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The Influence of Dust on Physiological Responses of Sweet Potato (*Ipomoea batatas*) Leaves

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ABSTRACT

An increase in quarrying, mining and road traffic activities have resulted in dust deposition onto plant vegetation. This study was conducted to evaluate the physiological responses of sweet potato leaves to dust pollution. Four kinds of soil dust (namely, clay, silt, sand and carbon-black), which were different in particle size but all with pH values around 7.0, were applied to upper surface of sweet potato leaves at various density. The results revealed that the small dust particles caused stomata closure, water loss and net photosynthetic rate decline. Even though, carbon-black and clay particles were similar diameter, physiological responses to these two types of particles were significantly different, which suggesting that other parameters other than particle size are critical for the observed difference in physiological responses. It appeared that the additional absorption of incident radiation by the carbon-black had consequently changed the photosynthetic rate.

Key words: Dust, *Ipomoea batatas*, Leaf temperature, Stomatal conductance, CO_2 exchange rate.

粉塵對甘藷葉生理反應之影響

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摘　要：本試驗主要探討甘藷葉片受粉塵污染後之生理反應。利用4種酸鹼值皆接近中性，但粒徑大小不同之土壤(黏土、坋土、砂土及碳粉) 爲處理材料，將不同濃度粉塵塗抹於甘藷葉片的上表皮，觀測對葉片的傷害情形。結果顯示，粒徑小之粉塵顆粒可引起氣孔的關閉、脫水及二氧化碳交換速率下降。雖然碳粉和黏土兩者粒徑相近，但生理反應則顯著不同。顯示除了粉塵顆粒大小之外，其他因素對生理反應亦有重要影響。

關鍵詞：粉塵、甘藷、葉溫、氣孔導度、二氧化碳交換速率。

Introcduction

Dust consists of solid fine particles which are small enough to be raised up and carried away by wind. They may be originated from various sources. For example, an increase in mining activities to meet an increased demand of construction materials and an increase in highway traffic activities are all potential sources of dust particles in

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A number of characteristics of dust are important in considering its impacts in plants. Dust particles could induce both physical and chemical impact on plants. Dust falling onto plants may physically smother the leaves. In this aspect, the absolute level of dust deposition may be important. This is affected by dust emission rates, meteorology and the micro-environment of leaf surface. Dust can also physically block stomata (Risks and William, 1974), increase leaf temperature (Eller, 1977; Fluckiger et al., 1978) and transpiration (Eveling, 1969). From a chemical point of view dust particles have been found to reduce photosynthesis (Darley, 1966; Hirano et al, 1990; Hirano et al, 1995), remove cultivar wax (Eveling and Bataille, 1984) and increase the uptake of gaseous pollutants (Risks and William, 1974), although the exact mechanism for these detrimental effects are still not clear.

Some of the early experiments on commercial crops were conducted by using chemically inert dusts such as silica gel. However, various sources of dust particles might have different, effects on plants. Thus, the results from artificial dusts of silica gel may not be representing the effects of other dusts, such as fertilizer, cement, lime or ashes. In this study, we investigated the effects of dust particles on physiological responses of sweet potato plants.

Materials and Methods

Twenty centimeter stem cutting of sweet potato (*Ipomoeas batatas* L. cv. Tainung 57) were grown in plastic pots (18cm in diameter, 25 cm in depth) filled with 2L of loamy soil. Fertilizer containing N, P, and K was applied to the soil at a rate of 80:100:100 kg ha^{-1} as $N:P_2O_5:K_2O$ prior to plantation. Those plants were then grown in a greenhouse.

Four types of soil dust particles (clay, silt, sand and carbon-black) were washed in distilled water to remove chemical impurities and then dried. They were different in particle size, and the pH values range from 6.7 to 7.0 (Table 1) Weighted quantities of dust (from 1 to 7 gm^{-2}) were applied to leaves of measured area with a fine brush, control leaves were also brushed but without applying dust.

To determine the rate of net photosynthesis, the aerial parts of a plant, including leaves and petioles, were placed in an forced air mixing plant assimilation chamber (14 cm in length, 10 cm in width and 8 cm in height) 14 days after dusting treatments. Photosynthesis rate was measured under 1100 $\mu mol\ m^{-2}\ s^{-1}$ PPFD. The light was filtered through a layer of heat absorbing water and a glass filter placed between the illumination system and the chamber. Single leaf CO_2 exchange rate (CER) was determined on fully expanded leaves using a CO_2 analyzer (IRGA) (LI-6252, LI-COR, Lincoln, Nebraska, U.S.A) and flow control (LI-670). The air flow rate was 6 L min^{-1}. Each photosynthesis measurement took about 10-20 min to ensure a steady rate. Stomatal conductance was measured on a fully developed leaf with a steady-state porometer (Model LI-1600, LI-COR, Lincoln, Nebraska, U.S.A).

Photosynthetically active radiation (PAR) was measured with a quantum sensor (model QS, Delta T, Cambridge, U.K.). These sensors were mounted approximately 2m

Table 1. Characteristics of dust particles.

Kind	Diameter (mm)	Color	pH
Clay	<0.02	yellow	6.8
Silt	0.02-0.05	yellow	7.0
Sand	>0.05	yellow	6.7
Carbon-black	<0.02	black	6.8

*pH was measured by dust solution (0.5g dust dissolved in 10 ml H_2O).

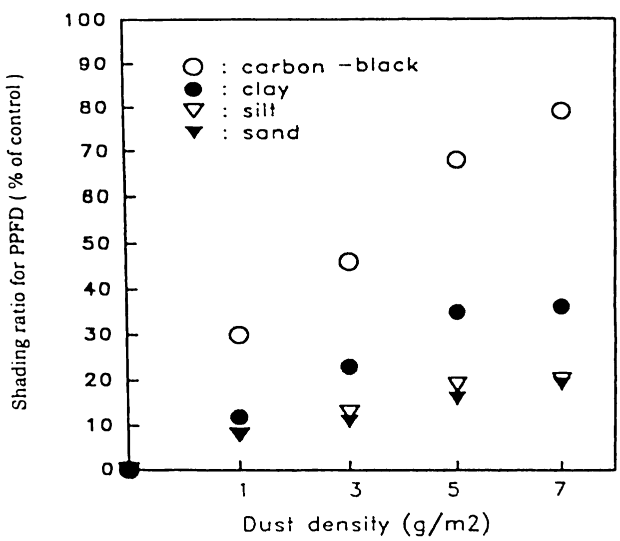

Fig.1. Relation between shading ratio for PPFD of dust and dust density.

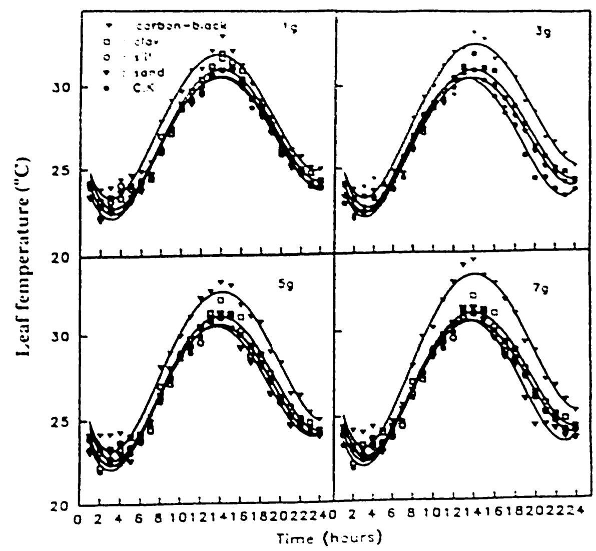

Fig. 2. Daily leaf temperature in plants 14 days after had been treated with four kinds of dust particles.

above the benches holding the pots. In order to evaluate the shading properties of dusted leaves, QS quantum sensor was placed on the underside of treatmented leaves, to detect the extent of the incident light transmission through the surface. Air temperature and relative humidity (RH) were measured with a Delta T model RHA1 probe mounted under a reflective surface approximately 0.5 m above the plant canopy. Leaf temperature was measured with a 0.1mm diameter Cu-Cn thermocouple placed on the underside of two, fully expanded leaves. which were fully exposed to sun. Leaf temperature, RH and other environmental parameters were monitored continuously during the experiment. All measurements were collected with an electronic data acquisition system (Delta-T Data Logger). Input channels were scanned at 30 sec intervals and the average or totals were calculated and stored every 15 min.

Fresh weight (Wf) was measured immediately after the leaf tissue was collected and the fully turgid fresh weight (Wt) was measured after the leaf tissue had been brought to fully turgor by floating the cut leaves in water for 2 hours. The dry weight (Wd) was determined by drying the leaf

Table 2. Changes of relative water content (RWC) in sweet potato leaves after dust treatments.

Treatment	Dust density (g m^{-2}) 1	3	5	7
Control	94.4 ± 3.5	93.4 ± 5.1	93.1 ± 2.2	94.6 ± 3.4
Clay	93.5 ± 4.5	92.3 ± 3.1	91.6 ± 4.1	90.7 ± 5.6
Silt	93.6 ± 3.6	92.8 ± 3.6	94.1 ± 5.4	92.6 ± 3.6
Sand	90.6 ± 5.7	93.2 ± 2.7	93.0 ± 3.7	92.3 ± 4.2
Carbon-black	90.6 ± 5.1	88.1 ± 3.2	85.0 ± 4.5	80.1 ± 3.3

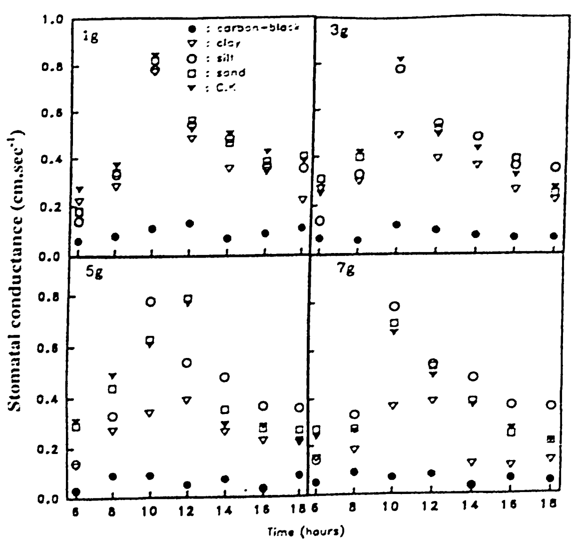

Fig. 3. Effects of dust on leaf stomatal conductance 14 days after the plant had been treated with four kinds of dust particles.

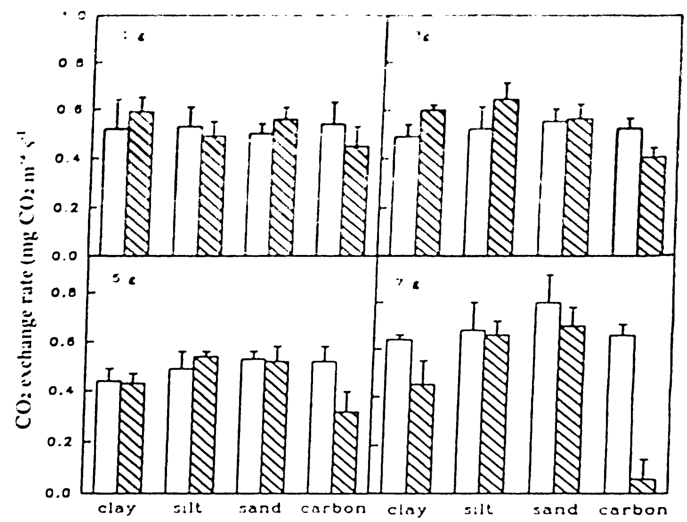

Fig. 4. Effects of dust on single leaf CO_2 exchange rate (CER) after the plant had been treated with four kinds of dust particles for 14 days. Vertical bars indicate standard error. □:before dusting, ▨:after dusting.

samples at 100 ℃ until the weight no longer decreased. Relative water content (RWC) is expressed as follow :

$$RWC\ (\%) = 100 \times (Wf - Wd)/(Wt - Wd)$$

Chlorophyll content was measured on sub-samples of fully expanded leaves collected from the upper half of four plants per treatment. Six discs of 1.0 cm in diameter were taken from interveinal region of leaves. The chlorophyll content was determined followed the method of Arnon (1949) .

Results and Discussion

(1) Light interception by dusts

Surface area is the characteristic most affected by the small size and fine subdivision of different soil texture. A grain of fine clay has about 10,000 times as much surface area as the same weight of medium-sized sand. The specific surface (area per unit weight) of clay ranges from about 10 to 1000 square meters per gram. Since the difference of leaf surface light absorption is a surface phenomena, Fig.1 compares the transmission of light through given densities of dust. For example, in 7 gm^{-2} treatment, the relative shading ratio of carbon-black was 79.4% of the control. Thus, the reduction in transmission for PPFD was associated with an increase in dust weight. Shading ratio were higher for clay than those for silt and sand, however, there were no difference between silt and sand.

(2) Leaf temperature

Higher leaf temperature, were detected in leaves received carbon-black treatment than those leaves treated with other soil particles. The temperature of leaves covered with carbon-black was higher than control leaves by 1.4-4.2 ℃ in the air temperature range between 20 and 35 ℃. This effect probably resulted from its light-shading properties. An additional absorption of incident radiation by the carbon-black treatment was found. For other dust particles with light-color, there were no significant changes in leaf temperatures. Increased leaf temperatures come with increasing densities of carbon-black. Leaf or foliage temperature measurements have been utilized to characterize crop plants response to the environments (Idso, 1982). The difference between leaf temperature and ambient air temperature has also been used as an indicator of crop water stress. Jackson et al. (1981) indicated that the temperature difference between well watered plants and the ambient air is affected by the gradient in water vapor pressure between the leaf and the atmosphere. As shown in Table 2, the relative water content was reduced when exposed to carbon-black in 5 and 7 gm^{-2} densities. On the other hand, leaves which were dusted with other three kinds of soil particles, there were no change in water loss. Therefore, the reduction in relative water content was very likely caused by an increase in leaf temperature after exposure to carbon-black.

(3) Stomatal conductance

It is generally observed that most plant species have stomata on both leaf surfaces. The two surfaces also vary consider ably in their response to light intensity. Frequently, the stomata on the abaxial epidermis are more sensitive to light than those on the adaxial surface. This is also true in sweet potato leaves, ie. stomata are present on both the upper and the lower leaf surface, but are more numerous on the lower surface. Stomatal density for adaxial surface for sweet potato leaves was 87.0 mm^{-2} (Bhagsari and Harmon, 1982). In this study, dust was applied only to the adaxial leaf surface. It was reported that plants of many species were contaminated by dust not only on the adaxial leaf surface but also on the abaxial surface (Pyatt, 1973). However, the dust load on the abaxial surface is usually smaller than that on the adaxial surface. For clay treatment in our study, stomatal conductance declined slowly and was coincided with an increase in the density of dust particles. Regardless of dust density used in this experiment (Fig. 3), stomatal conductance was nearly zero by carbon-black treatments, whereas sand particle had no effect on conductance. There was a decline but not significant decrease in silt treatments as compared to control leaf. The results of these experiments showed that only the dust particles with small diameter could cause a decrease in stomatal conductance.

The opening and closing of the stomata are tightly regulated by mechanisms which are

Table 3. Changes of chlorophyll content (mg m^{-2}) in sweet potato leaves after dust treatments.

	Dust density (gm^{-2})			
Treatment	1	3	5	7
Control	920.2 ± 24.5	921.6 ± 30.5	908.7 ± 21.6	913.6 ± 18.9
Clay	918.7 ± 20.6	908.6 ± 30.0	896.7 ± 20.6	876.3 ± 21.6
Silt	920.1 ± 17.6	917.1 ± 21.1	900.6 ± 17.8	892.6 ± 17.7
Sand	940.2 ± 16.7	930.5 ± 25.5	916.6 ± 19.3	902.7 ± 22.3
Carbon-black	890.1 ± 15.3	830.6 ± 18.6	784.3 ± 20.6	730.4 ± 18.6

highly sensitive to all environment changes. The effects of dust treatments on stomata conductance may occur via many pathways. Risk and Williams (1974) found that coal dust blocked stomata and reduced diffusive resistance in leaves of *Quercus petraea*. However, dust particles accumulated on the surface of the guard cell may stimulate the mechanism regulating the opening and closing of the stomata (Krajickova and Mejstrik, 1984). In our study, carbon-black and clay particles have similar diameter. However, their effects on stomatal conductance, leaf temperature and relative water content were significantly different. Thus, there were something other than the diameter of the dust particles may be responsible for those differences. In fact, application of dust may cause cells to plasmolyzed (Farmer, 1993). Sung (1985) indicate that sweet potato leaves were capable of turgor maintenance depending upon the stress intensity imposed. If the stress progressed and the leaf water potential dropped below -0.80 MPa, the sweet potato leaf would ultimately lose turgor and consequently resulted in a stomatal closure. It appeared that mechanical and water potential factors were responsible for the decreased exchange of gases in dusted leaves, but the phenomenon needs further detailed study.

Chlorophyll contents of dust treated plants were shown in Table 3. An slight increase in the chlorophyll content was noted for leaves treated with sand at 1 and 3 gm^{-2} densities. However, at other treatments, the chlorophyll content decreased in all dusted plants, indicating a shading effect which might reduce chlorophyll contents. The most significant reduction in chlorophyll contents was caused by carbon-black accompanied by a significant increase in leaf temperature. In some case, an increase in leaf temperature may reduce chlorophyll synthesis (Singh and Rao, 1981).

(4) Photosynthesis

All plants are dependent on the diffusion of carbon dioxide, entering through either the stomata or the cuticle and passing across the boundary layer of the leaf, for photosynthesis. If the stomata are closed as the consequence of dust particle coverage, both gas diffusion and water vapor diffusion become severely restricted. In our study, the CO_2 exchange rate (CER) of the sweet potato leaves during and after exposure to dust for 14 days are shown in Fig 3. In carbon-black treatment, the CER began to decrease at about 3 gm^{-2} density. In leaves which were exposed to 7 gm^{-2}. Carbon-black CER rate was reduced to 75% of the control leaves value at the end of experiment period. In leaves treated with clay dust, the CER began to decrease at about 5 gm^{-2}

application rate. In leaves treated with silt and sand dust, on the other hand, there was only a slight reduction in CER at the highest application rate of 7gm^{-2}. McPherson et al.(1983) measured maize leaf temperature and CER. Their results suggest that the photosynthetic rates were not affected by the increase of leaf temperature. Garrity et al. (1984) also reported that CER was not affected by changes in the leaf temperature. It is thus likely that our observation of a reduced photosynthesis rate in leaves treated with dust particles was not caused by an increased leaf temperature. With a few exceptions, most dust particles are relatively inert and harmless, but might become harmful if their concentration become too high. Under an extremly high dust particle density, it may cause stomatal closure or smother the leaf. The consequence is either a partial or a completely leaf restriction of the gas exchange, which in turn may cause a reduction in photosynthesis and the growth of a crop plant.

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