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Yellow nutsedge (Cyperus esculentus) Growth and Tuber Production in Response to Increasing Glyphosate Rates and Selected Adjuvants
--Manuscript Draft--

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Abstract:	Greenhouse studies were conducted to evaluate the influence of selected adjuvants on glyphosate efficacy on yellow nutsedge and tuber production. Glyphosate was applied at 0, 0.25, 0.43, 0.87, 1.26 (1x rate), and 1.74 kg ae ha-1 31 d after yellow nutsedge was planted. Each rate was mixed with one of the following adjuvants: ammonium sulfate (AMS); or AMS plus NIS; or AMS plus an experimental adjuvant (W-7995) plus NIS. Plants were evaluated for visual injury and the number and size of tubers produced. Dose response curves based on log-logistic models were used to determine the effective glyphosate rate plus adjuvant that provided both 90% visual yellow nutsedge injury (ED90) and reduced tuber production. Addition of NIS to glyphosate plus AMS resulted in the greatest yellow nutsedge injury 28 DAT. Addition of the experimental adjuvant plus NIS resulted in similar injury as NIS alone. The ED90 for visual injury at 28 DAT was 2.12 kg ha-1 with glyphosate plus AMS and NIS compared to 2.18 kg ha-1 for W-7995 plus NIS and 3.06 kg ha-1 with AMS alone. The ED90 rates with different adjuvants represent 168%, 173%, and 243% of the highest glyphosate rate (1.26 kg ha-1) labeled for application on many glyphosate resistant crops. However, the estimated ED90 to reduce small, medium, large, and total tubers were 1.60, 1.50, 1.63, and 1.66 kg ha-1, respectively. The results suggest that increases in labeled rates of glyphosate may be required to reduce yellow nutsedge tuber production in field conditions. Use of lower glyphosate rates should be discouraged as it may increase tuber production and exacerbate yellow nutsedge expansion in infested fields.

1   Felix et al.: Yellow nutsedge response to glyphosate and adjuvants

2   **Yellow nutsedge (*Cyperus esculentus*) Growth and Tuber Production in Response to Increasing**

3   **Glyphosate Rates and Selected Adjuvants**

4   Joel Felix, Joseph T. Dauer, Andrew G. Hulting, and Carol Mallory-Smith[*]

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6   glyphosate efficacy on yellow nutsedge and tuber production. Glyphosate was applied at 0,

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8   rate was mixed with one of the following adjuvants: ammonium sulfate (AMS); or AMS plus NIS;

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10   injury and the number and size of tubers produced. Dose response curves based on log-logistic

11   models were used to determine the effective glyphosate rate plus adjuvant that provided both

12   90% visual yellow nutsedge injury (ED$_{90}$) and reduced tuber production. Addition of NIS to

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14   experimental adjuvant plus NIS resulted in similar injury as NIS alone. The ED$_{90}$ for visual injury

15   at 28 DAT was 2.12 kg ha^{-1} with glyphosate plus AMS and NIS compared to 2.18 kg ha^{-1} for W-

16   7995 plus NIS and 3.06 kg ha^{-1} with AMS alone. The ED$_{90}$ rates with different adjuvants

17   represent 168%, 173%, and 243% of the highest glyphosate rate (1.26 kg ha^{-1}) labeled for

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18   application on many glyphosate resistant crops. However, the estimated ED_{90} to reduce small,

19   medium, large, and total tubers were 1.60, 1.50, 1.63, and 1.66 kg ha^{-1}, respectively. The results

20   suggest that increases in labeled rates of glyphosate may be required to reduce yellow

21   nutsedge tuber production in field conditions. Use of lower glyphosate rates should be

22   discouraged as it may increase tuber production and exacerbate yellow nutsedge expansion in

23   infested fields.

24   **Nomenclature:** Glyphosate; yellow nutsedge, *Cyperus esculentus* L. CYPES.

25   **Key words:** adjuvants, yellow nutsedge tubers, furrow irrigated systems.

26

27   Yellow nutsedge is a perennial weed found throughout the world in many crop production

28   systems (Anderson 1999; Holm et al. 1991; Schippers et al. 1995). It is naturalized within the

29   United States (U.S.), where it was first reported in the northeastern states in 1889 (DeFelice

30   2002). Yellow nutsedge has since spread to nearly all crop producing regions of the U.S. The

31   impact of yellow nutsedge on production agriculture has led to its listing as a prohibited

32   noxious weed in 10 states (Anderson 1999). Hauser (1971) suggested that the increase of

33   yellow nutsedge in agricultural fields is largely due to reduced competition from annual weeds,

34   which tend to have effective control measures.

35   Populations of yellow nutsedge can expand and contract in individual fields based on a

36   variety of environmental and management factors. However, given its perennial nature, yellow

37   nutsedge remains a problem once it produces mature tubers in a field. Control of yellow

38   nutsedge is difficult because reproduction is mainly by underground vegetative propagules

39 (rhizomes and tubers), which persist for 3 to 5 yr (DeFelice 2002). Population dynamic models

40 have indicated that farming operations were the main cause of yellow nutsedge dispersal in the

41 fields (Schippers et al. 1993). Tillage caused a threefold increase in infestation expansion level

42 compared to no-tillage. Tuber adherence to field machinery during physical weed management

43 activities also play a significant role in horizontal yellow nutsedge distribution in infested fields

44 (Schippers et al. 1993; Webster 2005).

45   Yellow nutsedge is an important weed problem of agricultural fields in the Treasure Valley

46 of eastern Oregon and southwestern Idaho, mainly due to lack of effective control strategies in

47 direct-seeded onion (*Allium cepa* L.) crops. Surveys conducted by Ransom et al. (2003) indicated

48 dry bulb onion yield reductions averaged 42 percent in fields that were heavily infested with

49 yellow nutsedge. Mechanical control through well-timed soil cultivation can be used to destroy

50 yellow nutsedge plants before tuber formation, but it is not an option in the furrow irrigated

51 fields after beds are formed. In the Treasure Valley, beds are designed to facilitate furrow

52 irrigation and are formed during the fall preceding spring onion planting before yellow

53 nutsedge emerges. Agricultural equipment used to create a uniform gradient and furrow

54 irrigation beds possibly contributes to further distribution of yellow nutsedge in the fields.

55 Onions are relatively short-statured plants with narrow, round, vertical leaves which produce

56 an open canopy and are easily outcompeted by yellow nutsedge (J. Felix, personal observation).

57 The openness of onion canopy allows yellow nutsedge to flourish under prevailing high air

58 temperature conditions, which are often accompanied by high light intensity and constant soil

59 moisture in the furrow irrigated fields. Onion management practices, including frequent

60 irrigation and the high nitrogen fertilization required to maximize yield, also favor yellow

3

61   nutsedge growth (Keeling et al. 1990). Additionally, the direct-seeded dry bulb onion based

62   crop rotations in the Treasure Valley limit the use of most soil-applied or postemergence

63   herbicides with efficacy on yellow nutsedge. For example, onions are sensitive to even low soil

64   residues of halosulfuron-methyl, which persist after corn (*Zea mays* L.) harvest (J. Felix,

65   personal observation).

66   Herbicides registered to control yellow nutsedge in direct-seeded dry bulb onions include *S*-

67   metolachlor and dimethenamid-p, which are applied when seedlings are at the 2-leaf stage.

68   However, by the time onions reach the 2-leaf stage, yellow nutsedge has already emerged, and

69   both *S*-metolachlor and dimethenamid-p do not control emerged weeds (Anonymous 2008;

70   Anonymous 2010a). Consequently, current efforts to control yellow nutsedge rely on the use of

71   glyphosate applications in transgenic corn and sugar beets (*Beta vulgaris* L.) grown in rotation

72   with onion.

73   Reported results for yellow nutsedge control with glyphosate have varied. Pratt et al. (2003)

74   reported that adjuvants improved weed control with glyphosate, but none was superior to that

75   achieved with the addition of ammonium sulfate (AMS). Adjuvants are defined as ''any

76   substance in a herbicide formulation or added to the spray tank to modify herbicidal activity or

77   application characteristics'' (Ahrens 1994). Adjuvants counteract antagonisms with solution

78   components that reduce herbicide activity. They also help to improve herbicide movement

79   across the cuticle. Yellow nutsedge has a thick waxy cuticle on the adaxial leaf surface

80   (Schippers et al. 1995), which may present a barrier for herbicide absorption under hot

81   conditions (Dayan et al. 1996). The relatively high amount of epicuticular wax on yellow

82   nutsedge leaves may be responsible for a low absorption rate of herbicides in the absence of

83   adjuvants (Dayan et al. (1996). Nelson et al. (2002) suggested that addition of adjuvants to

84   glyphosate may increase yellow nutsedge control under hot, dry conditions. Ammonium sulfate

85   increased glyphosate phytotoxicity (Nalewaja and Matysiak 1993; Thelen et al. 1995) and

86   improved weed control, especially when used with alkaline water as a carrier. Recently

87   however, Webster et al. (2008) reported reduction of yellow nutsedge tuber production with a

88   single glyphosate application in greenhouse conditions without the use of adjuvants. Nelson et

89   al. (2002) reported little glyphosate efficacy on yellow nutsedge when applied with adjuvants,

90   and Ethridge and Mueller (1998) found that sequential applications were required to provide

91   effective yellow nutsedge control.

92   Control of yellow nutsedge is also reported to be affected by glyphosate rate and

93   application timing. Stoller et al. (1975) reported poor control of yellow nutsedge with

94   glyphosate rates below 2.2 kg ha^{-1}. Several reports suggest that glyphosate application rate and

95   the plant age at the time of application influence yellow nutsedge control and viable tuber

96   production (Appleby and Paller 1978; Keeley et al. 1985; Pereira and Crabtree 1986; Stoller et

97   al. 1975). However, differences in yellow nutsedge biotype response to glyphosate should not

98   be discounted (Holt 1994).

99   The adoption of glyphosate resistant crops (GRC) in the Treasure Valley, including corn,

100   sugar beets (*Beta vulgaris* L.) and alfalfa (*medicago sativa* L.), enables growers to apply

101   glyphosate directly to these crops during the growing season. Improved glyphosate efficacy

102   when used in these crops could reduce yellow nutsedge tuber production in years preceding

103   direct-seeded onions in the Treasure Valley. Glyphosate labels recommend addition of

104   surfactants only when the carrier volume is above 280 L ha^{-1} and glyphosate rates are below 0.6

105   kg ha^{-1} (Anonymous 2010b), but anecdotal evidence indicates that addition of nonionic

106   surfactants may improve yellow nutsedge control even at low spray volumes. Currently, most

107   onion growers in the Treasure Valley apply a mixture of glyphosate plus AMS at rates ranging

108   from 0.6 to 1.26 kg ha^{-1} to manage yellow nutsedge in GRC. The objective of this greenhouse

109   study was to compare the effect of glyphosate applied in mixture with an experimental

110   adjuvant, W-7995, and a non-ionic surfactant to glyphosate plus AMS on yellow nutsedge visual

111   injury and tuber production.

112

Materials and Methods

114   **Greenhouse Experiments.** Yellow nutsedge tubers were collected from a field in Malheur

115   County, Oregon (N 43° 59.615, W -117° 00.404) in October 2008 and 2009, placed in plastic

116   bags and stored at 4 C until used in the experiments. Greenhouse studies were conducted in

117   February 2009 and 2010 at Corvallis, Oregon. Pots were filled with greenhouse commercial

118   potting mix[1], watered and left on greenhouse benches to equilibrate to room conditions. An

119   experimental unit consisted of a circular 35 cm deep by 29 cm diam pot. Tubers were

120   positioned between two pieces of wet germination paper and placed in a plastic tray filled with

121   sterile sand to 2.5 cm depth and wetted to capacity. The trays were placed in a germination

122   chamber set at 24/20 C with 14/10 h of light/dark and the tubers were monitored daily for

123   germination. After 9 d, tubers with a 2 mm bud protrusion were removed from the tray and

124   one tuber planted in each pot in the greenhouse at a depth of 2 to 3 cm. The greenhouse had

125   natural light supplemented with metal halide lamps, with average day/night temperatures of

126   24/20 C and light duration of 14/10 h light/dark. The experiment was a complete randomized

127   design with three replications and was repeated. Pots were systematically rotated on the

128   benches within each replication to avoid shade and positional effects in the greenhouse. Pots

129   were watered twice per week and each was fertilized during the first 4 weeks with 40 ml of

130   9.875 g L^{-1} solution of 16-16-16 (NPK) fertilizer[2].

131   Isopropopylamine salt of glyphosate[3] was applied 31 d after nutsedge tubers were

132   transplanted, when the average plant height was 57 cm. The list of treatments including

133   adjuvant combinations are presented in Table 1. Spray products were mixed in the following

134   order prior to application: 1) half of the required amount of water; 2) AMS; 3) glyphosate; 4) W-

135   7995[4]; 5) NIS and then the remaining water. Treatments were applied using a spray chamber[5]

136   equipped with a single TeeJet 8003 EVS nozzle[6] calibrated to deliver 112 L ha^{-1} at 221 kPa.

137   Yellow nutsedge visual injury ratings relative to the nontreated control were performed at

138   21 and 28 d after treatment (DAT). Evaluations were based on a 0 to 100% scale, where 0%

139   represented no injury and 100% complete plant death. Plants were harvested after the last

140   evaluation by clipping the aboveground biomass and tubers separated from the roots by

141   washing over sieves. Tubers were quantified based on diameter and divided into extra small (≤

142   0.254 cm), small (0.254 to 0.508 cm), medium (0.508 to 0.76 cm), and large (≥ 0.76 cm) sizes

143   using stacked sieves. All tubers were air dried for 6 h, cold conditioned for 7 d at 4 C, and

144   planted in 10 cm pots containing commercial potting mix to assess their viability. Germination

145 of the tubers was quantified 3 wk after planting based on tuber bud sprout and protrusion.

146 Tubers with any evidence of bud protrusion were considered to have germinated.

147 **Statistical Analysis.** The data from visual evaluations of yellow nutsedge injury and number of

148 tubers were subjected to a normality test before ANOVA. Because transforming the data did

149 not change the results of analysis, the actual values are presented. Data were pooled over

150 study when there was no significant study-by-treatment interaction and tested for

151 heterogeneity of variance. ANOVA was performed using PROC MIXED in SAS[7] (1999) to assess

152 the effect of study, glyphosate rate, adjuvant combination, and their interactions on the visual

153 yellow nutsedge plant injury response and the number and size of tubers produced ($P \le 0.05$).

154 Regression of yellow nutsedge plant injury ratings over herbicide rate was performed using a

155 four-parameter log-logistic model as described by Seefeldt et al. (1995) and indicated below:

156 $$Y = C + (D - C)/\{1 + \exp[B(\log X - \log E)]\}$$ [1]

157 where Y is the response (e.g., percent of yellow nutsedge injury), C is the lower limit, D is

158 the upper limit, B is the slope of the line, X is the herbicide rate, and E is the rate resulting in a

159 50% response (e.g., 50% injury, which is also known as effective dose 50 (ED_{50}, also called I_{50}).

160 Analysis of the dose-response curves and ED_{90} values was completed using the statistical

161 software, R 2.7.2[8], and the *drc* package as described by Knezevic et al. (2007). When the data

162 did not fit the model (lack of convergence), only ANOVA was performed and the means were

163 compared using Fisher's protected LSD ($P \le 0.05$).

164

Results and Discussion

166   **Visual Injury.** There were no significant differences between study or glyphosate rate-by-study

167   interactions for any of the variables; therefore, the data were pooled over study and analyzed

168   for glyphosate rate and adjuvant effects. Visual evaluations at 21 DAT were similar to ratings at

169   28 DAT; therefore, only evaluations at 28 DAT are presented. Injury symptoms on yellow

170   nutsedge were characterized by leaf chlorosis followed by necrosis of the tissue. Differences in

171   yellow nutsedge visual injury at 28 DAT were due to glyphosate rate and adjuvant selection

172   (Figure 1). At low glyphosate rates (<0.5 kg ha^{-1}), the addition of AMS and NIS resulted in

173   greater visual injury. Addition of the experimental adjuvant (W-7995) plus AMS and NIS or NIS

174   alone performed similarly at higher glyphosate rates ($\geq$ 0.87 kg ha^{-1}). The ED$_{50}$ glyphosate rate

175   for yellow nutsedge injury at 28 DAT was 0.79 kg ha^{-1} when W-7995 plus NIS were added to the

176   spray solution (Table 2). The corresponding rate to elicit 50% injury when AMS and NIS were

177   added was 0.54 kg ha^{-1} compared to 0.82 kg ha^{-1} for glyphosate plus AMS alone. It is not clear

178   why the experimental adjuvant performed similar to AMS alone even with the inclusion of NIS.

179   These results suggest that growers in eastern Oregon could benefit from the addition of NIS to

180   the mixture of glyphosate plus AMS to control weeds in GRC, especially when targeting yellow

181   nutsedge. Also, the use of glyphosate at rates $\leq$ 0.87 kg ha^{-1} to control yellow nutsedge should

182   be discouraged. Estimates for ED$_{90}$ for visual injury at 28 DAT ranged from 3.06 kg ha^{-1} with

183   AMS alone to 2.12 kg ha^{-1} with the addition of NIS. These results partly corroborate findings by

184   Stoller et al. (1975) who reported poor control of yellow nutsedge with glyphosate rates below

185   2.2 kg ha^{-1}. Our results suggest that the addition of NIS in the glyphosate plus AMS mixture may

186   enhance yellow nutsedge injury. With the commercialization of GRC, growers are able to apply

187   glyphosate directly to GRC preceding onion production, yet yellow nutsedge infestations

188   continue to expand in the furrow irrigated systems of eastern Oregon. Unpublished information

189   indicates that growers in the Treasure Valley apply glyphosate at rates ranging from 0.473 to

190   0.946 kg ha^{-1} (J. Felix, personal observation). It is possible that the use of lower glyphosate

191   rates may be partly contributing to the expansion of yellow nutsedge in the area through the

192   production of small and medium size tubers (Figure 2).

193   **Yellow Nutsedge Tuber Production.** Tubers were produced at all glyphosate rates applied.

194   There has been anecdotal indication that yellow nutsedge plants sprayed with glyphosate tend

195   to produce smaller tubers. Most of the tubers in this study were either small (0.25 to 0.51 cm)

196   or medium (0.51 to 0.76 cm) size in diameter, but extra small (≤0.25 cm) and large (>0.76 cm)

197   were also produced (Figure 2). Differences in the number of tubers for each category were only

198   influenced by glyphosate rate; therefore, the data were combined over adjuvants for analysis.

199   **Total number of Tubers.** The total number of tubers produced was greater when glyphosate

200   was applied at 0.25 and 0.43 kg ha^{-1} relative to the nontreated control (Figure 2). A similar

201   number of tubers were produced in the nontreated control and when glyphosate was applied

202   at ≤ 0.87 kg ha^{-1}. The lowest number of tubers was produced when glyphosate was applied at

203   rates ≥ 1.26 kg ha^{-1}. The ED_{50} and ED_{90} were estimated to be 1.03 kg ha^{-1} and 1.66 kg ha^{-1},

204   respectively (Table 2). The ED_{90} for total tubers (1.66 kg ha^{-1}) was lower than that estimated to

205   elicit 90% visual injury to yellow nutsedge at 28 DAT (2.12 kg ha^{-1}). These results suggest that,

206   ultimately, yellow nutsedge visual injury may not be a good predictor of tuber production.

207   **Extra Small Tubers.** There was no difference among glyphosate rates for the number of extra

208   small tubers produced relative to the nontreated control, which ranged from 0 to 4 tubers pot^{-1}

209   (data not shown). Production of extra small tubers in particular is troublesome for land

210   managers of the furrow irrigated fields of the Treasure Valley because this size may possibly

211   increase tuber buoyancy and contribute to the dissemination through irrigation water

212   movement in canals and ditches, especially during the initial irrigation event when the soil is

213   still loose from tillage. Even though the water is filtered at entry points into different farms,

214   extra small tubers may enter the fields in case of an overflow due to accumulation of plant

215   debris at water filtration points, which is very common.

216   **Small Size Tubers.** The greatest number of small size tubers relative to the nontreated control

217   was produced when glyphosate was applied at the rate of 0.43 kg ha^{-1} (Figure 2). The ED_{50} rate

218   for small size tubers reduction was 0.95 kg ha^{-1} and the ED_{90} glyphosate rate was estimated to

219   be 1.60 kg ha^{-1} (Table 2).

220   **Medium Size Tubers.** Medium size tubers comprised the largest proportion of the total tubers

221   produced (Figure 2). Yellow nutsedge plants treated with glyphosate at 0.25 and 0.43 kg ha^{-1}

222   produced the greatest medium size tubers, which was similar to the nontreated control. The

223   fewest medium size tubers were produced when glyphosate was applied at 1.26 kg ha^{-1} or

224   greater (Figure 2). The ED_{50} and ED_{90} for the medium size tubers were estimated to be 0.78 kg

225   ha^{-1} and 1.50 kg ha^{-1}, respectively (Table 2).

226   **Large Size Tubers.** Yellow nutsedge plants produced relatively few large tubers compared to

227   small and medium size tubers (Figure 2). The fewest large tubers relative to the nontreated

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228   control were produced when glyphosate was applied at rates $\geq$ 1.26 kg ha^{-1}. Plants treated with

229   the lowest glyphosate rate (0.25 kg ha^{-1}) produced 1.6 times the number of large tubers

230   compared to the nontreated control. The ED$_{50}$ rate for the large tubers was 0.86 kg ha^{-1}, while

231   the estimated glyphosate rate to provide 90% reduction of large size tubers was 1.63 kg ha^{-1}

232   (Table 2).

233   Visual injury provides an insight into vegetative plant effects resulting from glyphosate

234   application, but long-term yellow nutsedge management is dependent on inhibiting tuber

235   production. The results from these studies indicated that glyphosate rate determines the

236   number and size of yellow nutsedge tubers produced. Tuber production in yellow nutsedge is a

237   result of plant response to excess carbohydrates and is regulated by the availability of growth

238   substances (Bhowmik 1997). Yellow nutsedge, as with all plants, must have sufficient leaf area

239   for photosynthesis to occur and produce sufficient carbohydrates in the form of

240   photoassimilates (Hopkins 1995). Therefore, reducing healthy leaf tissue could decrease the

241   amount of carbohydrate, thus reducing tuber population. At low application rates, there is the

242   least leaf tissue injury and the plant initiates tuber production as a survival mechanism. Because

243   the level of assimilates is limited due to tissue injury, many small and medium size tubers are

244   produced at low glyphosate rates. As the glyphosate rate increases, the leaf tissue injury

245   increases and yellow nutsedge can not generate enough assimilates to sustain many tubers,

246   hence the limited tuber production at glyphosate rates of 1.26 kg ha^{-1} or greater. Our results

247   suggest that the use of glyphosate at rates lower than 0.87 kg ha^{-1} to control yellow nutsedge

248   should be discouraged. Furthermore, the continued prevalence of glyphosate resistant weeds

249   in the US necessitates the use of different strategies including herbicides with soil residual to

250   manage yellow nutsedge instead of total glyphosate weed control programs.

251   **Yellow Nutsedge Tuber Germination**. Germination of 7 d cold conditioned tubers varied by size

252   and was only affected by glyphosate rates (Figure 3). In general, the greatest tuber germination

253   was observed for tubers produced when glyphosate was applied at rates ≤ 0.43 kg ha^{-1}.

254   Germination of small and medium size tubers ranged from 0 to 45% and 0 to 36%, respectively

255   (Figure 3A and B). Large size tubers had the lowest germination, which ranged from 0 to 27%

256   (Figure 3C). The combined total germination ranged from 0 to 34% (Figure 3D). Germination of

257   extra small tubers for the nontreated, glyphosate applied at 0.25, 0.43, 0.87, 1.26, and 1.74 kg

258   ha^{-1} was 10, 4, 22, 11, 6, and 0%, respectively (data not shown). It is unclear, but likely, that

259   most of the tubers that did not germinate were viable but still dormant as a result of the short

260   cold conditioning period. These results suggest that application of glyphosate at rates ≥ 1.26 kg

261   ha^{-1} may possibly reduce tuber production. Field studies are needed to validate these results

262   under furrow irrigated conditions.

263   The above results further demonstrated that the addition of the experimental adjuvant W-

264   7995 plus NIS to glyphosate plus AMS spray mixture did not improve yellow nutsedge visual

265   injury at 28 DAT. The addition of AMS and NIS improved visual injury but did not influence tuber

266   production. Nelson et al. (2002) reported that addition of NIS, methylated seed oil, or crop oil

267   concentrate to glyphosate plus diammonium sulfate did not increase yellow nutsedge control in

268   the greenhouse or field. Our results show that visual injury increased with the addition of NIS,

269   but reduction in the number of produced tubers was only attributed to the glyphosate rate

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270 used. These results corroborate the findings by Webster (2008) that glyphosate will reduce

271 tuber production. Furthermore, the use of lower glyphosate rates produced greater number of

272 tubers and should be discouraged in order to avoid increases in the number of yellow nutsedge

273 tubers in individual fields. The estimated glyphosate rates to reduce small, medium, large, and

274 total tubers were 1.60, 1.50, 1.63, and 1.66 kg ha^{-1}, respectively, and are slightly greater than

275 the current highest single application rate recommended on the label (1.26 kg ha^{-1}) and used by

276 growers on GRC. The use of lower glyphosate rates to manage yellow nutsedge should be

277 discouraged as it may result in the production of small size tubers and further contribute to the

278 distribution of yellow nutsedge in the furrow irrigated systems in the Treasure Valley of eastern

279 Oregon. Finally, it should be emphasized that growers and weed managers need to practice a

280 diversified yellow nutsedge control program in light of the increasing prevalence of glyphosate-

281 resistant weed species in the US. Use of soil residual herbicides followed by glyphosate POST

282 might be better than sequential application of glyphosate POST alone.

283

284   **Sources of Materials**

[1] Sunshine Mix #1, Sun Gro Horticulture Inc., 15831 N.E. 8th Street, Suite 100, Bellevue, WA 95008.

[2] Osmocote fertilizer, Scotts-Sierra Horticultural Products Company, 14111 Scottslawn Road, Marysville, OH 43041.

[3] Roundup PowerMax®, Monsanto Company, 800 Lindbergh Blvd., St. Louis, MO 63167.

[4] W-7995, Wilbur-Ellis, P. O. BOX 16458, Fresno, CA 93755.

[5] Spray chamber, DeVries Manufacturing, 28081 870th Ave, Hollandale, MN 56045.

[6] TeeJet 8003 EVS flat-fan nozzle tips, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60188.

[7] SAS user's guide. Version 9.2. Statistical Analysis Systems Institute, Inc., P.O. Box 8000, Cary, NC 25712-8000.

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345   Table 1. Treatments used in the greenhouse studies conducted at Corvallis, OR 2009 and 2010.

| Treatment | Rate (kg ae ha^{-1}) | Adjuvants | | |
		AMS[a] alone	+ NIS[a] + W-7995[b]	+ NIS
		--------------------------------- % V/V ---------------------------------		
Glyphosate	0	0.5		
Glyphosate	0	0.5	0.25 + 0.26	
Glyphosate	0	0.5		0.25
Glyphosate	0.25	0.5		
Glyphosate	0.25	0.5	0.25 + 0.26	
Glyphosate	0.25	0.5		0.25
Glyphosate	0.43	0.5		
Glyphosate	0.43	0.5	0.25 + 0.26	
Glyphosate	0.43	0.5		0.25
Glyphosate	0.87	0.5		
Glyphosate	0.87	0.5	0.25 + 0.26	
Glyphosate	0.87	0.5		0.25
Glyphosate	1.26	0.5		
Glyphosate	1.26	0.5	0.25 + 0.26	
Glyphosate	1.26	0.5		0.25
Glyphosate	1.74	0.5		
Glyphosate	1.74	0.5	0.25 + 0.26	
Glyphosate	1.74	0.5		0.25

346   [a] Abbreviations: AMS, ammonium sulfate; NIS=non ionic surfactant.

347   [b] W-7995is an experimental adjuvant intended to be used in conjunction with NIS.

348   Table 2. Regression parameter estimates and glyphosate rate (kg ae ha^{-1}) and adjuvants

349   required to provide 90% yellow nutsedge control (ED$_{90}$ (±SE)) based on visual ratings at 28 d

350   after treatment and tuber production. [a]

| Variable | Adjuvants | Regression parameters[b] (± SE) | | | | ED$_{90}$ (± SE) |
		B	C	D	I$_{50}$	
Injury 28 DAT	AMS alone	-1.67 (0.44)	0.001 (8.7)	110.2 (56.8)	0.82 (0.16)	3.06 (0.89)
	W-7995+NIS	-2.16 (0.51)	0.001 (7.3)	79.8 (11.1)	0.79 (0.11)	2.18 (0.50)
	NIS	-1.60 (0.37)	0.001 (8.6)	108.6 (43.3)	0.54 (0.10)	2.12 (0.62)
Small tubers	Combined [c]	4.22 (1.98)	0.002 (5.79)	23.4 (2.2)	0.95 (0.09)	1.60 (0.27)
Medium tubers	Combined	3.35 (1.20)	0.001 (8.09)	32.3 (3.2)	0.78 (0.10)	1.50 (0.35)
Large tubers	Combined	3.39 (3.73)	0.255 (2.78)	5.9 (1.2)	0.86 (0.44)	1.63 (1.59)
Total tubers	Combined	4.63 (2.54)	-1.118 (17.35)	60.2 (4.8)	1.03 (0.22)	1.66 (0.71)

351   [a] Abbreviations: AMS, ammonium sulfate; DAT, days after treatment; NIS, nonionic surfactant.

352   [b]Parameters: *B*, slope of line; *C*, lower limit; *D*, is the upper limit; *I$_{50}$*, the glyphosate rate needed

353   to cause a 50% visual injury; ED$_{90}$, is the glyphosate rate needed to cause 90% foliar injury or

354   tuber reduction. Values in the brackets represent ± one standard error.

355   [c] The data were pooled across adjuvants within each category and fit to a nonlinear model

356   (equation 1) after ANOVA indicated no difference among adjuvants.

357   Figure Legends

358   Figure 1. Regression lines (Equation 1) were fit to combined yellow nutsedge percent foliar

359   visual injury 28 d after treatment. Data points represent average (replication and years) injury.

360   Regression parameters estimates for glyphosate rates required to provide 50% and 90% injury

361   are presented in Table 2. Values on the x-axis are in log scale.

362

363   Figure 2. Yellow nutsedge tubers produced in response to increasing glyphosate rate in

364   greenhouse studies, 2009-2010, Corvallis, OR. The number of small yellow nutsedge tubers

365   (0.254 to 0.508 cm); medium size (5.08 to 7.6 mm); large size (≥ 7.6 mm); and the total number

366   of tubers pot^{-1} produced were combined across adjuvants and studies. The regression lines are

367   plotted using Equation 1, and parameter values for the glyphosate rates required to obtain 50%

368   and 90% tuber reduction are presented in Table 2. Values on the x-axis are in log scale.

369

370   Figure 3. Percent germination of yellow nutsedge tubers from plants treated with variable

371   glyphosate rates in the greenhouse, 2009 to 2010, Corvallis, OR. Small tubers had a diameter of

372   0.254 to 0.508 cm (3A); medium size were 5.08 to 7.6 mm (3B); large size were ≥ 7.6 mm (3C);

373   and total tuber numbers produced pot^{-1} (3D) were combined across adjuvants and studies.

374   Vertical line represents LSD ($P \leq 0.05$).

361

362   Figure 1.
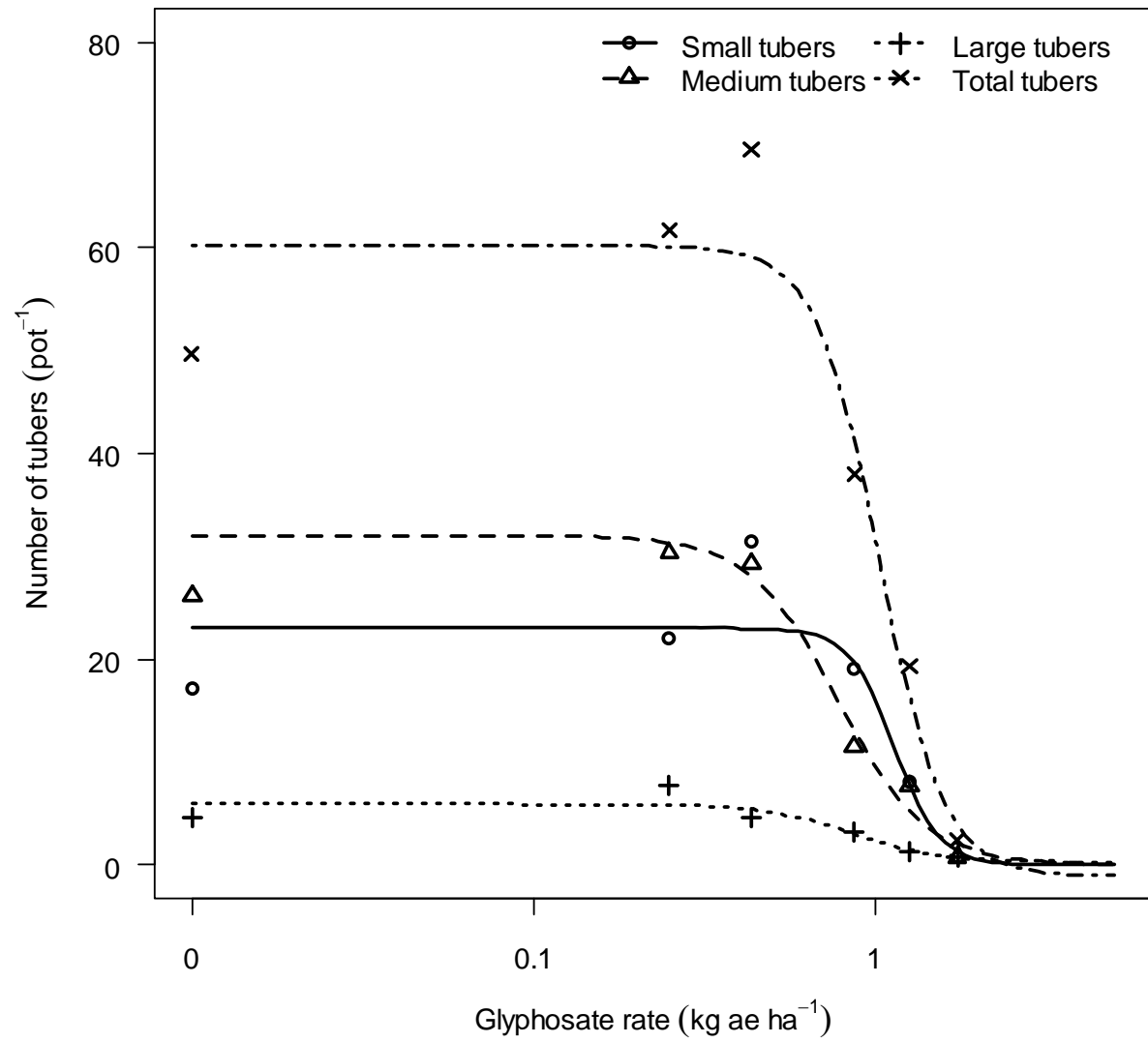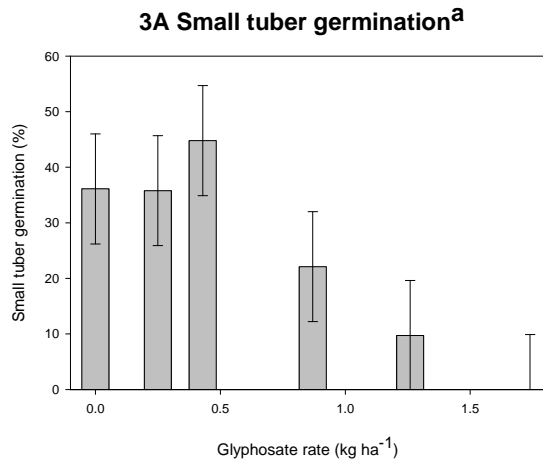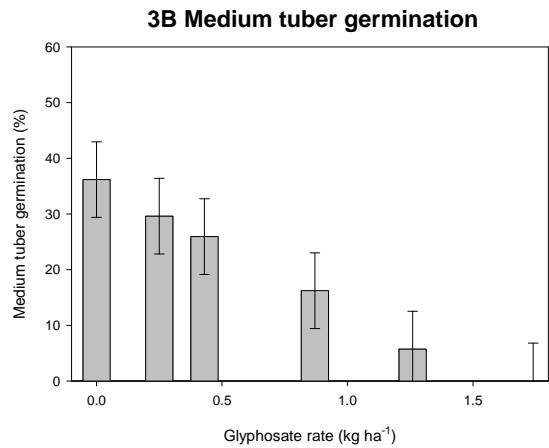
Figure 2

**3A Small tuber germination[a]**

3B Medium tuber germination
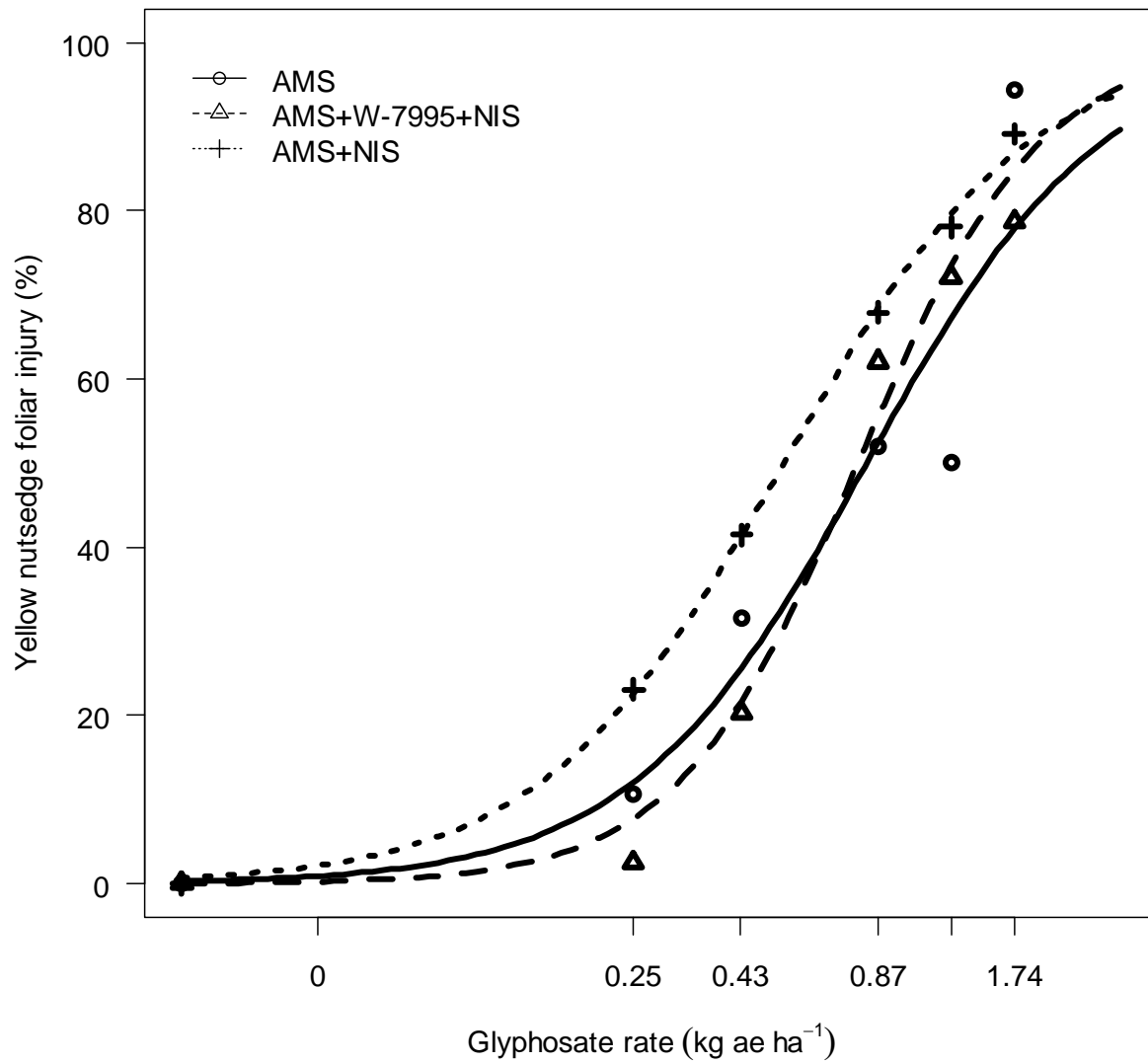
[a]Harvested number of small tubers pot[-1] was 17, 22, 31, 19, 8, and 0 for the untreated, glyphosate at 0.25-, 0.43-, 0.87-, 1.26-, and 1.74 kg ha^{-1}, respectively.

Harvested number of medium tubers pot[-1] was 26, 30, 29, 12, 8, and 1 for the untreated, glyphosate at 0.25-, 0.43-, 0.87-, 1.26-, and 1.74 kg ha^{-1}, respectively.

3C Large tuber germination

3D Total tuber germination
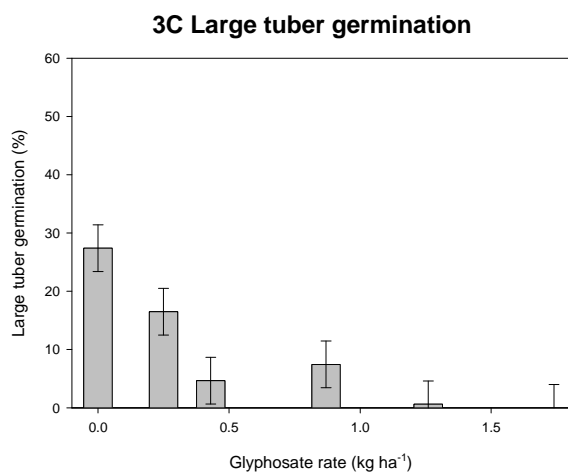
Number of large tubers pot[-1] harvested was 5, 8, 5, 3, 1, and 1 for the untreated, glyphosate at 0.25-, 0.43-, 0.87-, 1.26-, and 1.74 kg ha^{-1}, respectively.
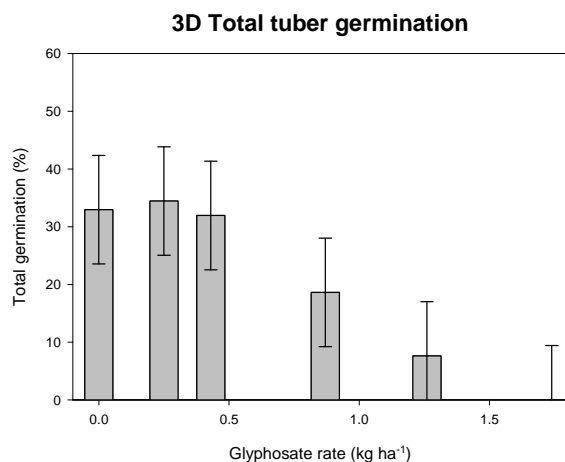
Harvested total number of tubers pot[-1] was 50, 62, 70, 38, 19, and 3 for the untreated, glyphosate at 0.25-, 0.43-, 0.87-, 1.26-, and 1.74 kg ha^{-1}, respectively.

364   Figure 3.

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