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Role of Thiourea in Improving Productivity of Wheat (*Triticum aestivum* L.)

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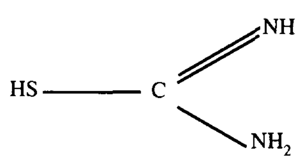
Abstract. The role of thiourea (TU), a sulfhydryl compound, was assessed in wheat via soil and foliar treatments. Results showed that at 30 days after flowering, soil-applied TU treatments did not influence dry matter accumulation or its distribution in leaves, stems, and ears, but foliar-applied treatments brought about significant effects varying with the timing of spray. At harvest, however, soil-applied treatment of 10 kg/ha TU increased the number of ears, grains/ear, weight/grain, biological yield (total above ground biomass), grain yield, and harvest index. Grain yield increased by 17.3% over control. Soil-applied 20 kg/ha TU increased the grain yield by 1.6% over control. Foliar applied treatment of 0.5 kg/ha TU at tillering increased the number of ears, grains/ear, weight/grain, biological yield, grain yield, and harvest index. Grain yield increased by 15.2% over control. Foliar spray of 0.5 kg/ha TU at flowering tended to improve only weight/grain, but biological yield and grain yield increased significantly. Grain yield increased by 6.6% over control. TU spray at both tillering and flowering increased the number of ears, grains/ear, weight/grain, biological yield, grain yield, and harvest index. Grain yield increased by 23.9% over control, and when compared with spray at tillering there was a significant increase of 7.5%. Thus, two foliar sprays of thiourea, at tillering and at flowering, at 1 kg/ha can be recommended for improving wheat productivity.

A key goal in crop physiology is whether economic yield can be increased through more efficient use of photosynthate available to the plant or whether more can be gained by improving net photosynthate supply of the plant to fulfill an already established, but unsatisfied, demand (Wardlaw 1980). There is good evidence in many crops that the demand for assimilates can directly influence net assimilation rate and translocation patterns (Wardlaw 1968). In cereals most of the carbohydrate in the grain results from photosynthesis after anthesis (Barnell 1936, Carr and Wardlaw 1965, Lupton 1966). Therefore, the photosynthetic capacity of the crop at anthesis and the duration of that capacity are of considerable importance. Photosynthesis up to anthesis affects kernel number. Storage capacity might continue to be affected by photosynthesis until 2–3 weeks after anthesis when the endosperm cell number is determined (Brocklehurst et al. 1978, Evans 1978, Fischer 1975).

Recently, Sahu et al. (1993) reported that foliar spray of thiourea (TU) significantly increased growth and yield of maize, most probably via improvement of the photosynthetic efficiency and canopy photosynthesis. TU $[CS(NH_2)_2]$ is a nonbiological thiol (Jocelyn 1972) having the following structural formula.



TU stimulates dark fixation of CO_2 in embryonic axes of chickpea (Hernandez-Nistal et al. 1983). Because of the -SH group, TU may play several bioregulatory roles in crop plants, as the -SH group has diverse biological activities (Jocelyn 1972). Involvement of -SH groups in phloem transport of sucrose has been suggested (Giaquinta 1976, Giaquinta 1977). Since the -SH group is essential at the substrate binding site of the amino acid carrier (McCor-

Abbreviations: TU, thiourea; DMA, dry matter accumulation; DMD, dry matter distribution.

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mick and Johnstone 1990), TU may also enhance formation of the ternary complex, sucrose-H^+-carrier, thus improving phloem loading of sucrose and hence translocation of photosynthate. TU is reported to exhibit cytokinin-like activity (Erez 1978, Vassilev and Mashev 1974). As cytokinins are well known for delaying leaf senescence (Osborne 1967; Paranjothy and Wareing 1971, Woolhouse 1974), TU may also increase the photosynthetically active leaf surface during grain filling in cereals.

In cereals the sink characteristics of the grain can limit the yield in many environmental situations (Bingham 1969). Wellbank et al. (1968) concluded that factors in addition to photosynthesis were important in determining grain yield, from the relationship of solar radiation and temperature to assimilation and yield over a period of years. They suggested that the translocation rate or the capacity of the grain to accept carbohydrates may be an important factor. The rate of the photosynthate translocation, in turn, influences the partitioning of dry matter between grain and vegetative parts of the plants. The partitioning of dry matter in the wheat plant depends on the distribution among leaves, stem, and ear before anthesis and on the relocation of the stem and leaf reserves after anthesis (Spiertz 1980). In this context the discovery that sulfhydryl compounds play a role in improving dry matter partitioning for grain production in maize (Sahu and Solanki 1991) is of considerable significance for improving crop productivity. In the present study, therefore, a sulfhydryl compound, TU, was tested with a view to improving the productivity of wheat.

Materials and Methods

The experiment consisted of three soil and four foliar treatments of TU. The three soil treatments (0, 10, and 20 kg/ha TU) were combined with three 0.5 kg/ha TU spray treatments (spray at tillering, at flowering, and at both tillering and flowering) in addition to a control without spray. Thus, 12 treatments (three soil × four foliar) were arranged in a factorial randomized complete block design with four replicates. TU at 10 and 20 kg/ha was applied in bands (in furrows opened with a manually operated tool, locally known as *Kudali*) at a depth of 8–10 cm, followed by 3–4 cm of soil layering, thus exposing about 5-cm-deep furrows for the sowing of wheat seeds. Wheat (var Lok-1) was sown in the winter season of 1988–1989 in microplots (2 × 2 m) on a site having calcareous clayloam soil of high fertility. The net harvested area was 1.7 m^2 (1.5 × 1.13 m), leaving guard strips in equal measure along both sides of the plot.

The total N content of the experimental soil was 0.084%, and the available P and K contents were, respectively, 21.5 and 456.5 kg/ha. The soil had 1.2% organic carbon, and the available sulfur content was 25 mg/kg, a level above the critical limit of 10–23 mg/kg (Tandon 1991). Available sulfur was measured by the method of Chesnin and Yien (1950) using $Ca(H_2PO_4)_2$ as the extractant. As per fertilizer recommendations for wheat growing in Rajasthan (India), 90 kg/ha N and 25.6 kg/ha P were applied to ensure optimum crop nutrition. A half-dose of N and the entire quantity of P, alone or mixed with TU as per treatments, were applied at sowing, using urea and diammonium phosphate fertilizer materials. The remaining 45 kg of N/ha was top dressed, using urea, at 45 days after sowing. Foliar sprays of TU were applied, using 1,000 L/ha spray solution, after mixing Teepol, a surfactant, at 0.5 ml/L. Spray, at tillering, was applied at 30 days after seedling emergence, and the spray at flowering was applied at 7 days after full flowering.

To evaluate the effects of TU treatments, dry matter accumulation (DMA) in leaves, stem, and ear was measured at 30 days after flowering. For this, plants in 1-m row length were harvested from each plot; and leaves, stems, and ears were separated for dry weight measurements. At harvest, number of ears/m row length, number of grains/ear, weight/grain (based on 1,000-grains weight), and biological and grain yields/m^2 area were recorded. Biological yield represents total above ground biomass (grain yield plus straw yield). From the data of DMA, dry matter distribution (DMD) among leaves, stem, and ear was calculated. DMD in leaves, stem, and ear denotes the percentage of the total DMA plant. Harvest index, a measure of dry matter partitioning to economic (grain) yield, was also computed by the formula as given by Singh and Stoskopf (1971).

$$\text{harvest index (\%)} = \frac{\text{economic yield}}{\text{biological yield}} \times 100$$

Results

It may be noted here that the interaction effects of the soil and foliar applied treatments were not found to be significant either for growth or yield data. Hence, only the main effects of these treatments are presented, the data having been averaged over soil application rates including control for foliar applied treatments or over foliar application rates and control for soil-applied treatments.

Results (Table 1) show that soil application of TU had no significant effect on DMA or DMD. On the other hand, the effects of foliar applied TU were significant. DMA by leaves showed significant reduction, whereas DMA by ear increased only under TU sprays at tillering and flowering as compared with control. No effect was observed on DMA by stem as well as total DMA/plant. Further, TU spray treatments reduced DMD to leaves but increased DMD to ear; thus DMD to stem was unaltered in comparison with that under control.

Soil application of TU at 10 kg/ha significantly increased all of the yield components: number of ears, number of grains/ear, and weight/grain (Table 2). However, TU at 20 kg/ha increased only the number of ears slightly over control, but as compared with TU at 10 kg/ha there was a significant reduction. TU at 10 kg/ha significantly increased grain yield by 17.5%, albeit at 20 kg/ha only marginally (1.6%). Biological yield increased signifi-

Table 1. Effect of thiourea soil application and foliar spray on dry matter accumulation and distribution in wheat plants at 30 days after flowering (average of four replicates).

Treatment	Dry matter accumulation (g/plant)				Dry matter distribution (%)		
	Leaves	Stem	Ear	Total	Leaves	Stem	Ear
Soil application							
(averaged over foliar rates and control)							
Control	3.8	5.8	3.8	13.5	28.5	43.0	28.5
TU (10 kg/ha)	3.8	5.6	3.9	13.4	28.3	41.8	29.9
TU (20 kg/ha)	3.8	5.8	3.8	13.5	28.1	42.8	29.1
S.E. ±	0.34	0.11	0.08	0.38	0.83	0.61	0.59
L.S.D. (0.05)	NS[a]	NS	NS	NS	NS	NS	NS
Foliar spray							
(averaged over soil rates and control)							
Control	4.0	5.7	3.8	13.6	29.2	42.2	28.6
TU at tillering (0.5 kg/ha)	3.8	5.7	3.9	13.5	27.9	42.3	29.9
TU at flowering (0.5 kg/ha)	3.8	5.7	3.8	13.4	28.5	42.6	28.8
TU at tillering and flowering (1.0 kg/ha)	3.7	5.7	4.0	13.4	27.6	42.4	29.9
S.E. ±	0.05	0.10	0.07	0.32	0.33	0.64	0.35
L.S.D. (0.05)	0.16	NS	0.20	NS	0.91	NS	0.91

[a] NS = F test not significant at 5% level of probability.

Table 2. Effect of thiourea soil application and foliar spray on yield components and yield of wheat (average of four replicates).

Treatment	Ears/m row length	Grains/ear	Weight/grain (mg)	Total above ground biomass (g/m^2)	Grain yield (g/m^2)	Harvest index (%)
Soil application						
(averaged over foliar rates and control)						
Control	116.8	31.0	39.0	860	399	45.1
TU (10 kg/ha)	128.8	34.9	41.8	1,007	469	46.6
TU (20 kg/ha)	120.3	32.3	40.9	883	406	46.9
S.E. ±	0.97	1.31	0.74	24	2	0.31
L.S.D. (0.05)	2.89	3.91	2.23	67	6	0.92
Foliar spray						
(averaged over soil rates and control)						
Control	116.8	30.2	38.1	829	381	46.0
TU at tillering (0.5 kg/ha)	121.6	34.1	41.1	933	439	46.7
TU at flowering (0.5 kg/ha)	117.0	30.1	40.4	887	406	45.9
TU at tillering and flowering (1.0 kg/ha)	123.0	36.6	42.6	1,010	472	46.7
S.E. ±	0.80	1.22	0.86	19	3	0.20
L.S.D. (0.05)	2.41	3.65	2.44	57	8	0.59

cantly by 17.1% under 10 kg/ha TU but not under 20 kg/ha TU. Harvest index, however, improved significantly under TU applied at both 10 and 20 kg/ha rates. Thus, whereas TU at 10 kg/ha had beneficial effects on the crop, 20 kg/ha applied TU proved largely ineffective possibly because of growth inhibitory effects.

Furthermore, foliar spray of TU at tillering significantly increased the number of ears, the number of grains/ear, and the weight/grain. Increases in biological and grain yields under this treatment were 12.5 and 15.2%, respectively. Improvement in harvest index, although marginal, was statistically significant. Although TU spray at flowering had no significant effect on yield components, there was an increasing trend in weight/grain as compared with control, although not over TU spray at tillering. Biological and grain yields increased significantly by 7.0 and 6.6%, respectively, because of TU spray at flowering (Table 2). Effects from TU sprayed at both tillering and flowering were similar to those of TU sprayed at tillering, but stronger; biological and grain yields increased by 21.8 and 23.9%, respectively, as compared with control. It may be further noted that when compared with TU spray at tillering alone, TU spray at both tillering and flowering increased the grain yield by 7.5%. Similarly, when compared with TU spray at flowering alone, TU spray at both tillering and flowering increased the grain yield by 16.3%. Two sprays of TU, totalling 1 kg/ha TU, proved more beneficial than one single spray, 0.5 kg/ha. Thus, soil and foliar treatments considered together, it is inferred that foliar spray of TU at both tillering and flowering, because of lower dose and hence lower cost, can be recommended for increasing the grain productivity of wheat.

Discussion

From the results of the present study, it appears generally assumable that the effects of TU on growth and yield of wheat are not attributable to the nutritional impact of N and S. In maize, foliar spray of 2 kg/ha TU increased the grain yield by 34.1%, whereas foliar spray of 2 kg/ha urea had no effect (Sahu and Solanki 1991). Thiourea contains 36.8% N and 42.1% S. Calculations reveal that in the present experiment the soil applications of 10 and 20 kg/ha TU, respectively, added nearly 4 and 8 kg/ha each of N and S, and the foliar sprays of 0.5 and 1.0 kg/ha TU supplied nearly 0.2 and 0.4 kg/ha each of N and S, respectively. It is interesting to note that 1.0 kg/ha TU foliar applied in two sprays increased the grain yield of wheat by 23.9%, whereas 10 kg/ha soil-applied TU increased the grain yield by 17.3% only, despite supplying tenfold N and S. More notably, 20 kg/ha soil-applied TU, which provided only about 8 kg each of N and S, exerted inhibitory effects, which supports the contention that the nutritional roles of N and S in TU were not strong enough to influence the growth and yield of wheat eventually, particularly when both N and S nutrition of the crop was optimum as ensured by fertilizer N addition and high available S status of the soil. In barley, seed soaking treatment of a substituted TU, *N*-methyl,*N'*-2-(6 methyl pyridyl) TU showed an increase in percentage germination and shoot and root elongation by 32–95% over controls at a 10 mg/L concentration (Uppal and Banerji 1985). Therefore, it may be safely concluded that in the present study the observed effects of TU are suggestive of a bioregulatory role due to its reactive sulfhydryl content (Erez 1978, Sahu and Solanki 1991, Sahu et al. 1993). Bokarev and Satarova (1957) had also concluded that the activity of TU in breaking the dormancy of potato tubers depends on its ability to isomerize to a form with a sulfhydryl group whose presence is necessary for an active compound.

Both soil and foliar treatments of TU increased the number of ears and grains/ear, indicating an improved storage capacity. In this context, it is noteworthy that dithiothreitol, a thiol containing two -SH groups, stimulated carbon dioxide assimilation in the dark up to fivefold (Werdan et al. 1975). Because of its cytokinin-like activity, TU might have also delayed leaf senescence (Halmann 1990). In maize, foliar spray of TU increased both canopy photosynthesis and photosynthetically active leaf surface during grain filling (Sahu et al. 1993). It is therefore conceivable that in the present experiment TU treatments might have improved either the photosynthetic capacity of the crop plants or the duration of that capacity.

Jenner and Rathjen (1972) reported that in wheat the flow rate of sucrose into the grain determines the rate at which carbohydrate can accumulate in the ear. Further, the transport of sucrose in the grains is restricted on the final stages of its passage into the endosperm of ripening wheat plants (Jenner 1970). In the present study, since individual grain weight showed significant improvement under soil and foliar treatments of TU, it may be speculated that there was enhanced metabolic transport of sucrose to grains via effects on phloem loading.

Mobilization of dry matter (reserves) from leaves to grains was observed under TU spray at tillering, for DMD to ear increased, and DMD to leaves decreased, without significant variations in total DMA/plant. Such a trend was apparent under 10 kg/ha soil-applied TU treatment also. Improvement in harvest index under TU treatments lends further credence to the role of TU in improving dry matter partitioning to grains (Sahu and Solanki 1991). Reduced grain yield with 20 kg/ha soil-applied TU compared with 10 kg/ha treatment might be attributed to inhibitory effects perhaps on phloem transport of sucrose, as herbicidal properties of a similar overdose of TU have also been observed (Uppal 1986).

This is the first report highlighting the role of TU as a thiol and a growth-regulating chemical for improving the productivity of field-grown wheat. It is interesting to quote here that TU has been detected in at least one plant seed, *Laburnum* sp., and therefore it may be considered as a naturally occurring substance (Klein and Farkass 1930). TU has also been shown to affect hormonal activities in animals and to have antithyroid activity (Poljakoff-Mayber and Mayer 1960). Together with these earlier reports, the results of the present study strongly indicate a further need for conducting elaborate experiments, testing several rates, methods, and timings of TU application to refine this agrobiotechnology for wheat. Studies at the cellular and molecular level are necessary as well to pinpoint the site(s) of action of this novel bioregulator.

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