Effects of Foliar Methanol Applications on Crop Yield

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ABSTRACT

Recent reports indicate that vegetative growth and yield of C_3 crops are enhanced by foliar methanol application and that overall crop water use was reduced by methanol sprays. It has been suggested that methanol may act as a C source for the plant and a photorespiration inhibitor. Field experiments were conducted near Pendleton, OR, during 1993 and 1994 to determine if foliar methanol applications would increase crop growth and yield in the dryland agroecosystems common to the Pacific Northwest. Methanol solutions (200 or 400 mL L^{-1} with a surfactant) were applied to winter wheat (*Triticum aestivum* L.), spring wheat, spring barley (*Hordeum vulgare* L.) and pea (*Pisum sativum* L.) at several plant growth stages. Phytotoxic symptoms were observed only with the highest concentration of methanol. No significant response, either beneficial or detrimental, to methanol application was found in any crop. No differences were found in stomatal conductance or leaf specific weight between any methanol treatment and the controls. Methanol applications did not significantly increase crop growth or yield. We concluded that methanol applications will not benefit grain and pea production in the northwestern USA.

FOLIAR APPLICATIONS of aqueous methanol have been reported to increase yield, accelerate maturity, and reduced drought stress and irrigation requirements in crops grown in arid environments, under elevated temperatures, and in direct sunlight (Nonomura and Benson, 1992c). Spraying C_3 plants with 100 to 500 ml L^{-1} methanol solutions doubled plant growth and crop yield in several species. Durum wheat (*Triticum durum* Desf.) was treated with three applications of 200 ml L^{-1} methanol and yielded twice the number and weight of seeds than the controls (Nonomura and Benson, 1992c). Barley treated with methanol showed an increase in vegetative growth compared with controls (Nonomura and Benson, 1992c). Methanol applications had no effect on C_4 plants (Nonomura and Benson, 1992c). The effect of foliar methanol applications on growth was far beyond that expected of any foliar nutrient. The increased growth and yield was attributed to the action of methanol as a C nutrient and as an inhibitor of photorespiration (Benson and Nonomura, 1992; Nonomura and Benson, 1992a,b). In an earlier study, Bhattacharya et al. (1985) found methanol promoted root formation in mung bean [*Vigna radiata* (L.) R. Wilczek].

In field trials, plant response was greatest when methanol was applied during periods of high solar radiation (Nonomura and Benson, 1992c). Beneficial plant response was not observed when plants were treated in the shade or during winter months. Methanol applications to plants grown indoors, under artificial illumination, caused foliar damage. Phytotoxic responses to methanol varied according to anatomical location, plant species, and methanol concentration (Nonomura and Benson, 1992c). Plants frequently sprayed with methanol solutions exhibited nutrient deficiency symptoms and metha-

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Abbreviations: AN, anthesis; EDTA, ethylenediaminetetraacetic acid; FLE, flag leaf emergence; LB, late boot; PPFD, photosynthetic photon flux density.

nol solutions were supplemented with N and microelements to reduce nutrient deficiency stress (Nonomura and Benson, 1992c). Following the foliar application of methanol, plant leaves increased in turgidity and crops matured earlier, thus reducing the water requirement for irrigation (Nonomura and Benson, 1992c).

Recent reports in scientific journals (Benson and Nonomura, 1992; Nonomura and Benson, 1992a,b,c), the popular press (Maugh, 1992; Bishop, 1992), and trade journals (Mauney, 1993; LeStrange and McGiffen, 1993) of increased yield from methanol applications have generated significant interest in the agricultural community. The need for increased yields and water conservation is expanding in agroecosystems with low rainfall and mechanized farming practices. The objective of this study was to evaluate the efficiency of foliar methanol applications in the dryland Pacific Northwest.

MATERIALS AND METHODS

The trials were conducted at the Columbia Basin Agric. Research Center, Pendleton, OR, during 1993 and 1994. The soil at this location is a Walla Walla silt loam (coarse-silty, mixed, mesic, Typic Haploxeroll). Crops treated included winter wheat (cv. Stephens, in 1993; cv. Madsen, in 1994), spring wheat (cv. Penawawa), pea (cv. Dual), and spring barley (cv. Steptoe). Seeding rate, row spacing (0.18 m), plot size (16.6 m^2), fertilization, and herbicide treatments were uniform across each trial. Winter wheat was seeded at 9.0 g m^{-2}, pea at 23.6 g m^{-2}, spring barley at 7.8 g m^{-2}, and spring wheat at 9.0 g m^{-2}. All crops received fertilizer applications consistent with recommended fertilization practices in eastern Oregon. Pea received a fall application of 1.8 g N m^{-2} and 1.0 g P m^{-2}, winter wheat received an early fall application of 8.9 g N m^{-2}, and spring grains received 7.8 g N m^{-2} and 2.2 g S m^{-2} just before sowing. All herbicide applications were made before methanol treatments were initiated. Seeds were treated with Vitavax[1] (carboxin, 5,6-dihydro-2-methyl-*N*-phenyl-1,4-oxathiin-3-carbosamide) and Lindane (γ-1, 2,3,4,5,6-hexachlorocyclohexane) at concentrations of 3.3 and 0.7 mL kg^{-1}, respectively, before sowing. In 1993, weed control in the winter wheat was accomplished with preplant applications of glyphosate [*N*-(phosphonomethyl)glycine] at 0.56 kg a.i. ha^{-1} and diclofop-methyl [(±)-2-[4-(2,4-dichlorophenoxy)-phenoxy]propanoic acid methyl ester] at 0.84 kg a.i. ha^{-1} and a postemergence applicant of bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) at 0.42 kg a.i. ha^{-1} and MCPA [(4-chloro-2-methylphenoxy) acetic acid] at 0.42 kg a.i. ha^{-1}. In 1994, glyphosate (at 0.42 kg ai. ha^{-1}, preplant) and bromoxynil (at 0.56 kg a.i. ha^{-1}) and MCPA (at 0.56 kg a.i. ha^{-1}) postemergence were applied to the winter wheat. Weed control in the spring grains in 1993 was accomplished by the preplant application of glyphosate (0.90 kg a.i. ha^{-1}) and Dicamba (3,6-dichloro-2-methoxybenzoic acid) at 0.13 kg a.i. ha^{-1} and 2,4-D [(2,4-dichlorophenoxy)acetic acid] at 0.56 kg a.i. ha^{-1}. In 1994, bromoxynil (at 0.56 kg a.i. h^{-1}) and MCPA (at 0.56 kg a.i. ha^{-1}) were applied postemergence. In 1993, the pea plots received a preplant application of glyphosate (0.35 kg a.i. ha^{-1}) and a pre-emergence application of imazethapyr [(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid at 0.04 kg a.i. ha^{-1}]. In 1994, glyphosate (at 0.42 kg a.i. ha^{-1}) was applied preplant and imazethapyr (at 0.04 kg a.i. ha^{-1}) was applied pre-emergence. Insecticides and fungicides were not applied to any of the crops after planting. The sites were not irrigated.

Methanol solutions were applied within 3 to 5 d of three distinctive cereal growth stages: flag leaf emergence (FLE), late boot (LB), and anthesis (AN). Methanol was applied to pea at the same times as spring wheat. Methanol applications were made during periods of elevated photosynthetic photon flux density (PPFD) and temperature (Table 1), between 1300

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Table 1. Application dates of foliar methanol for 1993 and 1994. Temperature, incoming photosynthetic photon flux density (PPFD), and stage of crop development at the time of application is given for each year.

1993				1994			
Date	Temperature	PPFD	GS†	Date	Temperature	PPFD	GS†
	°C	μmol photon m^{-2} s^{-1}			°C	μmol photon m^{-2} s^{-1}	
			Winter wheat				
11 May	28.9	2130	FLE	9 May	29.4	1890	FLE
21 May	22.2	1730	LB	23 May	29.4	1960	VLB
8 June	20.0	2150	AN	10 June	27.9	2150	AN
			Spring wheat				
18 May	30.6	1760	FLE	2 June	27.2	1980	EB
8 June	35.6	1860	LB	10 June	27.2	2150	LB
24 June	24.5	2150	AN	21 June	31.8	2040	AN
			Spring barley				
18 May	30.6	1950	FLE	23 May	29.4	1960	EB
21 May	35.6	1420	EB	2 June	27.2	1980	LB
8 June	35.6	1970	LB	10 June	27.2	2150	AN
24 June	24.5	2150	AN	ND	ND	ND	ND
			Pea				
12 May	31.1	2195	6.5‡	24 May	28.9	1960	9.0‡
21 May	20.6	1600	9.5‡	2 June	27.2	1980	14.0‡
8 June	19.4	1920	15.0‡	17 June	25.6	1990	15‡

† GS = growth stage; FLE = flag leaf emergence; LB = late boot; AN = anthesis; EB = early boot; VLB = very late boot.
‡ Number of main stem nodes.

and 1600 Pacific Daylight Time. In 1993, the winter wheat was sprayed with a formula containing methanol (either 200 or 400 mL of 100% methanol was added to 800 or 600 mL water, respectively) and Triton X-100 (1.0 g L^{-1}) added to deionized water (final pH 6.7 to 7.0). Treatments included single methanol applications at either FLE, LB, or AN, applications at FLE and LB or LB and AN, and applications at all three growth stages. The barley and spring wheat received only the 200 mL L^{-1} methanol including applications at AN, AN and LB, and applications at all three growth stages. Pea received only the 200 mL L^{-1} methanol with application times corresponding to those of the spring grains. The urea and Fe ethylenediaminetetraacetic acid (EDTA) present in Nonomura and Benson's formulations (Nonomura and Benson, 1992c) were omitted in 1993. In 1994, additional treatments (methanol, 400 or 200 mL L^{-1}; Triton X-100, 2.5 g L^{-1}; urea, 10 g L^{-1}; and Fe EDTA, 0.08 g L^{-1}) were included in the spray regime. A mixture containing 400 mL L^{-1} methanol and surfactant was sprayed on winter wheat, whereas 200 mL L^{-1} methanol was sprayed on pea, barley, and spring wheat. Treatment combinations were similar to 1993; however, the 200 mL L^{-1} application was omitted from winter wheat. Methanol (200 mL L^{-1}, with and without Fe and urea supplements) was applied to spring barley, pea, and spring wheat at FLE; FLE and LB; and FLE, LB, and AN.

Methanol solutions were applied with a CO_2 pressurized backpack sprayer equipped with a hand-held 2.5-m boom fitted with flat-fan nozzles and operating at 0.242 MPa. Leaves were sprayed to wetness, 20 to 52 mL m^{-2} depending on growth stage (Nonomura and Benson, 1992c), with the appropriate solution.

A dose response curve or methanol dilution trial was generated for each crop to test for methanol toxicity in 1993 (Nonomura and Benson, 1992c). Six plots for each crop were sprayed with a methanol concentration ranging from 100 to 600 mL L^{-1} in 100 mL L^{-1} increments. Additional tests were made later in the season with methanol concentrations as great as 900 mL L^{-1}. The dose response plots were sprayed, at 20 mL m^{-2}, before methanol applications were made to the methanol experiment.

Incident PPFD was monitored with a quantum sensor (Model LI-185, LI-COR Inc., Lincoln, NE). Canopy temperatures were determined with a portable infrared thermometer (Model AG-42, Teletemp Corp., Fullerton, CA). The thermometer was pointed at the center of a plot, at a 45° angle, and 15 to 30 cm from the top of the canopy. Measurements of stomatal conductance and transpiration were made following methanol applications, usually 1 to 5 d after spraying. A steady-state diffusion porometer (Model LI-1600, LI-COR Inc.) fitted with a narrow aperture (0.35 by 2.86 cm) was used for measuring stomatal conductance and transpiration on the abaxial and adaxial surfaces of one of the uppermost, fully expanded leaves (Gollan et al., 1986; Turner, 1991). Specific leaf weights were determined by the method of Potter and Breen (1980).

Several yield parameters were determined, including grain yield, total yield, and harvest index. Test weight, 1000 kernel weight, number of heads per square meter, and grain water content were measured for small grains; tenderometer (Food Machinery and Chemical Corp. Canning Machinery Div., Hoopeston, IL) values were determined for pea (Martin, 1937; Lee, 1941). Yield and test weight for cereals and yield and tenderometer values for pea were the only measurements made in 1994.

The experimental design was a randomized complete block with four replications. An analysis of variance was performed for all measured parameters to determine the significance of methanol application.

RESULTS AND DISCUSSION

The dose response study was performed before any methanol applications were made to the methanol experiment. This preliminary experiment was done to determine if the projected methanol concentrations would produce tissue damage in any of the crops under investigation. In contrast to the observations of Nonomura and Benson (1992c), no leaf toxicity or necrosis was observed on any of the crops when aqueous methanol was applied at concentrations < 600 mL L^{-1}. These tests were replicated at different locations during the first year of the experiment. Methanol concentrations exceeding 600 mL L^{-1} were not tested on spring wheat and barley; however, methanol concentrations up to 900 mL L^{-1} were tested on winter wheat and pea. There was no damage observed on pea even at methanol concentrations of 900 mL L^{-1}; however, a few small necrotic lesions were observed, but not quantified, on winter wheat at methanol concentrations of 800 mL L^{-1} and slightly more at 900 mL L^{-1}. Nonomura and Benson (1992c) reported leaf damage with methanol concentrations as low as 200 mL L^{-1} on tomato (*Lycopersicon esculentum*).

The amount of methanol solution used by Nonomura and Benson (1992c), 19 to 23 mL m^{-2}, was inadequate to cover the maturing grain and pea canopies at this location. To provide sufficient solution to achieve leaf wetness at LB and AN, applications of 33 and 52 mL m^{-2} of methanol solutions, respectively, were made. Application of any chemical to grain fields late in the growing season is difficult, and spraying aqueous methanol at 52 mL m^{-2} could be impractical in dryland grain production.

The urea and Fe EDTA present in Nonomura and Benson's formulations (Nonomura and Benson, 1992c) were not included in the spray formulation in 1993 so that the direct effects of methanol could be examined without the confounding caused by foliar application of fertilizers. However, in 1994, additional treatments with urea and Fe EDTA in the spray formulation were included to determine if these compounds were required in conjunction with methanol to stimulate plant growth.

There were no visual differences among the treatments for any crop at any time during either growing season. During the first year of the experiment, several parameters were measured for 2 h to 5 d following methanol application. Canopy temperatures among different methanol treatments and controls were not significantly

Table 2. Mean canopy temperatures of winter wheat following methanol application, 1993.

	Methanol concentration	
Applications†	200 mL L^{-1}	400 mL L^{-1}
	°C	
AN	20.5	20.8
LB, AN	20.7	20.7
FLE, LB, AN	21.0	21.1
Control	20.8	20.8
LSD (0.05)	ns	ns

† Growth stages when methanol was applied. Measurements made on 9 June 1993, 24 h after methanol applications; AN = anthesis; LB = late boot; FLE = flag leaf emergence; LSD = least significant difference.

Table 3. Leaf temperature, stomatal conductance, and transpiration of winter wheat sprayed with methanol, 1993.

Applications†	Methanol concentration	Leaf temperature	Stomatal conductance	Transpiration
	ml L^{-1}	°C	mmol m^{-2} s^{-1}	μg cm^{-2} s^{-1}
LB	200	26.8	316	6.98
FLE, LB	200	27.1	335	7.60
LB	400	26.8	330	7.50
FLE, LB	400	26.9	309	8.22
Control w/H_2O‡	–	26.5	364	9.68
Control w/Triton‡	–	26.7	358	8.21
LSD (0.05)	–	ns	ns	ns

† Growth stage when methanol was applied. Last methanol application 21 May 1993; porometer measurements made at between 12:30 and 2:30 pacific daylight time, 22 May 1993; LB = late boot; FLE = flag leaf emergence; LSD = least significant difference.
‡ Controls were sprayed with a water or a Triton X-100 solution.

different (Table 2). If methanol opens the stomata, as suggested by Nonomura and Benson (1992c), then a reduction in canopy temperature should be observed in the methanol-treated plants as a result of increased transpiration. There was no difference in individual leaf temperatures, stomatal conductance or transpiration (Table 3) between treated and untreated plants. No differences in leaf specific weight of pea between methanol treated and untreated plants were found (Table 4); however, methanol applications slightly reduced stomatal conductance (data not shown). These results differ from the findings of Gerik and Faver (1994), who found that methanol applications increased stomatal conductance to CO_2, transpiration, and CO_2 exchange rate in cotton (*Gossypium hirsutum* L.) in a greenhouse study, and Lee and Rowland (1994), who reported a slight increase in the rate of photosynthetic activity in a field study with snapbeans (*Phaseolus vulgaris* L.).

There were no significant differences among treatments in harvest index, 1000 kernel weight, number of heads per square meter, or grain water content in any of the grain crops (data not shown). There were several slight, nonsignificant yield increases associated with some methanol treatments in both 1993 and 1994. However, the yield increases were not related to either methanol concentration, number of applications, spray formulation, or the growth stage at application. There were no statistically significant differences among treatments for yields

Table 4. Specific leaf weights of peas following foliar methanol applications, 1993.

Applications†	Specific leaf weight	
	3 days after application	5 days after application
	mg cm^{-2}	
15.0	0.72	0.50
9.5, 15.0	0.71	0.57
6.5, 9.5, 15.0	0.70	0.56
Control	0.73	0.59
LSD (0.05)	ns‡	ns

† Growth stage (number of main stem nodes) when methanol was applied. Last application on 8 June 1993; Leaf disks were taken at 0700 and 1800 Pacific Daylight Time on 11 and 13 June 1993; LSD = least significant difference; methanol concentration was 200 mL L^{-1}.
‡ ns = not significant.

Table 5. Mean yields of winter wheat sprayed with 400 mL L^{-1} methanol.

Applications†	Year	
	1993	1994
	g m^{-2}	
FLE	718	617
LB	739	588
AN	789	599
FLE, LB	699	630
LB, AN	721	617
FLE, LB, AN	737	603
Mean of all methanol treatments	734	609
Control w/H_2O‡	731	631
Control w/Triton‡	671	639
Mean of all treatments	726	615
LSD (0.05)	64	47

† Growth stage when methanol applied; FLE = flag leaf emergence; LB = late boot; AN = anthesis; LSD = least significant difference.
‡ Controls were sprayed with only water or a Triton X-100 solution.

of winter wheat, spring wheat, barley, and pea (Tables 5 and 6) or grain test weight. The slight increase in some grain yields in 1993 was not correlated with the quantity of methanol applied. The tenderometer measurements of vined and cleaned peas (Table 7) did not significantly differ from the controls in either 1993 or 1994. These measurements reflect pea development and suggest that the methanol applications did not result in a change in maturation time in pea.

This research does not support the observations of Nonomura and Benson (1992a,b,c). However, these results are consistent with reports from field experiments at other locations in Oregon with peppermint (*Mentha piperita*; Mitchell et al., 1994), sugarbeet (*Beta vulgaris* L.; Rykbost and Dovel, 1994), wheat (Wysocki, 1993), and potato (*Solanum tuberosum* L.; Rykbost et al., 1994). Methanol application on bluegrass (*Poa pratensis* L.) caused a significant reduction in vegetative growth, tillers, and seed yield (Crowe et al., 1994). An extensive evaluation of methanol usage has been conducted in the cotton-producing states (Mauney and Gerik, 1994). They report that most researchers found little effect of foliar-applied methanol on gas exchange, plant water relations, growth, yield, or the fiber properties of cotton. Lee and Rowland (1994) found no significant increase in the growth and pod yield of field-grown snapbean, and Hartz et al. (1994) found that foliar methanol applications were totally ineffective in enhancing melon (*Cucumis melo* L.) and tomato performance under irrigated field conditions.

Table 6. Mean seed yields of spring wheat, spring barley, and pea sprayed with 200 mL L^{-1} methanol or water in 1993 and 1994.

Application	Yield					
	1993			1994		
	Wheat	Barley	Peas	Wheat	Barley	Peas
	g m^{-2}			g m^{-2}		
Methanol	287	579	680	363	589	539
Control†	274	581	669	342	606	549
LSD (0.05)‡	ns	ns	ns	ns	ns	ns

† Controls were sprayed with only water.
‡ LSD (0.05) for means of both years for spring wheat, spring barley, and peas are not significant (ns).

Table 7. Tenderometer readings on cleaned pea seed, 1994.

	Tenderometer reading	
	Treatments	
Applications†	200 mL L^{-1} methanol	200 mL L^{-1} methanol with nutrients
15.0	94	96
9.5, 15.0	97	97
6.5, 9.5, 15.0	96	96
Control	97	99
LSD (0.05)	ns	ns

† Growth stage (number of main stem nodes) when methanol was applied. Measurements made on 22 June 1994; control plants were sprayed with either water and surfactant or water and surfactant and nutrients, respectively; LSD = least significant difference.

Under the conditions of these trials, the foliar applications of methanol solutions to barley, wheat, and pea provided no increase in yield. We conclude that methanol applications to crops in dryland agroecosystems similar to ones in the Pacific Northwest will not benefit producers.

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