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The Effect of Foliar Application of Fulvic Acid on Water Use, Nutrient Uptake and Yield in Wheat

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Abstract

The effect of foliar application of fulvic acid (FA) on water use, nutrient uptake and yield in wheat was studied in pot experiments and in field trials.

FA reduced the stomatal conductance of well-watered plants in pots from ~0·80 to ~0·25 cm s^{-1}. The stomatal conductance of control plants fell continuously from ~0·85 m s^{-1} to almost zero over a 9-day drying cycle. Plants sprayed with FA at the beginning of the cycle maintained a stomatal conductance of ~0·30 cm s^{-1} for the whole period. Spraying with FA resulted in a higher level of chlorophyll in the leaves and a greater uptake of ^{32}P by the roots. When droughted at ear-development stage, grain yield was depressed by 30%. Spraying with FA increased the yield of droughted plants to 97% of the irrigated controls.

Field trials in North China demonstrated that when FA was used to decrease the water stress or the stress imposed by hot, dry winds during ear development, grain yield increased by 7·3–18·0%.

Introduction

In North China spring drought usually arises at the critical ear development stage of wheat plants and, in addition, hot dry winds occur during grain filling. These events can severely reduce wheat production in the area. The possibility that applied chemicals could improve drought resistance has been investigated both in glasshouse conditions and in the field since 1979. The results of the work carried out with fulvic acid (FA) are reported in the present paper.

Materials and Methods

Pot Experiments

Pot experiments were carried out in a shade house which was protected against rain by a polyethylene sheet suspended 3 m above the ground. Wheat plants of the variety Zheng Yin-1 were grown in 150 mm pots filled with soil. Whenever the soil moisture fell to 13–15%, water was applied through a perforated plastic tube inserted obliquely into the soil until the content reached 30%. The soil surface was cultivated to decrease evaporation. The plants were grown until the mainstems were close to meiosis stage, judged as the time when the apices of flag leaves were 20 mm below the ligules of the enclosing leaves.

In the first experiment two treatments were imposed:

1. Irrigated every 2 days.
2. Same as (1), sprayed once with 0·05% FA.

In the second experiment the soil water content was adjusted to 18% and the following treatments imposed:

1. Irrigated every 2 days.
2. No irrigation for 9 days.
3. Same as (2), sprayed once with 0·01% fulvic acid.
4. Same as (2), sprayed once with 0·05% fulvic acid.

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At the end of the 9-day drought period all treatments were irrigated and managed in the same way until harvest. The experiment was repeated in 2 years with similar results. The results from one year are presented here.

The pots were weighed every day to determine the evapotranspiration rate. The stomatal conductance was measured early in the morning with a transient porometer (LI-700). Water potential was measured on fully expanded leaves which were cut off and placed immediately in a pressure bomb. The stomatal aperture was measured 2 days after the beginning of the droughting treatment by the impression method. The uptake of phosphorus by the root system was estimated by applying 250 ml of nutrient containing 0·35 μC of ^{32}P to each of five pots. The plants were harvested 24 h later, ground and aliquots of the powder were counted in an autocounter, type JDC-152.

Wind-Tunnel Experiment

Wheat plants of the variety Zheng Yin-1 were grown in pots as for the previous experiment. FA was sprayed on the plants at early grain-filling stage. After 2 weeks the plants were placed in a wind tunnel and subjected to a wind of 3·8 m s^{-1} at a temperature of 32–34°C with a relative humidity of 30% for 1 day. At the end of the day measurements of relative water content, chlorophyll content and evapotranspiration were made.

Fulvic Acid (FA)

Fulvic acid was prepared by the Henan Institute of Chemistry. Weathered coal was extracted with 1 M HCl and purified by passing the extract through cation exchange resin columns. The elemental composition was C, 55·8%; H, 1·8%; O, 40·9%; N, 1·2%; S, 0·3%. The distribution of oxygen containing functional groups in the FA (m.e.) was as follows: total acidity, 9·4; COOH, 8·45; OH, 0·95; C=O, 2·24; C–OCH_3, 0·0023.

Field Experiments

In 1982 field experiments were carried out at 27 sites in Henan Province. Seed was sown at the rate of 120 kg ha^{-1} between the beginning of October and mid-November 1981. The soil preparation, fertiliser application and wheat varieties used were representative of those used in the province. FA was sprayed at boot stage (5–15 April) or early grain-filling stage (5–10 May 1982) at a rate of 600 g ha^{-1} at a concentration of 0·4%. The FA spray was applied at a higher concentration in the field than in the pot experiments to reduce the volume of water which had to be transported.

Results

Pot Experiments

Stomatal conductance and transpiration

The foliar application of FA to irrigated plants caused partial closure of the stomata, and the FA treatment had a lower stomatal conductance than the unsprayed control for a period of 13 days (Fig. 1). Two days after treatment the stomatal aperture of the sprayed plants was 0·6 μm compared with 2·2 μm for the control.

When plants were sprayed at the beginning of a 9-day drought period, the stomatal conductance initially fell below that of the droughted control and a steady level of between 0·2 and 0·4 cm s^{-1} was maintained over the period (Fig. 2). In the control plants the stomatal conductance fell steadily as the plants dried, and by day 5 it was lower than that of the sprayed plants. At the end of the 9-day drying cycle, the leaves of plants, which had been sprayed with FA, had a higher relative water content and a higher water potential than the droughted controls (Table 1).

Chlorophyll Content of the Leaves

The leaves of wheat plants that had been under the drought treatment became yellow. Spraying with FA alleviated or prevented the yellowing, as evidenced by the chlorophyll analysis of flag leaves collected at the end of the 9-day period (Fig. 3).

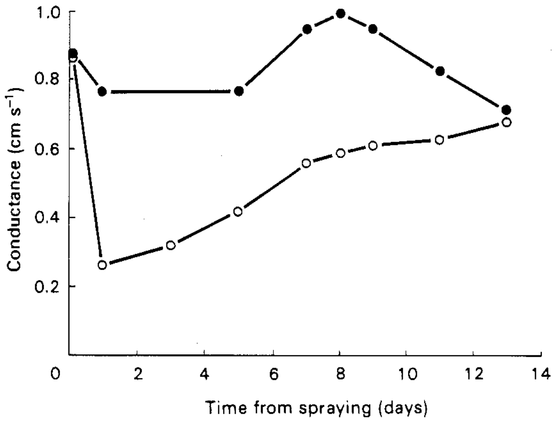

Fig. 1. The stomatal conductance of irrigated wheat plants with time from spraying: ● control; ○ sprayed with 0·05% FA.

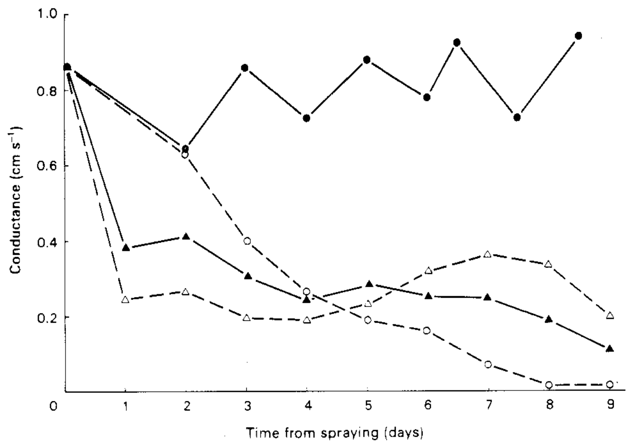

Fig. 2. The stomatal conductance of wheat plants sprayed at the beginning of a 9-day drying cycle. ● Irrigated control; ○ droughted control; ▲ droughted and sprayed with 0·01% FA; △ droughted and sprayed with 0·05% FA.

Table 1. Effect of spraying FA on the water status of wheat leaves at the end of a 9-day drought period

	Relative water content of leaves (%)	Water potential of leaves (bar)
Drought control	64·9	−15
Drought + FA (0·05)%	70·6	−11
Irrigated	79·8	−8

The effect persisted for a relatively long time period, and both leaf water content and chlorophyll content were higher in the sprayed plants than the drought controls at the middle of the grain filling stage.

Uptake of ^{32}P by the Roots

The total amount of ^{32}P taken up by the plants after 48 h was greater for the sprayed plants than for the droughted treatment, the differences being more pronounced in the older leaves (Table 2).

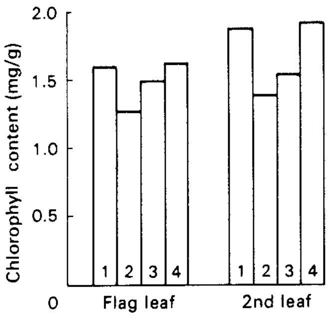

Fig. 3. Chlorophyll content of wheat leaves sprayed with FA, measured 9 days after the commencement of drought. 1, Irrigated control; 2, droughted control; 3, droughted and sprayed with 0·01% FA; 4, droughted and sprayed with 0·05% FA.

Table 2. Effect of spraying FA on the absorption of ^{32}P by the roots of droughted wheat plants
Unit: disintegrations per min (dpm)

	Ear	Stem	Flag leaf	2nd leaf	3rd leaf	Total	Per cent
Control	7514	6879	1203	954	173	16723	100·0
FA (0·01%)	9804	6779	1150	1103	313	19149	114·5
FA (0·05%)	9076	10366	1800	1474	827	23543	140·8

Yield Components

Droughting at the critical developmental stage reduced the yield per pot by 30% (Table 3). Ear number was susbtantially reduced, while there was a marginal reduction in grain number per ear which was partially offset by an increase in 1000 grain weight. Spraying droughted plants with 0·05% FA increased the yield per pot to 97% of the irrigated controls by increasing the number of ears per pot and the number of grains per ear.

Table 3. Effect of spraying FA on grain yield of pot-culture wheat plants

Treatment	Ear Height (cm)	Ear Length (cm)	No. of ears per pot	No. of spikelets per ear	Percentage of fertile spikelets	No. of grains per ear	1000 grain weight	Yield (g per pot)	Yield (%)
Irrigated	69·5	9·4	13·0	17·8	78·1	33·7	34·2	15·0	100
Drought control	66·5	9·7	8·8	18·0	68·4	31·6	37·9	10·5	70
Drought + FA (0·01%)	66·9	9·7	9·2	17·8	74·3	36·9	40·3	13·6	90
Drought + FA (0·05%)	66·3	10·0	9·2	18·8	76·5	40·9	38·9	14·5	97

The number of grains per spikelet for each spikelet position on the mainstem ear is shown in Fig. 4 for the four treatments. The difference between the seed numbers per ear was much greater for mainstem ears than for the average of all ears in the pot.

Effect of Spraying FA on Resistance to Hot-dry Wind

Spraying with FA increased the resistance to hot-dry winds. The flag leaves of sprayed plants had higher water and chlorophyll contents than unsprayed plants (Table 4). Damage to the leaves of unsprayed plants resulted in a drop in evapotranspiration, while a high rate was maintained in the leaves of the sprayed plants.

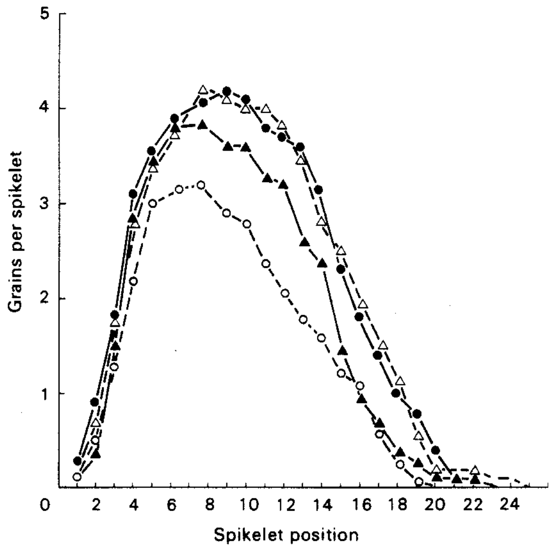

Fig. 4. The distribution of seed in the mainstem ears of plants undergoing four treatments. ● Irrigated control; ○ droughted control; ▲ droughted and sprayed with 0·01% FA; △ droughted and sprayed with 0·05% FA.

^{32}P was applied to the pots after the hot dry wind treatment, and the levels of activity in the plant parts were measured 48 h later. The radioactivity in the ears of FA-treated plants was 20 times greater than that in the unsprayed control, although the difference in the stem was slight, indicating that the difference in transport of ^{32}P into the ears was very great (Table 5).

Table 4. Influence of spraying FA on some of the physiological characteristics in plants subjected to simulated hot-dry wind

	Relative water content of flag leaves (%)	Chloride content (mg/g dry weight)	Evapo-transpiration rate (pot^{-1} day^{-1})
Drought			
control	67·2	0·45	249
FA (0·05%)	70·2	0·53	279

Application of FA in the Field

Encouraged by the results of the pot experiments, field experiments were carried out at different places in Henan Province. The spring drought and hot-dry wind were more serious in 1982 than usual. The average rainfall in the province during the growing season was 11 mm, which was only 21% of the long-term mean. The pan evaporation ranged from 184 to 240 mm at the various sites.

The application of FA increased grain yield under all conditions (Table 6), but the effect was greater when sprayed at boot stage than when sprayed at early grain-filling stage. The increase persisted over plots with widely different yield levels, but it was higher on a percentage basis on plots which had a lower yield level.

Table 5. The effect of spraying FA on the uptake of ^{32}P by plants exposed to 1 day of hot-dry wind
Unit: dpm

	Ear	Flag	Flag-1	Flag-2	Stem	Total	Per cent
Control	302	720	1168	276	19170	21636	100
FA (0·05%)	7730	3865	947	755	21532	34829	161

It is interesting to note that very strong hot-dry winds prevailed over the period 21–25 May 1982, with the temperature at midday reaching 38°C. The ears and flag leaves of control plants turned yellow and became dry, whereas those in FA-treated plots remained quite green. The difference in yield between FA-treated and control plants could easily be accounted for by the mitigation of senescence by FA spraying.

Table 6. The effect of spraying FA (0·04%) on the yield of wheat in the field at a range of sites having different yield potentials

Yield level (kg/ha)	Sprayed at boot stage: Number of exp. sites[A]	Average seed yield (t/ha): CK	FA	% of control	Sprayed at early grain-filling stage: Number of exp. sites	Average seed yield (t/ha): CK	FA	% of control
<1500	5	1·08	1·27	118	4	1·22	1·36	112
1500–3000	8	2·33	2·68	115	4	2·52	2·82	112
3000–4500	6	3·84	4·23	110	7	3·89	4·24	109
>4500	6	5·76	6·30	109	6	6·07	6·51	107

[A] The plot area was 33·3 m^2; the replication was 3 or 4 at each site.

In 1983 and 1984 FA spraying was carried out on about 30 000 ha. In 1983, in which there was neither a spring drought or hot-dry wind, the application of FA increased the yield by 6·8%. In 1984 there was a slight spring drought, but no hot-dry wind and the spraying of FA increased yield by 8·7%.

Discussion

Agronomists and plant physiologists agree that there is a particular stage of development of the wheat plant which is very sensitive to water stress. Drought at this stage causes the destruction of the flowers and the developing pollen, so that the seed number per ear is reduced (Bierhuizen 1976; Morgan 1980). Droughting at the sensitive stage caused a decrease of 30% in grain yield in the pot experiment.

Foliar application of FA improved the drought resistance of wheat, and this was associated with partial closure of the stomata, which reduced transpiration loss and raised the water potential during the period of flower development. FA also slowed down leaf senescence, and leaf function was maintained for a longer period. During exposure to hot-dry winds, the evapotranspiration rate of sprayed plants was higher than that of the unsprayed control. This seemed to be due to reduction in function of the leaves of control plants which were obviously damaged. Spraying with FA enhanced root activity, and there was an increase in ion uptake. FA application also resulted in the maintenance of a high rate of transport of phosphorus to the grains, which presumably was accompanied by a high rate of transport of organic substances.

That stomatal conductance and transpiration could be decreased by humic substances has been reported recently (Molho *et al.* 1981; Mei and Yang 1983), but previous experiments were not carried out on intact plants or used in crop production, nor had the possibility that FA spraying might enhance the activity of roots been investigated systematically.

Hot-dry wind during flower development is a danger to wheat production in China, U.S.A., Australia and other arid countries. In our experiments with a hot-dry wind simulator, the wheat plants which were sprayed with FA maintained a higher water and chlorophyll content than the control and root absorption rate was higher. The loss of grain number due to hot-dry winds at booting can be reduced by spraying with FA.

Since the discovery of the antitranspirant effect of phenylmercuric acetate (Zelitch 1961; Zelitch and Waggoner 1962), many studies have been carried out to find the ideal antitranspirant (Gale and Hagan 1966; Zelitch 1969; Davenport and Hagan 1975; Davenport 1977; De 1978; Das and Raghavendra 1979). Some advances have been made, but antitranspirants have not been applied on a large scale to field-grown crops (National Academy of Science USA 1974; Das and Raghavendra 1979; Kramer and Kozlowski 1979; Agepati 1981; Xu 1983). Compared with the other chemicals used, FA is very cheap and non-toxic, and no pollution problems will be caused by its extensive use. As FA has been shown to improve yield under a range of climatic conditions, it should have widespread application in field crop production. The mechanism of action of FA should be further investigated.

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