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Factors Influencing Metham Efficacy on Yellow Nutsedge (*Cyperus esculentus*) Tubers

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Yellow nutsedge infests a large number of hectares in the Treasure Valley of eastern Oregon and western Idaho. Much of its continued expansion appears to be related to onion production in the valley. Fall applications of metham often produce inconsistent results when used to control yellow nutsedge before planting an onion crop. Trials were conducted in the laboratory to determine the influence on yellow nutsedge control of metham dose, duration of exposure, temperature during exposure, and tuber conditioning by washing and chilling at 3 C. All factors influenced metham efficacy against yellow nutsedge tubers. The dose causing 50% reduction in sprouting tubers (I_{50}) for metham ranged from 22 to 76 mg kg^{-1} of soil and was lower for conditioned tubers than nonconditioned tubers across all conditions, except when tubers were exposed at 25 C for 3 d. Nonconditioned tubers were unaffected by metham after 1 d exposure at 5 C. Increasing exposure temperature or increasing exposure duration decreased sprouting for nonconditioned tubers. As exposure duration and exposure temperature increased, differences among conditioned and nonconditioned tubers were less. Temperature and exposure duration affects metham efficacy against yellow nutsedge, and the condition of the tubers at the time of treatment also has a significant effect. Applications of metham at a time when yellow nutsedge tubers are not dormant may improve yellow nutsedge control.

Nomenclature: Metham; yellow nutsedge, *Cyperus esculentus* L.; onion, *Allium cepa* L.
Key words: Fumigation, dormancy, dose–response, temperature, exposure duration.

Yellow nutsedge is a perennial weed that is problematic throughout the world (Bendixen and Nandihalli 1987) and is common in the irrigated row-crop production areas of the Treasure Valley of eastern Oregon and southwestern Idaho. It is particularly problematic in onion production because of onion growth habit and culture. Onion plants are relatively short in stature, with vertical leaves producing an incomplete canopy that has limited potential to effectively suppress weeds. Conditions of high light intensity, frequent irrigation, and high nitrogen fertilization stimulate yellow nutsedge growth and are the conditions required to maximize onion yields (Keeley and Thullen 1978; Keeling et al. 1990).

Prolific tuber production is the primary means of yellow nutsedge reproduction and survival (Tumbleson and Kommendahl 1961). Without competition, a single yellow nutsedge plant can produce more than 18,000 tubers in a single year under irrigation that is similar to onion production (Rice et al. 2004). Heavily infested commercial onion fields in the Treasure Valley contain as many as 19,000 tubers m^{-2} in the top 25 cm of soil (Ransom and Rice, unpublished data). Stoller and Wax (1973) have shown that tubers can remain viable in the soil for 22 mo.

Herbicides for controlling yellow nutsedge in onion production are limited, and control can be variable. Because of the competitive nature of yellow nutsedge and the limited number and effectiveness of available herbicides, onion producers often rely on fumigation for yellow nutsedge control before the onion crop. Metham is a fumigant registered for application before the planting of numerous crops and is extremely active against yellow nutsedge (Hutchinson et al. 2003). Metham also controls soilborne disease and insect pests but, generally, at lower rates than those required for yellow nutsedge control. Metham is often applied in the fall before onions are planted in the spring and can be applied by injection into the soil or through chemigation. Cost is a limiting factor for metham use, with typical rates (179 to 358 kg ha^{-1}) applied for yellow nutsedge control costing as much as \$60 to \$120 ha^{-1}. Control with metham is often variable and seems to be dependant on a number of environmental factors, including soil structure, moisture, and temperature (Ben-Yephet and Frank 1985, Saeed et al. 2000, Leistra and Smelt 1974).

Once applied to the soil, metham is converted to methyl isothiocyanate (MITC), a volatile compound that diffuses through the soil as a gas and exhibits strong pesticidal properties (Smelt and Leistra 1974). Other forms of isothiocyanate that are released during the breakdown of certain plant species have also been shown to inhibit yellow nutsedge growth (Norsworthy and Meehan 2005; Norsworthy et al. 2006). Conversion of metham to MITC reaches its maximum 2 to 6 h after application, depending on soil type and temperature, whereas the total amounts of MITC produced are not affected by temperature or soil type (Smelt and Leistra 1974). A portion of converted MITC is lost through volatilization to the air, with maximum losses occurring within 8 h of application (Saeed et al. 2000). This research was conducted to better understand the factors influencing metham activity on yellow nutsedge tubers. The objective of this research was to determine the effect of metham rate, exposure duration, exposure temperature, and conditioning of yellow nutsedge tubers on metham efficacy.

Materials and Methods

Trials were conducted in the laboratory at the Oregon State University, Malheur Experiment Station. Yellow nutsedge tubers were extracted from the soil in November and subjected to one of two treatments. Nonconditioned tubers were stored at a constant 10 C in a small volume of air-dried soil for approximately 12 or 20 wk. To generate conditioned tubers, a set of tubers were washed and chilled at 3 C for 4 wk before the initiation of the experiment. Tuber treatments were

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Table 1. Parameters estimated for nonlinear regression analysis of yellow nutsedge sprouting in response to metham rate, exposure temperature, exposure duration, and yellow nutsedge tuber conditioning. Standard errors are in parentheses.[a]

Temperature	Time	Tuber condition	D	C	I_{50}	b	R^2
C	d		%	%	mg kg^{-1}		
5	1	Nonconditioned	—	—	—	—	0.00
		Conditioned	93.2 (6.23)	0.0 (56.29)	50.1 (37.13)	1.8 (1.15)	0.65
	3	Nonconditioned	96.2 (3.21)	6.3 (26.29)	63.8 (7.16)	6.6 (3.73)	0.84
		Conditioned	90.0 (3.83)	0.0 (4.33)	29.9 (2.11)	3.8 (0.68)	0.92
	5	Nonconditioned	95.8 (1.86)	0.0 (2.87)	46.3 (1.41)	10.8 (2.05)	0.97
		Conditioned	90.8 (2.84)	1.7 (2.04)	21.9 (4.65)	10.0 (26.71)	0.96
15	1	Nonconditioned	98.2 (2.78)	0.0 (126.09)	76.0 (37.56)	5.6 (4.91)	0.80
		Conditioned	97.5 (2.37)	0.0 (1.86)	23.9 (0.96)	6.0 (1.14)	0.98
	3	Nonconditioned	87.8 (2.86)	0.0 (3.67)	35.2 (1.61)	4.3 (0.81)	0.95
		Conditioned	98.3 (2.46)	0.0 (1.88)	23.9 (1.06)	6.4 (1.44)	0.97
	5	Nonconditioned	98.0 (1.83)	0.1 (2.62)	37.9 (3.06)	10.8 (14.37)	0.98
		Conditioned	98.3 (1.00)	0.0 (0.71)	27.4 (1.58)	12.1 (2.17)	0.997
25	1	Nonconditioned	95.9 (1.64)	0.0 (2.65)	39.0 (0.64)	6.7 (1.76)	0.98
		Conditioned	93.3 (2.41)	0.0 (2.06)	24.4 (0.95)	4.8 (0.70)	0.97
	3	Nonconditioned	94.2 (1.78)	0.0 (1.29)	28.9 (1.49)	9.2 (1.35)	0.99
		Conditioned	96.6 (2.86)	0.0 (2.22)	26.5 (1.32)	6.2 (0.94)	0.97
	5	Nonconditioned	96.2 (2.11)	0.0 (1.45)	28.7 (1.27)	8.0 (0.99)	0.98
		Conditioned	95.0 (2.95)	0.0 (2.31)	25.6 (1.32)	6.0 (1.06)	0.96

[a] Abbreviations: D, percentage of tubers sprouting in nontreated treatment; C, percentage of tubers germinating at high metham dose; b, slope at I_{50} dose; I_{50}, dose causing a 50% reduction in sprouting tubers. For one treatment the I_{50} was higher than the rates evaluated.

meant to either preserve or overcome dormancy. Washing and chilling have been reported to effectively overcome tuber dormancy in yellow nutsedge (Tumbleson and Kommendahl 1961). All tubers were produced clonally the previous summer. Fifteen tubers were placed in 950-ml sealed jars with 800 g of Owyhee silt loam soil. The soil was wetted to 14% moisture on a weight-for-weight basis by adding one-third of the water to the bottom of the jar, adding half the volume of soil, then adding the yellow nutsedge tubers, adding another third of the water, adding the remaining soil, and then adding the final third of the water. The jars were placed in growth chambers at 5, 15, or 25 C for 24 hr to equilibrate. Metham was injected with a syringe into the soil 1.3 cm below the tubers at rates of 0, 20, 40, 61, and 81 mg ai kg^{-1} of soil. All treatments were adjusted to an application volume of 3 ml with water. Jars were sealed and placed back in their respective temperatures for 1, 3, or 5 d. After each exposure period, the soil was removed from the jars, and tubers were washed from the soil. Extracted tubers were placed in 90-mm-diam petri dishes between two pieces of filter paper,[1] and 5 ml of water was added to each dish. The water contained 0.2% wt/wt captan to prevent fungal growth. The petri dishes were sealed and placed in the dark at 25 C. Tubers were considered to be germinated when at least one rhizome greater than 2 mm long had emerged from the tuber. Germinated tubers were recorded at the time of removal from the fumigated soil and weekly for 6 wk. Treatments were replicated four times, and the trial was repeated. Total percentage of tuber germination was analyzed by ANOVA.[2] Data from both runs were combined in the absence of run-by-treatment interactions. For each combination of exposure temperature, exposure duration, and tuber conditioning, tuber sprouting response to metham dose was fitted to the logistic model[3]:

$$y = (D - C)\Big/\left[1 + (x/I_{50})^{b}\right] \quad [1]$$

where y is the percentage of sprouting yellow nutsedge tubers, x is the metham dose, C is the percentage of tubers sprouting at high doses, D is the percentage of tubers sprouting in the nontreated control, I_{50} is the dose causing 50% reduction in sprouting tubers, and b is the slope at the I_{50} dose (Seefelt et al. 1995).

Results and Discussion

In general, tuber sprouting was affected by all factors: metham dose, exposure temperature, exposure duration, and yellow nutsedge tuber conditioning. This is in agreement with Boydston and Williams (2003) research, which evaluated fumigant effects on volunteer potato tubers. All main effects and interactions were highly significant ($P < 0.00001$). The I_{50} dose for metham under various conditions ranged from 22 to 76 mg kg^{-1} and was lower for conditioned tubers than nonconditioned tubers across all conditions, except when they were exposed at 25 C for 3 d (Table 1). Nonconditioned tubers were not affected by 1-d exposure to metham at 5 C (Figure 1). For nonconditioned tubers, increasing exposure temperature and increasing exposure duration decreased sprouting. Differences among conditioned and nonconditioned tubers were less as exposure duration or exposure temperature increased. At lower temperatures, conversion of metham to MITC occurs at a slower rate (Smelt and Leistra 1974). In addition, the reduced response of yellow nutsedge tubers at cooler temperatures could also be attributed to reduced metabolic activity. The similar response of conditioned tubers, regardless of exposure duration, at 15 or 25 C, and the increased response of nonconditioned tubers to increasing exposure duration, suggests that, at 15 and 25 C, the conversion of metham to MITC is not the limiting factor, but rather, uptake by the nonconditioned nutsedge tubers may be limiting. In contrast, at 5 C, both conditioned and nonconditioned tubers responded to increasing exposure duration, suggesting that both rate of metham conversion to MITC and uptake by the tubers were having an effect on metham efficacy.

I_{50} values were actually lower for conditioned tubers exposed for 5 d at 5 C compared with exposure at 15 or 25 C. This result is difficult to explain. It may be that

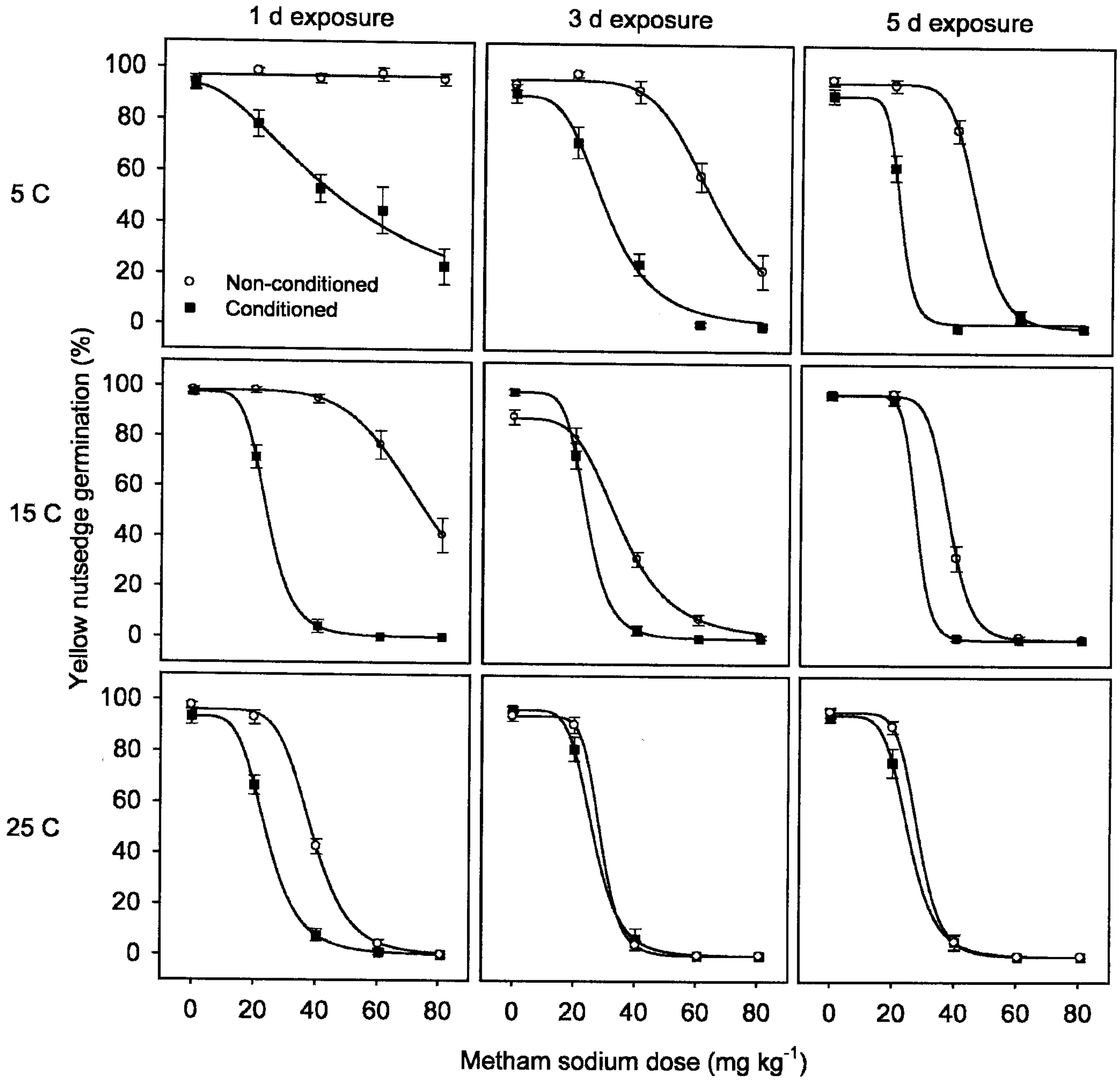

Figure 1. Yellow nutsedge germination in response to metham rate, temperature of exposure, duration of exposure, and conditioning of the yellow nutsedge tubers. Conditioned tubers were washed and chilled at 3 C for 4 wk before trial initiation. Nonconditioned tubers were stored in soil at a constant 10 C. Parameter estimates are shown in Table 1. Symbols and whiskers represent the means and standard errors of four replicates of combined runs.

although conversion of metham to MITC is faster at high temperatures, breakdown of MITC is also increased (Smelt and Leistra 1974). In the field, where MITC is lost to the atmosphere, warmer soil temperatures, while increasing the conversion of metham to MITC, are also likely to increase MITC loss from the soil to the air (Saeed et al. 2000). I_{50} values in our trial were magnitudes greater than reported by Hutchinson et al. (2003). Tuber treatment, temperature, soil moisture, and exposure duration for their research fell within parameters used in this trial. A major difference in the research was that Hutchinson et al. (2003) placed 15 tubers in 45 ml of soil, and the fumigant treatments were pipetted directly into gas-tight chambers, not applied to the soil. Less soil to inhibit movement of MITC to the yellow nutsedge tubers and less total water volume for MITC to partition into (Smelt and Leistra 1974) may have allowed higher activity at much lower doses. Also the soil used by Hutchinson et al. (2003) was autoclaved before trial initiation, whereas the soil in this experiment was not. It is possible that greater metabolism occurred in our research system as a result of greater abundance of soil microbes. Microbial degradation of metham plays an important role in its persistence and is accelerated when applications of metham are repeated, resulting in enhanced metham breakdown and shorter half-life in the soil

(Matthiessen et al. 2004). Soils previously treated with metham can also exhibit enhanced metabolism of isothiocyanate compounds released from soil-incorporated mustard [*Brassica juncea* (L.) Czern.] green-manure crops, which exhibit fumigant properties similar to metham (Warton et al. 2003). The soil used in this research had not been treated with metham for 5 yr or longer. Another possible explanation for difference between this and previous work is that germination was recorded for up to 6 wk after treatment in this trial, whereas Hutchinson et al. (2003) only evaluated germination 5 d after fumigation. In this trial, significant shoot emergence continued to occur up to 2 wk after fumigation.

The relative response of yellow nutsedge in our trials is in agreement with field observations and label recommendations that suggest that metham doses of 40 to 80 mg kg^{-1} are required for acceptable yellow nutsedge suppression. This research illustrates that fumigant efficacy is dependant on the dose reaching the target organism. Although the dose applied directly influences the amount of metham in the soil, environmental or physiological factors may affect the dose that yellow nutsedge tubers receive. Applying metham when soil temperatures are warmer may increase activity on yellow nutsedge, but applications to warmer soils could potentially reduce duration of tuber exposure to metham because of increased volatilization of metham from the soil or because of increased decomposition (Smelt and Leistra 1974). The use of higher metham doses or extending the exposure duration through use of mulch or other methods will likely improve the level and consistency of yellow nutsedge control but can be economically restrictive. The differential response of conditioned and nonconditioned tubers to metham observed in these trials suggests that more research needs to focus on yellow nutsedge tuber physiology to identify the conditions that will increase susceptibility to metham.

Sources of Materials

[1] Whatman No. 2 filter paper, Whatman Inc., 200 Park Ave., Suite 210, Florham Park, NJ 07932.

[2] Number Cruncher Statistical Software, NCSS, 329 North 1000 East, Kaysville, UT 84037.

[3] SigmaPlot 9.0, SigmaPlot 2004 for Windows, Version 9.0.1, SYSTAT Software, Inc., 501 Canal Blvd, Suite C, Point Richmond, CA 94804-2028.

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