richfield silt loam (fine, montmorillonitic, mesic Aridic Argiustolls), Ulysses silt loam (fine-silty, mixed, mesic Aridic Haplustolls), and fluorescent dust (Pigment 2266, United States Radium Corp., Hackettstown, NJ)[3] (49.5:49.5:1 by weight) using a dust

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[3] Product name is given for information only and does not constitute an endorsement by the USDA.

chamber 0.47 m in diam and 1.5 m high. The dust mixture was placed on a 0.106-mm sieve at the top of the chamber and vibrated through the sieve and a stream of air (35 L min^{-1}) injected horizontally 0.30 m below the bottom of the sieve. Soil particles of the size and texture used in this study (< 0.106 mm) comprised approximately 92% of the soil material suspended by a wind erosion event from a silt loam soil between 0.61 and 6.1 m above the soil surface (2).

Calibration of the dust chamber for distribution and for developing the calibration equation was carried out in the following manner: Twenty-one weighed, 70-mm diam, lined filter papers were placed evenly on the floor of the dust chamber and coated with varying, weighed amounts of dust. Filter papers were weighed to determine dust amount, and number of fluorescent spots were counted under magnification. After uniformity of distribution was obtained by adjusting air injection volume and dust mixture placement on the 0.106-mm sieve, 72 runs with 24 different weighed amounts of dust mixture were used to develop a regression equation relating dust amount ($\mu g\ m^{-2}$) to number of fluorescent spots per square millimeter. Dust mixture uniformity was determined by placing microscope slides on the floor of the dust chamber and counting the number of dust and fluorescent spots under a microscope (1×).

Amount of dust on each leaf was determined by counting the fluorescent particles in 10 randomly selected 100-mm^2 areas under magnification. The average of the 10 readings was used to calculate quantities of dust on each leaf using the calibration equation. The calibration equation is:

$$D = 0.1144S - 0.33$$

where D = dust concentration in $\mu g\ m^{-2}$ and S = number of fluorescent spots in 1 m^2.

Amount of dust applied was calculated by the equation:

$$\frac{\Sigma_1^L D_L A_L}{A_1} = DA$$

where D_L = dust concentration on a particular leaf in $\mu g\ m^{-2}$, A_L = area of a particular leaf in m^2, A_1 = area of leaves with dust on their surfaces in m^2, and DA = dust concentration applied in $\mu g\ m^{-2}$.

Amount of dust on the plant at sampling times was calculated by the equation:

$$\frac{\Sigma_1^L D_L A_L}{AT} = DT$$

where AT = total area of leaves in m^2 and DT = dust concentration for total plant in $\mu g\ m^{-2}$. Leaf area was determined by using a LI-COR Model LI-3000 portable area meter and LI-3050A belt conveyer (LI-COR, Inc., Lincoln, NE).[3]

Photosynthesis rate and dark respiration rate were determined on plants in four randomly selected pots, 1, 3, 7, and 14 days after dust application. Net carbon exchange in both light and dark was determined with a 0.30-m diam by 0.60-m-high plexiglas plant chamber adapted for syringe sampling. Air was circulated upward through the chamber at an average velocity of 2.8 m s^{-1} by a fan in the heat exchanger. Temperature in the chamber was maintained at 20±2°C. Light at an intensity of 900μmol photon $m^{-2}\ sec^{-1}$ (400-700 ηm) was supplied to the chamber by four 300-W, cool-beam, medium spotlights.

Three 10-mL samples of chamber air were taken every 10 min with the lights on until CO_2 was about 200 $\mu L\ L^{-1}$. Lights were turned off and samples were taken every 15 min until CO_2 approached 400 $\mu L\ L^{-1}$. Syringes were injected into a flowing N_2 stream, which passed through the sample cell of a Beckman Model 865 infrared gas analyzer (Beckman Instruments, Inc., Fullerton, CA)[3] previously calibrated by injecting known CO_2 samples ranging from 0 to 400 $\mu L\ L^{-1}$.

After CO_2 assimilation was measured, plant leaves were removed, fluorescent particles were counted, dust was removed from the leaves, leaf area was measured, and fresh weight was determined. Stems were cut off at sand surface and weighed. The leaves and the stems were combined, dried for 48 h at 70°C, and weighed. All data were subjected to an analysis of variance (ANOVA) and linear and multiple regression techniques (17).

RESULTS

Concentration of dust applied and dust present at each sample date are given in Table 1. Leaf expansion and the emergence and growth of new leaves reduced the average dust concentration by 2, 18, 39, and 70% at 1, 3, 7, and 14 days after dust application, respectively.

Dust concentrations that exceeded 13.5, 10.4, and 5.8 $\mu g\ m^{-2}$ significantly reduced total dry weight at 3, 7, and 14 days after application, respectively, (Table 2). Dust application did not have time to affect the dry weight at the 1-day sample (24 h).

Dry weight accumulation was reduced by increasing dust concentrations from 1 to 3 days after dust was applied but not between 3 and 7 or 7 and 14 days after dust application (Table 2). When dust application exceeded 28.6 $\mu g\ m^{-2}$, the plants lost weight between the

Table 1. Concentration of dust applied to and concentration of dust on cotton plants, 1, 3, 7, and 14 days after dust application. Average of four plants.

	Days after dust application			
Dust applied	1	3	7	14
	$\mu g\ m^{-2}$			
0	0	0	0	0
10.8	10.6	8.6	5.0	2.6
15.2	15.1	14.5	10.4	5.0
16.5	16.2	13.5	12.4	5.0
22.1	21.8	18.3	13.6	5.8
28.6	28.2	23.5	16.4	7.1
38.5	37.3	28.9	21.8	11.6
51.1	49.1	40.6	30.6	20.1
Average	22.3	18.5	13.8	7.1
LSD (0.05)†	5.1	4.0	2.6	3.0
$s_{\bar{x}}$	1.7	1.4	0.9	1.0

† LSD = Least significant difference, $s_{\bar{x}}$ = standard error of the mean of the sample.

Table 2. Effect of dust concentration on cotton total dry weight, 1, 3, 7, and 14 days after dust application and dry weight accumulation. Average of four plants.

	Days after dust application			
Dust applied	1	3	7	14
$\mu g\ m^{-2}$	g $plant^{-1}$			
0	3.07 (0.66)‡	4.39 (0.60)§	7.19 (0.52)¶	10.87
10.8	2.60 (0.52)	3.64 (0.66)	6.02 (0.55)	10.10
15.2	2.79 (0.40)	3.60 (0.71)	6.46 (0.76)	11.79
16.5	3.08 (0.43)	3.93 (0.50)	5.46 (0.64)	9.92
22.1	2.67 (0.07)	3.14 (0.53)	4.76 (0.46)	10.52
28.6	1.75 (0.23)	1.89 (0.40)	4.01 (0.82)	7.26
38.5	2.61 (−0.36)	1.88 (0.68)	4.62 (0.48)	8.00
51.1	2.90 (−0.46)	1.98 (0.68)	4.67 (0.56)	8.56
Average	2.68 (0.18)	3.06 (0.60)	5.28 (0.60)	9.50
LSD (0.05)†	NS (0.74)	1.15 (NS)	1.07 (NS)	1.55
$s_{\bar{x}}$	0.28 (0.25)	0.39 (0.11)	0.36 (0.10)	0.53

† LSD = Least significant difference, $s_{\bar{x}}$ = standard error of the mean of the sample.
‡ Dry weight accumulation (g $plant^{-1}$ day^{-1}) for day 1 to day 3.
§ Dry weight accumulation for day 3 to day 7.
¶ Dry weight accumulation for day 7 to 14.

Table 3. Effect of dust concentration on cotton photosynthesis rates, 1, 3, 7, and 14 days after dust application. Average of four plants.

Dust applied	Days after dust application 1	3	7	14
$\mu g\ m^{-2}$	$mg\ CO_2\ h^{-1}$			
0	21.42	14.14	13.29	12.12
10.8	16.96	16.30	15.52	10.57
15.2	16.23	17.15	9.99	9.17
16.5	20.10	17.08	13.15	10.08
22.1	16.92	18.75	12.09	13.27
28.6	18.82	14.67	15.71	9.76
38.5	15.82	18.37	13.98	11.76
51.1	7.70	9.05	11.17	9.14
Average	16.75	15.69	13.11	10.73
LSD (0.05)†	5.27	4.90	NS	NS
$s_{\bar{x}}$	1.79	1.67	1.51	1.14

† LSD = Least significant difference, $s_{\bar{x}}$ = standard error of the mean of the sample.

Table 4. Effect of dust concentration on cotton dark respiration, 1, 3, 7, and 14 days after dust application. Average of four plants.

Dust applied	Days after dust application 1	3	7	14
$\mu g\ m^{-2}$	$mg\ CO_2\ h^{-1}$			
0	4.00	4.98	3.26	5.56
10.8	3.98	5.27	4.40	4.71
15.2	6.82	6.69	4.38	4.39
16.5	7.16	6.52	2.84	4.52
22.1	5.34	4.82	4.37	5.64
28.6	5.36	4.88	3.05	4.35
38.5	8.21	8.11	4.34	4.34
51.1	10.44	9.77	4.94	4.99
Average	6.41	6.38	3.94	4.81
LSD (0.05)†	3.91	2.55	1.15	NS
$s_{\bar{x}}$	1.33	0.86	0.39	0.30

† LSD = Least significant difference, $s_{\bar{x}}$ = standard error of the mean of the samples.

Table 5. Regression equations and correlation coefficients of cotton plant dust concentration (*DT*) on dry weight (*DW*), photosynthesis (*P*), and dark respiration (*R*). Analysis of 128 observations.

Dependent variable	Regression equation	Correlation coefficient
P	$14.12 - 0.19\ DT$	−0.06
R	$3.69 + 1.02\ DT$	0.67
DW	$7.38 - 1.42\ DT$	−0.59

first and second sample dates. This weight loss reduced dry weight accumulation for 1 to 7 and 1 to 14 days after dust application (data not shown). The weight loss experienced soon after dust was applied (< 3 days) was not recovered by 2 weeks after application (Table 2), although dry weight accumulation after the third day was unaffected by dust concentration on the leaves.

Photosynthesis rates were significantly reduced when dust concentration on the leaves exceeded 28.2 $\mu g\ m^{-2}$ at day 1 and 28.9 $\mu g\ m^{-2}$ at day 3, but dust concentration had no effect on photosynthesis rates at later sample dates (Table 3). Dark respiration rates increased significantly when dust concentration on the leaves was greater than 28.2, 23.5, and 21.8 $\mu g\ m^{-2}$ at day 1, 3, and 7, respectively (Table 4). At day 14, dust concentration had no effect on dark respiration rates. Dust present on the plants was not related to photosynthesis rates, as indicated by the low correlation coefficient ($r = -0.06$), and was well related to dark respiration rates ($r = 0.67$) (Table 5).

DISCUSSION

Dust particles deposited on cotton leaves reduced dry weight by altering plant physiology. This alteration involved a reduction in photosynthesis (Table 3) and an increase in respiration (Table 4), which reduced the amount of photosynthate available for plant growth 1 to 3 days after dust was deposited. The rate of growth returned to normal (Table 2) after that time (1–3 days after dust was deposited), but the initial loss of photosynthate production was not recovered and was still evident in the lower total dry weight at the end of 2 weeks (Table 2).

The decrease in net photosynthesis rates soon after dust application may have been caused by blocking of the stomata on the top leaf surface or the amount of radiation available for photosynthesis due to the absorption or reflection of the dust coatings. Photosynthesis rates returned to normal as new leaves appeared and coated leaves expanded, reducing the concentration on the dusted leaves.

Increased absorption of radiation by the dust could raise plant leaf temperature and thereby increase photorespiration. Road dust raised leaf temperatures 2 to 4 °C (7). Leaf temperature increases of 2 to 3 °C caused greater increases in photorespiration relative to photosynthesis for soybean (*Glycine max* (L.) Merr.) (12, 13) and spinach (*Spinacia oleracea* L.) (11). The importance of photorespiration would decrease with time as more new leaves emerged and expanded, shading the lower dust-coated leaves and reducing their temperature.

The results of this study show that dust deposits of the size suspended by wind erosion events can reduce cotton plant weight for up to 2 weeks when deposited on leaves in sufficient concentrations (> 28.6 $\mu g\ m^{-2}$) over a short interval of time. However, when simulated fallout particles (0.044–0.177 mm) labeled with ^{137}Cs were deposited on meadow grasses, the retention time of the particles on the leaf surface was short (5, 15). Loss of particles due to wind was 46% in 2.5 days and 90% due to wind and rain in 1 week. Maximum retention time for the larger particles (0.088–0.77 mm) was 10 days (5).

The rapid removal by wind and rain of dust deposited on plant leaves, low natural deposition rates (1.5 $\mu g\ m^{-2}$) (16), and the short time reduction in dry weight accumulation (< 3 days) would seem to indicate that dust deposited on plant leaves would not be a major problem to cotton production under normal growing conditions.

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