Dikegulac-Sodium Sprays Stimulate Shoot Emergence in Asparagus Under Lathhouse Conditions

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Abstract. One-year-old greenhouse-grown 'Mary Washington', 'Emerald', 'UC 157 F₁', and 'UC 157 F₂' asparagus (*Asparagus officinalis* L.) seedlings were sprayed on 23 Sept. 1988 with dikegulac concentrations ranging from 0 to 750 mg-liter⁻¹ in 150-mg-liter⁻¹ increments. No significant shoot emergence occurred before frost killed the ferns in December. With increasing temperature in Jan. and Feb. 1989, dikegulac promoted shoot emergence in all cultivars, except 'Mary Washington'. At 600 mg-liter⁻¹, dikegulac had increased shoot emergence in 'Emerald', 'UC 157 F₁', and 'UC 157 F₂' by 310%, 161%, and 305%, respectively, over the control on 2 Feb. After frosts killed the first shoots, all cultivars responded to treatment as temperature increased. Dikegulac did not affect the height and dry weight of 'Mary Washington' ferns, but it reduced the height of 'Emerald' without affecting its dry weight. Both height and dry weight of 'UC 157 F₁' and 'UC 157 F₂' were reduced by the chemical. There was a significant effect of cultivar on shoot production regardless of treatment, but no significant cultivar × dikegulac interaction on shoot emergence. However, there were significant effects of cultivar and cultivar × dikegulac interaction on height and dry weight of the ferns. After the ferns had been cut off on 9 Aug. 1989, only 'UC 157 F₁' and 'UC 157 F₂' showed increased shoot emergence. A second treatment of the plants with the chemical on 23 Sept. 1989 resulted in no significant increase in shoot emergence before or after freezing temperatures killed the ferns. Chemical name used: 2,3:4,6-bis-(1-methyl ethylidene)-a-L-xylo-2-hexulofuranosonic acid (dikegulac).

The capability of the apical meristem to inhibit the growth of lateral buds is common not only in aerial shoots but also in underground organs, including rhizomes, tubers, stolons, and corms of various plant species (Hillman, 1984; Phillips, 1969). Domination of the apical region over lateral buds is referred to as correlative inhibition (Brenner et al., 1987; Hillman, 1984; Martin, 1987). Asparagus rhizomes also exhibit this phenomenon, characterized by growth suppression of the proximal buds due to the presence of shoots on the crown. This effect results in a progressive emergence of spears during growth and harvest of the plant.

Dikegulac-sodium (Atrinal), a commercially available plant growth regulator, is effective in promoting branching in several plant species, including peach (*Prunus persica*) (Arnold et al., 1983), azalea (DeSilva et al., 1976), *Columnnea microphylla* (Lyons and Hale, 1987), and pepper (*Capsicum annum*) (Matta, 1984). Dikegulac also stimulated shoot emergence under greenhouse conditions, with some residual effects after

the 'Mary Washington' asparagus crowns had been soaked in 300 mg-liter⁻¹ or when the ferns were sprayed with 300 to 500 mg of the compound/liter (Mahotiere et al., 1988, 1989). However, the effect of dikegulac on other asparagus cultivars has not been tested. Also unknown is the effect of exposure of the treated plants to freezing temperatures on the subsequent effectiveness of the chemical.

The objectives of this study were to determine growth and shoot emergence responses of four asparagus cultivars to dikegulac-sodium sprays under conditions simulating field temperatures and to assess further the residual effects of the chemical on the responses of these cultivars.

'Mary Washington', 'Emerald', 'UC 157 F₁', and 'UC 157 F₂' asparagus seedlings were grown in 30-liter pots containing a Pro-Mix medium consisting of 3 peatmoss : 1 perlite : 1 vermiculite (by volume). The medium, with an initial pH of 6.2, was fertilized with ground limestone (CaCO₃) at 30 g/pot, which had raised the pH to 7.1 at the initiation of the dikegulac treatment. Then three seeds were planted per pot on 9 Sept. 1987; seedlings were thinned to one plant per pot. During the growing period, the plants were fertilized monthly with 10 g of 10N-4.5 P-8.3K formulation and watered regularly as needed. The day/night temperatures in the greenhouse were set at 25 and 15C, respectively.

On 16 Aug. 1988, the plants were trans-

ferred to the lathhouse to simulate temperatures in the field. The 1-year-old seedlings were treated with dikegulac on 23 Sept. 1988. The number of shoots was recorded before spray application. Each potted plant was then sprayed to the drip point with the aqueous solutions of the dikegulac-sodium at the rates of 0 to 750 mg-liter⁻¹, at 150-mg-liter⁻¹ increments. Tap water was used as the control solution. Each treatment was replicated 10 times, with one potted seedling as an experimental unit. The pots, set on the ground, were arranged in a split-plot design with cultivars as main plots and treatments as subplots.

By 22 Dec., the ferns were completely killed by freezing temperature. They then were cut at the soil level to prepare the pots for shoot emergence with the rise of soil and air temperatures. Spear emergence in the field starts in early March under normal weather conditions of central Georgia, where this study was conducted. However, the unusually high temperatures recorded in late December and early January triggered early emergence of shoots. Therefore, the first phase of data collection began in January.

Following killing of ferns by freezing temperatures (Phase 1). The unusually high temperature prevailed until the 2nd week of February. During that period, data on cumulative shoot emergence were recorded daily until subsequent frosts killed the ferns. These data are reported on a weekly basis. The frozen shoots were cut at the soil level. The intervening temperature increases in mid-February promoted some insignificant emergence of shoots that subsequently were killed by frost. The emerged shoots were counted on a daily basis.

Following killing of first recorded shoots by freezing temperatures (Phase 2). In late February/early March and thereafter, the gradually rising temperatures triggered emergence of new shoots. Cumulative data on shoot number were recorded weekly from 3 Mar. through 7 Aug. 1989. The data are reported on a biweekly basis through 3 May. On 8 Aug., the plants were cut at the soil level and the length and dry weight of the shoots were measured.

Following cutting off of ferns (Phase 3). Shoot emergence subsequent to removal of the ferns was recorded weekly, and the height of the plants was measured on 9 Sept. On 23 Sept. 1989, the plants received a second application of dikegulac using the same concentrations and methods as previously described. The number of shoots in each pot was recorded before the ferns were sprayed. Then data on cumulative number of new shoots were recorded weekly until freezing temperatures killed the ferns in late fall. In early Jan. 1990, the dead ferns were cut at the soil level.

Following killing of treated ferns by freezing temperatures (Phase 4). Increasing temperature from mid-January on triggered shoot emergence. The cumulative number of new shoots was recorded daily until 9 Feb. 1990, when the experiment was terminated. These data are reported on a weekly basis for 4 weeks.

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Table 1. Effect of dikegulac sprays on shoot emergence of asparagus seedlings after the ferns had been killed by low temperatures (Phase 1).

Cultivar ^a	Dikegulac (mg·liter ⁻¹)	Cumulative no. shoots after emergence 1989			
		5 Jan.	18 Jan.	2 Feb.	9 Feb.
Emerald	0	0.2	0.8	1.0	2.0
	150	0.6	1.4	2.7	3.6
	300	0.8	1.6	2.3	3.6
	450	0.4	0.8	1.2	1.9
	600	2.3	4.1	4.7	5.8
	750	2.2	3.7	4.3	4.7
Linear		*	*	*	NS
Quadratic		NS	*	NS	NS
UC-157-F ₁	0	0.3	2.1	2.3	3.6
	150	0.9	2.3	3.0	3.7
	300	2.2	3.7	4.4	5.2
	450	2.3	4.3	5.2	5.4
	600	4.0	5.8	6.0	7.4
	750	4.7	7.7	7.8	9.4
Linear		***	***	***	***
Quadratic		***	***	***	***
UC-157-F ₂	0	0.9	1.8	1.9	2.2
	150	0.4	2.0	2.4	3.3
	300	2.7	4.3	4.4	5.0
	450	1.1	2.3	2.8	3.8
	600	6.0	7.4	7.7	8.2
	750	2.4	3.7	3.7	3.7
Linear		**	**	*	NS
Quadratic		*	*	*	NS
ANOVA					
Treatment (T)		***	***	***	***
Cultivars (C)		*	***	**	***
T × C		NS	NS	NS	*

^aTreatment had no significant effect on 'Mary Washington'.

NS,*,***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Regression analysis and analysis of variance (ANOVA) were performed on all data.

Phase 1. Dikegulac promoted shoot emergence in all cultivars, except 'Mary Washington' (Table 1). The concentrations of 600 and 750 mg·liter⁻¹ were most effective. 'Emerald' and 'UC 157 F₂' showed their highest response at 600 mg·liter⁻¹, whereas 'UC 157 F₁' showed its highest response at 750 mg·liter⁻¹.

We previously reported that soaking 'Mary Washington' in 300 mg·liter⁻¹ or spraying the ferns with 300 to 500 mg dikegulac/liter stimulated shoot emergence in greenhouse studies (Mahotiere et al., 1988, 1989). Yet, in Phase 1 of this experiment, 'Mary Washington' did not respond to the treatments at the level of probability tested, although there was a trend for increased number of shoots at the 300-mg·liter⁻¹ rate. Early spear emergence has been positively correlated with the vigor of the asparagus plants (Ellison et al., 1960). Low vigor of 'Mary Washington' as compared to the other cultivars may have been responsible for the lack of response in Phase 1. The reverse would be true for the vigorous 'UC 157 F₁', which responded in a highly significant manner in the first week of spear emergence.

As indicated by the lack of treatment × cultivar interaction, the overall response of the cultivars to dikegulac was similar. However, there was a significant cultivar effect on shoot production, regardless of treatment. 'UC 157 F₁' was the dominant shoot producer, followed in order by 'UC 157 F₂',

'Emerald', and 'Mary Washington'. 'Mary Washington' and 'Emerald' are dioecious cultivars, whereas 'UC 157 F₁' and 'UC 157 F₂' are androecious. Male plants produced more spears than females or mixed cultivars (Corriols and Doré, 1989; Ellison et al., 1960; Franken, 1970). In field trials, 'UC 157 F₁' produced higher yield and higher number of shoots per plant than most other cultivars (Hoult, 1987; Knaflowski, 1987). Therefore, its high shoot-producing ability displayed in this study is not surprising.

Phase 2. The sudden drop in temperature on 10 Feb. 1989 and the accompanying frosts killed the shoots produced in Phase 1. The subsequent increase in temperature from 11 to 18 Feb. 1989 triggered insignificant emergence of shoots, which were also destroyed by frost around 23 Feb. (data not shown). Therefore, Phase 2 of shoot emergence started in late Feb./early Mar. 1989. 'UC 157 F₁' was the first to respond to the treatments, thus demonstrating again its superior vigor (Table 2). It was followed by 'Mary Washington', which had not responded in Phase 1.

The cultivars differed in their growth response to the treatments (Table 2). In accordance with previous studies, dikegulac did not affect height and dry weight of 'Mary Washington' (Mahotiere et al., 1988, 1989). But, 600 and 750 mg·liter⁻¹ reduced the height of 'Emerald', 'UC 157 F₁', and 'UC 157 F₂' and the dry weight of 'UC 157 F₁' and 'UC 157 F₂'.

In contrast to the response in shoot pro-

duction, height of the cultivars did not differ significantly. However, cultivars showed different abilities to produce dry weight, regardless of treatment. 'UC 157 F₁', which showed early and consistent shoot production response to the chemical in Phases 1 and 2, accumulated the highest dry weight. Dry matter accumulation is a measure of plant growth. Therefore, these findings are consistent with the behavior of some cultivars, particularly 'UC 157 F₁', with respect to early emergence and increased number of new shoots.

Phase 3. Contrary to their behavior in the previous phases, 'UC 157 F₁' and 'UC 157 F₂' did not respond early to the treatments in Phase 3. The number of shoots produced was also smaller than in Phases 1 and 2. 'Mary Washington' and 'Emerald' did not respond at all, which explains the late-season treatment × cultivar interaction (Table 3).

The general lack of effectiveness of the chemical in this phase is not surprising. In a previous study, it also failed to stimulate shoot emergence in 'Mary Washington' in Phase 3 (Mahotiere et al., 1989). This result had been attributed to the end of the residual effects of the chemical or to the depletion of carbohydrate reserves in storage roots. But in this study, 'UC 157 F₁' and 'UC 157 F₂' showed some response to the chemical. In addition, as in Phase 2, dikegulac reduced height of 'UC 157 F₁' and 'UC 157 F₂' (Table 3). The effect of dikegulac in reducing plant height is well documented (Lyons and Hale, 1987; Malstrom and McMans, 1977; Schnall, 1978). However, different patterns of height responses to dikegulac, including no response at all, were noted among six cultivars of kalanchoe (Nightingale et al., 1985). Therefore, the reduction of height by the chemical in half of the cultivars casts doubt about the end of its residual effect. Also, even 'UC 157 F₁', which showed an early and strong response to the chemical in the previous phases (Tables 1 and 2), showed a late and weak response to the chemical in Phase 3. Asparagus plants produce and store carbohydrates for spear production and fern growth in the following year (Scott et al., 1939). But, the length of harvest also decreases soluble carbohydrates in the storage roots (Sanders, 1985; Shelton and Lacy, 1988). Carbohydrates also decrease in the roots during the early stage of fern growth and start increasing during fern maturation, reaching a maximum after the stalks reach maturity (Shelton and Lacy, 1980). Similarly, in this study, the killing of emerged shoots by frost around 9 and 23 Feb. and the cutting of the stalks in summer, before they may have reached maturity, may have contributed to the depletion of carbohydrate reserves in the storage roots.

Phase 4. In contrast to the effectiveness of dikegulac in the previous phases, the second application of the chemical promoted no significant increase of shoot emergence in any of the cultivars tested (data not shown). Also, cultivar differences in shoot production disappeared.

Even 'UC 157 F₁' and 'UC 157 F₂', which

Table 2. Residual effect of dikegualac sprays on shoot emergence after the previous shoots had been killed by freezing temperature (Phase 2).

Cultivar	Dikegualac (mg·liter ⁻¹)	Cumulative no. of shoots after emergence 1989					Terminal shoot growth	
		7 Mar.	21 Mar.	4 Apr.	18 Apr.	3 May	Ht (cm)	Dry wt (g)
Mary Washington	0	1.2	4.1	4.4	4.6	4.7	153	58.3
	150	1.8	6.2	6.7	6.8	7.6	208	81.3
	300	3.8	7.8	8.6	8.6	9.2	161	53.3
	450	2.9	6.7	7.6	7.9	8.4	183	68.1
	600	2.0	6.3	6.8	7.2	7.7	171	68.2
	750	1.6	7.8	8.4	8.9	10.1	169	61.3
Linear		NS	*	*	*	**	NS	NS
Quadratic		NS	NS	NS	**	*	NS	NS
Emerald	0	1.6	5.2	6.0	6.2	7.1	190	78.0
	150	1.9	6.1	6.9	6.1	6.7	181	76.2
	300	1.6	5.2	5.7	6.2	7.8	173	74.3
	450	2.0	5.6	5.6	6.3	6.8	187	78.0
	600	2.9	8.6	9.4	10.2	13.9	144	60.8
	750	1.7	6.0	7.2	7.7	9.1	170	72.8
Linear		NS	NS	NS	*	**	*	NS
Quadratic		NS	NS	NS	NS	**	NS	NS
UC-157-F ₁	0	2.4	6.0	6.9	7.0	7.9	201	95.2
	150	1.9	5.6	6.1	6.3	7.6	187	81.4
	300	2.4	6.7	8.7	8.9	9.6	182	78.9
	450	2.9	8.6	10.0	10.6	11.2	170	80.1
	600	2.1	9.8	10.2	10.2	10.1	170	80.1
	750	0.6	10.4	12.7	13.0	16.2	150	78.6
Linear		*	***	***	***	***	***	***
Quadratic		**	***	***	***	***	***	***
UC-157-F ₂	0	1.6	3.7	4.1	4.2	4.9	171	72.6
	150	2.3	3.7	6.2	6.2	6.3	168	80.3
	300	1.3	5.8	6.4	6.7	7.3	175	79.3
	450	2.0	5.2	6.3	6.6	6.7	175	82.9
	600	2.1	7.8	8.4	9.3	9.7	161	59.8
	750	0.7	5.3	6.8	7.7	9.6	139	38.6
Linear		NS	NS	*	**	**	**	***
Quadratic		NS	NS	NS	*	*	**	***
ANOVA								
Treatment (T)		NS	***	***	***	***	***	***
Cultivars (C)		**	***	***	***	***	NS	***
T × C		NS	NS	NS	NS	NS	***	**

NS,*,**,*Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 3. Residual effect of dikegualac sprays on shoot emergence after the previous shoots had been cut (Phase 3).

Cultivar ^a	Dikegualac (mg·liter ⁻¹)	Cumulative no. of shoots after emergence 1989					Terminal shoot growth	
		14 Aug.	22 Aug.	29 Aug.	6 Sept.	13 Sept.	Ht (cm)	
UC-157-F ₁	0	3.3	5.4	7.2	8.5	10.4	199	
	150	3.2	5.11	5.9	6.7	7.7	196	
	300	3.8	8.0	9.8	12.0	15.43	173	
	450	3.7	7.3	9.8	11.4	14.0	186	
	600	3.1	6.4	7.2	9.2	12.8	178	
	750	5.9	6.7	8.0	10.8	13.0	161	
Linear		NS	NS	NS	**	*	***	
Quadratic		NS	NS	NS	**	*	**	
UC-157-F ₂	0	2.0	5.1	5.4	8.0	10.8	158	
	150	3.1	5.3	6.6	7.8	10.0	184	
	300	2.0	5.2	6.3	8.2	9.6	157	
	450	1.6	5.4	7.3	9.3	11.8	177	
	600	1.4	4.8	6.6	7.9	10.3	146	
	750	1.0	2.9	3.7	5.3	5.8	92	
Linear		NS	NS	NS	NS	NS	*	
Quadratic		NS	**	**	NS	NS	***	
ANOVA								
Treatment (T)		NS	NS	NS	NS	NS	***	
Cultivars (C)		***	***	**	*	*	***	
T × C		NS	NS	NS	**	**	*	

^aTreatment had no significant effect on 'Mary Washington' or 'Emerald'.

NS,*,**,*Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

consistently responded to the chemical in the three previous phases, failed to respond in Phase 4. The most potent responses to the chemical, as measured by percent increase of shoots over the controls and shoot number, were obtained in Phases 1 and 2 for all cultivars. For example, at 750 mg·liter⁻¹ 'UC 157 F₁' had 9.4, 16.2, and 13.0 shoots/plant at the end of Phases 1, 2, and 3, respectively, while the controls had 3.6, 7.9, and 10.4 (Tables 1-3). These data suggest that, particularly in phases 1 and 2, the control plants, in producing fewer shoots, would have used less carbohydrates or fewer buds for shoot emergence. Thus, contrary to the treated plants, they were able to produce shoots at a normal and progressive rate during the course of the experiment. A preliminary study also indicated that 500 mg dikegualac/liter was more effective in stimulating shoot emergence in 2-year-old than 1-year-old crowns (Mahotiere et al., 1988). In light of this evidence, plant age is an unlikely explanation for this lack of response. These results cannot be attributed to temperatures 'either, for the temperatures in Jan. and Feb. 1990 were higher and more consistent than in 1989 (data not shown). Presumably, at the time of the second treatment, the stalks had not reached physiological maturity, which, as demonstrated by Shelton and Lacy (1980), coincides with the maximum carbohydrate level in the storage roots. Reduction in number of buds resulting from increased shoot emergence recorded in the previous phases is a possible explanation. Lack of effectiveness of dikegualac application in Phase 4 can be more plausibly explained by depletion of the plants than by termination of the residual effect of the chemical, a hypothesis that needs testing.

In conclusion, after freezing temperatures killed the ferns, dikegualac-sodium stimulated shoot emergence in all four asparagus cultivars tested, with lasting residual effects. If substantiated by field investigations, simultaneous and abundant spear emergence would reduce the number of passes in the field, thus shortening the harvest season and increasing early yields when prices are high.

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