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The effect of surfactant foliar applications on tomato, pepper, watermelon, and cabbage transplant growth.

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Introduction

Typically, the life span of a surfactant in a soilless medium is about six months. After this time the medium becomes increasingly difficult to wet thoroughly due to the hydrophobic nature of the peat. Surfactant application via irrigation with plants in place is not a standard practice in the vegetable transplant business, however it may be recommended in certain circumstances such as when media has been stored a long time or to achieve maximum "wettability" prior to field setting. The purpose of this trial was to screen tomato, pepper, watermelon, and cabbage seedlings for phytotoxicity when experimental surfactants were applied to the foliage approximately two weeks prior to field setting.

Methods

A trial was established at the Southwest FI Research and Education Center of the University of Florida in Immokalee, FL to test the foliar applied surfactant response. Aquatrols (Cherry Hill, NJ) surfactant formulations ACA 1513, ACA 1514, and ACA 1515 were added to irrigation water at rates of 0, 600, 1200, 2400, 3600, 4800, 9600, and 12,000 ppm and applied as a drench covering the foliage of tomato, pepper, watermelon, and cabbage seedlings. The particular material and rate was brought to volume in two liters of reverse osmosis water and applied via a standard watering can with a specially mounted flat fan head for even distribution.

The target date for surfactant application was two weeks prior to transplant field setting. Therefore, tomato, pepper, and cabbage seedlings were treated in week four and watermelon was treated in week two of the production cycle. This time frame assured that the seedlings were not overly "hardened" so as to heighten the phytotoxic response. Tomato, pepper, or cabbage transplants raised in 242 cell flats were transferred, a few days prior to testing, to smaller 20 cell flats and watered in. Watermelons were raised directly in the 20 cell flats due their fragility at two weeks of age.

The rigors of scheduling during spring production necessitated that the crops were treated on different dates. Tomato `Agrisett' and pepper `Aladdin X3R' (both PetoSeed, Saticoy, CA) were treated on Jan. 7, 1998, while cabbage `Conquest' (Asgrow, Kalamazoo, MI) and watermelon `Sangria' (Rogers Seed, Gilroy, CA) were treated on Feb. 26, 1998. Treatments were applied randomly between 9:30 a.m. and noon. All treatments were replicated three times and deployed in a randomized complete block design.

Plants were visually evaluated for 5 days following surfactant foliar application for signs of phytotoxicity such as necrosis, discoloration or stunting. Fourteen days after treatment (DAT) five seedlings from each treatment were "pulled" to determine various greenhouse growth parameters such as stem length and diameter, leaf area, dry weight of the leaf/stem/root/shoot, and where appropriate, leaf:stem and root:shoot ratio.

Air temperatures during the trial ranged from the low 50's to mid 80's. A March storm removed a single layer of the greenhouse roof increasing light levels encountered in the watermelon and cabbage trial (14.5 - 19.0 MJ/m²/day) compared to those observed in the tomato and pepper trial (9.5 - 11.0 MJ/m²/day). All data were analyzed by ANOVA (SAS) with mean separation via Fisher's Protected LSD at p<0.05.

The objective of this study was to determine which surfactant(s) at which rate(s) could be most effectively used with a number of vegetable crops without resulting in phytotoxicity. Therefore, emphasis was placed on differences that resulted from the use of surfactant or particular rates compared to the results noted in the control seedlings. Where differences between surfactants pointed to an obvious choice of one surfactant over another this also was stressed. Differences deemed minor or anomalous within or between surfactants and/or rates were noted, but not stressed.

Results

Tomato

No immediate phytotoxic effect resulted from the foliar application of any surfactant at any rate in tomato. However, two weeks following treatment, when plants were destructively sampled, "hidden" phytotoxic effects on growth were manifested.

By Surfactant. ACA 1514 exhibited a lower root to shoot ratio than ACA 1515 indicating a tendency of plants treated with a 1514 drench to partition more carbon into shoots (Table 1).

By Rate. The major effect of surfactant application in tomato was a response to rate (Table 1). It was noted that treatment with high rates of surfactant caused a "yellowing" of the cotyledons (ranking 1 - none, 5 - maximum) which progressed with time, to cotyledon loss. Tomato seedlings treated with rates equal to or exceeding 4800 ppm exhibited a significant decline in cotyledon number.

A linear decrease in leaf dry weight (DW) with increasing surfactant rate occurred. Leaf DW at surfactant rates equal to or exceeding 4800 ppm was significantly lower than the control. Reductions in leaf DW further impacted the leaf:stem and root:shoot ratio. Increasing surfactant rate above 600 ppm reduced the leaf:stem ratio indicating a unit of stem supported a smaller unit of leaf compared to the control. The root:shoot ratio of

plants treated with 12,000-ppm surfactant was comparable to the control but greater than most other surfactant rates. This can be explained by the fact that while root dry weight remained similar among the treatments, leaf DW declined with rate.

Over All Surfactants & Rates. Table 1 offers the opportunity to compare certain surfactants at certain rates with other surfactants at that or other rates. An averaged control was used to aid in the interpretation of the data in this section (i.e., the control mean for the individual surfactant comparisons summed and averaged). These data show significance was achieved in the areas of cotyledon loss, leaf DW, leaf:stem ratio, and root:shoot ratio. Cotyledon loss appeared most significant with the use of ACA 1514 at 12,000 ppm. Leaf DW was most reduced by 12,000 ppm regardless of surfactant, but the use of ACA 1515 at rates greater than 3600 ppm also lead to significant DW loss. Leaf:stem ratios were generally lower with higher surfactant rates, but ACA 1514 and 1515 exhibited more consistent rate related reductions.

Rate Within Surfactant. Table 2 compared the rate effect within an individual surfactant. ACA 1514 exhibited four instances of significance whereas ACA 1513 and 1515 only offered one instance of significance each. Cotyledon color and subsequently leaf loss increased with increasing rate in ACA 1514 with the greatest losses occurring at 9600 and 12,000 ppm (Table 2). Leaf DW loss in ACA 1515 was most significant above 2400 ppm. Leaf:stem ratio reductions with increasing surfactant rate were significant in ACA 1513 above 9600 ppm and ACA 1514 above 3600 ppm. And, the root:shoot ratio of plants treated with ACA 1514 at 12,000 ppm was greater than all other rates used.

Pepper

By Surfactant. Four-week-old pepper seedlings showed no phytotoxic response to a foliar drench with surfactants ACA 1513, 1514, and 1515, but plant measurements two weeks later revealed several “hidden” impacts of surfactant treatment (Table 3). ACA 1515 exhibited a greater leaf DW than 1513 and a greater root dry weight than 1514. Furthermore, ACA 1513 showed a higher root:shoot ratio than 1514.

By Rate. Rate played a dominant role in these data. All rates of surfactant reduced pepper leaf DW accumulation compared to the control (Table 3). Surfactant driven reductions in leaf DW lead to a decrease in total shoot DW for plants subjected to 1200 ppm and 3600 through 12,000 ppm surfactant. The decline in shoot DW was generally linear in fashion. Similarly the leaf:stem ratio was significantly lower in plants treated at 1200 ppm surfactant or greater compared to the control. Pepper seedling root:shoot ratios varied among rates, but none differed from the control.

Over All Surfactants & Rates. Stem diameter ranged from 2.12 (ACA 1515 at 3600 ppm) to 2.32 (ACA 1513 at 3600 ppm) as modified by surfactant drench (Table 3). In all but the former case, the stems of plants not treated with surfactant drenches were similar in diameter to plants from all surfactants at all rates.

All surfactants at rates of 3600 ppm or greater reduced leaf DW when compared to the averaged control (0.0697 g). ACA 1513 reduced leaf DW at all drench rates except 600 ppm and plants treated with ACA 1514 at 1200 ppm also exhibited a reduction in leaf DW. Shoot DW was negatively affected by surfactant drenches primarily at rates of 9600 to 12,000 ppm (additionally ACA 1513 at 1200 ppm, ACA 1514 at 4800 ppm) compared to the averaged control (0.1234 g).

Surfactant impact on leaf and shoot dry weights consequently influenced leaf:stem ratio and root:shoot ratio. Essentially all surfactants at rates greater than 1200 ppm reduced the leaf:stem ratio compared to the averaged control (1.301). Plants drenched with ACA 1513 at 9600 and 12,000 ppm achieved a greater root:shoot ratio and those drenched with ACA 1514 at 1200 ppm achieved a lower root:shoot ratio than the averaged control (0.503).

Rate Within Surfactant. The overwhelming responses to rate within surfactant were again in leaf DW and consequently shoot DW with associated changes in leaf:stem and root:shoot ratio (Table 4). The stem diameter response in ACA 1515 and true leaf number response in ACA 1513 bare further investigation, but are believed to perhaps be anomalies. The significantly lower root DW exhibited by all rates of ACA 1515 appeared to be a function of the control treatment within that trial. In general, root DW values in the ACA 1515 treatment were no different than those derived from other surfactants (Table 3) and in fact root DW variability was lower with ACA 1515 treatment.

Watermelon

By Surfactant. The phytotoxicity observed in the watermelon seedlings (Table 5) exposed to these surfactants was simply a yellowing of the foliage (ranking 1 - none, 5 - maximum). The yellowing was actually more of a paleness of leaf color even at the extreme and would most likely not affect the sale of the seedlings. While all surfactants registered mild leaf yellowing ACA 1514 exhibited more than ACA 1513, but was comparable to ACA 1515.

By Rate. Increasing surfactant rate increased the incidence of yellowing in watermelon seedling foliage (Table 5). Rates of 3600 ppm and greater showed significantly more yellowing than lower surfactant rates. Analysis of watermelon leaf area, shoot DW, and whole plant DW indicated a maximum surfactant rate of 4800 ppm before impeded shoot growth resulted. Root dry matter accumulation (often considered the focus of vegetable transplant growers) was reduced by rates greater than 2400 ppm.

It is interesting that the obvious visual response of yellowing, predicted the hidden phytotoxic responses of impeded growth. Furthermore root DW reductions, which occurred at rates lower than those that triggered leaf color loss, may have provoked the yellowing. Additionally, lower surfactant rates (< 2400 ppm) appeared to enhance seedling shoot growth, perhaps as the result of increased water availability. At four weeks the watermelon shoot is essentially all leaf tissue hence the leaf:stem ratio data were omitted here.

Over All Surfactants & Rates. The 12,000 ppm rate (Table 5), regardless of surfactant, resulted in the greatest differences in phytotoxicity rating, leaf area, shoot DW, root DW, whole plant DW compared to an averaged control (1.0, 17.38 cm², 0.1574 g, 0.034 g, 0.1919 g respectively). ACA 1514 exhibited more yellowing than the other surfactants (3600 – 12,000 ppm), but ACA 1513 showed more sensitivity to growth reductions in shoot and root DW (4800 – 12,000 ppm).

Rate Within Surfactant. Watermelon seedling phytotoxic response to surfactant drenches became significantly apparent at 3600 ppm with ACA 1514, but not until 9600

ppm with ACA 1513 or 1515 (Table 6). Other deviations from the control means included ACA 1514 and 1515 leaf area and root DW, both at 12,000 ppm, and ACA 1515 shoot DW and whole plant DW which were different at 4800 ppm, not different at 9600 and again different at 12,000 ppm.

Cabbage

By Surfactant. Phytotoxicity as foliar necrosis was noted within 24 hours of surfactant drench in this trial and progressed slightly over the following two days (Table 7). Initially, ACA 1515 exhibited the greatest level of phytotoxicity. Consequently two weeks after application ACA 1515 exhibited a leaf area that was significantly reduced compared to ACA 1514. Due to the excesses in phytotoxicity, leaf:stem and root:shoot ratio data have been omitted as these data were essentially meaningless.

By Rate. The first two phytotoxicity ratings showed all rates over 600 ppm were excessive when applied as a foliar drench to four-week-old cabbage seedlings (Table 7). However, with respect to plant parameters measured two weeks following drench application it was apparent that surfactant rates in excess of 1200 ppm resulted in decreased leaf area, shoot DW, Root DW, and whole plant DW. Leaf area reductions of approximately one half (at 9600 ppm) and two thirds (at 12,000 ppm) can be expected with high rates of surfactant drenches.

Over All Surfactants & Rates. These data (Table 7) while meaningful are perhaps less informative than the previous and following data. With the severity of phytotoxicity displayed in this trial the results are extremely clear cut obviating the necessity of comparing a particular surfactant at one rate with another at a different rate.

Rate Within Surfactant. An analysis of these data clearly describes the rate within surfactant effect. Cabbage plant leaf area, shoot DW, Root DW, and whole plant DW, two weeks following surfactant drenches distinctly show the maximum rate of surfactant for ACA 1513, 1514, and 1515 were 2400, 2400, and 1200 ppm respectively (Table 8). Significant phytotoxic responses, interestingly, appeared to be in general at the rate preceding the maximum rates mentioned above.

Discussion

In summary, all surfactant formulations could be used in tomato, pepper, and watermelon without fear of phytotoxicity provided appropriate rates were adhered to. Four-week-old tomato seedlings (i.e., at treatment application) appeared to be slightly more sensitive to ACA 1514 than to 1513 or 1515 as evidenced by the number of significant events observed in the data. The greatest impact of excessive surfactant rate on tomato was a reduction in leaf DW and possible cotyledon loss. An appropriate use rate for tomato would be less than 4600 ppm.

Four-week-old pepper seedlings appeared to be slightly more sensitive to ACA 1513 as evidenced by the greater reduction in leaf DW. The greatest impact of surfactant rate in pepper was a reduction in leaf DW beginning at 600 ppm. On an individual basis however, ACA 1514 did not show leaf DW reductions below 3600 ppm. General shoot DW loss, as a consequence of leaf DW losses particularly in ACA 1513 and 1515, further

altered the leaf:stem and root:shoot ratio in all surfactant treated plants. An appropriate use rate for pepper would be less than 2400 ppm.

Two-week-old watermelon seedlings appeared to be slightly more sensitive to ACA 1515 as evidenced by reductions in leaf area, shoot DW, root DW and whole plant DW. A reduction in root DW recorded for ACA 1514 may also be of concern. The By Rate data indicate that a negative impact on root DW may begin with rates as low as 3600 ppm. An appropriate use rate for watermelon would be less than 3600 ppm.

None of the surfactant formulations can be used on four-week-old cabbage transplants without fear of phytotoxicity. As previously stated light levels in this trial (which included watermelon) were significantly higher than those observed in the tomato and pepper trials. Additionally, the cabbage transplants, while not exhibiting wilt symptoms may have been of the verge of water stress when treated. Furthermore, this crop is known for its waxy cuticle that would perhaps undergo greater modification with the application of surfactant materials than the other crops tested. If a choice had to be made concerning the use of one of these surfactants it appeared that ACA 1513 had the lowest incidence of impact on cabbage seedlings. However, to err on the side of safety one would not want to apply more than 600 ppm.

This analysis does not logically point to a particular surfactant at a particular rate for all the crops tested. It should also be pointed out that these data were collected during a time frame when environmental stresses were at a minimum in south FL and testing during peak stress periods (Aug. or Sept.) would be advised. Further work is suggested before a commitment can be made concerning these materials.

Table 1. Tomato plant parameters 2 weeks after surfactant drench – main and overall effects.

Treatment	Stem Length (cm)	Stem Diameter (mm)	Cotyledon Rating	Cotyledon (no.)	Leaf Area (cm ²)	Leaf DW (g)	Stem DW (g)	Root DW (g)	Shoot DW (g)	Leaf Stem Ratio	True Leaf (no)	Root Shoot Ratio
By Surfactant												
ACA1513	10.4	2.20	1.5	1.7	19.00	0.0755	0.0597	0.0528	0.1352	1.269	3.3	0.392
ACA1514	10.3	2.21	1.5	1.8	18.84	0.0738	0.0587	0.0513	0.1325	1.258	3.3	0.388
ACA1515	10.4	2.19	1.4	1.8	18.94	0.0724	0.0580	0.0533	0.1304	1.248	3.3	0.409
LSD 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.014
By Rate												
0	10.2	2.23	1.4	1.9	19.44	0.0788	0.0589	0.0551	0.1377	1.337	3.4	0.401
600	10.2	2.16	1.4	1.9	18.59	0.0750	0.0570	0.0516	0.1320	1.319	3.1	0.392
1200	10.4	2.18	1.6	1.9	18.67	0.0743	0.0590	0.0503	0.1333	1.258	3.2	0.377
2400	10.4	2.21	1.5	1.8	19.14	0.0750	0.0604	0.0520	0.1354	1.243	3.3	0.385
3600	10.5	2.19	1.4	1.9	19.04	0.0746	0.0586	0.0519	0.1332	1.272	3.3	0.390
4800	10.5	2.20	1.5	1.7	18.80	0.0728	0.0589	0.0518	0.1317	1.237	3.3	0.394
9600	10.5	2.21	1.6	1.6	18.82	0.0716	0.0594	0.0534	0.1310	1.206	3.4	0.408
12000	10.4	2.23	1.6	1.5	18.90	0.0691	0.0581	0.0536	0.1272	1.193	3.4	0.422
LSD 5%	NS	NS	NS	0.2	NS	0.0050	NS	NS	NS	0.057	NS	0.022
Over All Surfactants & Rates												
ACA1513 0	10.1	2.23	1.5	1.8	19.25	0.0802	0.0597	0.0568	0.1399	1.350	3.1	0.410
600	10.0	2.18	1.4	1.9	19.02	0.0769	0.0564	0.0530	0.1333	1.379	3.2	0.398
1200	10.5	2.19	1.5	1.9	18.70	0.0741	0.0598	0.0507	0.1339	1.237	3.1	0.379
2400	10.5	2.17	1.5	1.5	18.66	0.0741	0.0582	0.0522	0.1323	1.285	3.2	0.398
3600	10.4	2.19	1.3	2.0	19.55	0.0768	0.0602	0.0519	0.1370	1.280	3.4	0.382
4800	10.6	2.21	1.6	1.9	18.80	0.0751	0.0587	0.0504	0.1338	1.300	3.3	0.379
9600	10.5	2.25	1.9	1.5	19.42	0.0760	0.0645	0.0542	0.1405	1.185	3.4	0.388
12000	10.4	2.20	2.0	1.5	18.63	0.0710	0.0599	0.0534	0.1309	1.182	3.5	0.409
ACA1514 0	10.2	2.27	1.5	1.9	19.28	0.0765	0.0580	0.0525	0.1345	1.328	3.6	0.392
600	10.3	2.15	1.1	1.9	18.37	0.0751	0.0569	0.0501	0.1320	1.321	3.1	0.380
1200	10.1	2.23	1.5	1.9	18.86	0.0743	0.0573	0.0501	0.1316	1.302	3.3	0.381
2400	10.5	2.21	1.6	1.9	18.82	0.0769	0.0622	0.0486	0.1391	1.234	3.1	0.349
3600	10.2	2.19	1.6	2.0	18.77	0.0756	0.0571	0.0523	0.1326	1.329	3.2	0.395
4800	10.7	2.22	1.6	1.7	19.19	0.0748	0.0615	0.0524	0.1363	1.228	3.5	0.387
9600	10.5	2.19	1.7	1.7	18.58	0.0701	0.0583	0.0522	0.1284	1.207	3.3	0.407
12000	10.2	2.24	1.8	1.4	18.82	0.0669	0.0585	0.0524	0.1254	1.148	3.3	0.418
ACA1515 0	10.2	2.18	1.3	1.9	19.79	0.0796	0.0590	0.0560	0.1386	1.350	3.4	0.405
600	10.3	2.14	1.6	1.9	18.37	0.0729	0.0576	0.0518	0.1305	1.269	3.1	0.399
1200	10.4	2.13	1.7	1.9	18.46	0.0745	0.0600	0.0502	0.1346	1.244	3.2	0.373
2400	10.3	2.26	1.5	1.8	19.96	0.0740	0.0608	0.0553	0.1348	1.225	3.5	0.411
3600	10.8	2.19	1.4	1.8	18.79	0.0714	0.0587	0.0514	0.1301	1.221	3.3	0.399
4800	10.2	2.16	1.3	1.5	18.40	0.0683	0.0566	0.0526	0.1250	1.216	3.3	0.421
9600	10.3	2.20	1.5	1.7	18.46	0.0687	0.0555	0.0537	0.1242	1.240	3.3	0.435
12000	10.6	2.24	1.6	1.6	19.26	0.0695	0.0558	0.0552	0.1253	1.253	3.4	0.441
LSD 5%	NS	NS	NS	0.4	NS	NS	NS	NS	NS	0.099	NS	0.039

Table 2. Tomato plant parameters 2 weeks after surfactant drench – individual surfactant data.

Surfactant & Rate (ppm)	Stem Length (cm)	Stem Diameter (mm)	Cotyledon Rating	Cotyledon (no)	Leaf Area (cm ²)	Leaf DW (g)	Stem DW (g)	Root DW (g)	Shoot DW (g)	Leaf Stem Ratio	True Leaf (no)	Root Shoot Ratio
ACA1513 0	10.1	2.23	1.5	1.8	19.25	0.0802	0.0597	0.0568	0.1399	1.350	3.1	0.410
600	10.0	2.18	1.4	1.9	19.02	0.0769	0.0564	0.0530	0.1333	1.379	3.2	0.398
1200	10.5	2.19	1.5	1.9	18.70	0.0741	0.0598	0.0507	0.1339	1.237	3.1	0.379
2400	10.5	2.17	1.5	1.5	18.66	0.0741	0.0582	0.0522	0.1323	1.285	3.2	0.398
3600	10.4	2.19	1.3	2.0	19.55	0.0768	0.0602	0.0519	0.1370	1.280	3.4	0.382
4800	10.6	2.21	1.6	1.9	18.80	0.0751	0.0587	0.0504	0.1338	1.300	3.3	0.379
9600	10.5	2.25	1.9	1.5	19.42	0.0760	0.0645	0.0542	0.1405	1.185	3.4	0.388
12000	10.4	2.20	2.0	1.5	18.63	0.0710	0.0599	0.0534	0.1309	1.182	3.5	0.409
LSD 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.114	NS	NS
ACA1514 0	10.2	2.27	1.5	1.9	19.28	0.0765	0.0580	0.0525	0.1345	1.328	3.6	0.392
600	10.3	2.15	1.1	1.9	18.37	0.0751	0.0569	0.0501	0.1320	1.321	3.1	0.380
1200	10.1	2.23	1.5	1.9	18.86	0.0743	0.0573	0.0501	0.1316	1.302	3.3	0.381
2400	10.5	2.21	1.6	1.9	18.82	0.0769	0.0622	0.0486	0.1391	1.234	3.1	0.349
3600	10.2	2.19	1.6	2.0	18.77	0.0756	0.0571	0.0523	0.1326	1.329	3.2	0.395
4800	10.7	2.22	1.6	1.7	19.19	0.0748	0.0615	0.0524	0.1363	1.228	3.5	0.387
9600	10.5	2.19	1.7	1.7	18.58	0.0701	0.0583	0.0522	0.1284	1.207	3.3	0.407
12000	10.2	2.24	1.8	1.4	18.82	0.0669	0.0585	0.0524	0.1254	1.148	3.3	0.418
LSD 5%	NS	NS	0.3	0.3	NS	NS	NS	NS	NS	0.088	NS	0.029
ACA1515 0	10.2	2.18	1.3	1.9	19.79	0.0796	0.0590	0.0560	0.1386	1.350	3.4	0.405
600	10.3	2.14	1.6	1.9	18.37	0.0729	0.0576	0.0518	0.1305	1.269	3.1	0.399
1200	10.4	2.13	1.7	1.9	18.46	0.0745	0.0600	0.0502	0.1346	1.244	3.2	0.373
2400	10.3	2.26	1.5	1.8	19.96	0.0740	0.0608	0.0553	0.1348	1.225	3.5	0.411
3600	10.8	2.19	1.4	1.8	18.79	0.0714	0.0587	0.0514	0.1301	1.221	3.3	0.399
4800	10.2	2.16	1.3	1.5	18.40	0.0683	0.0566	0.0526	0.1250	1.216	3.3	0.421
9600	10.3	2.20	1.5	1.7	18.46	0.0687	0.0555	0.0537	0.1242	1.240	3.3	0.435
12000	10.6	2.24	1.6	1.6	19.26	0.0695	0.0558	0.0552	0.1253	1.253	3.4	0.441
LSD 5%	NS	NS	NS	NS	NS	0.0068	NS	NS	NS	NS	NS	NS

Table 3. Pepper plant parameters 2 weeks after surfactant drench – main and overall effects.

Treatment	Stem Length (cm)	Stem Diameter (mm)	Leaf Area (cm ²)	Leaf DW (g)	Stem DW (g)	Root DW (g)	Shoot DW (g)	Leaf Stem Ratio	True Leaf (no)	Root Shoot Ratio
By Surfactant										
ACA1513	10.3	2.24	25.16	0.0625	0.0517	0.0591	0.1143	1.210	4.6	0.518
ACA1514	10.4	2.23	25.65	0.0632	0.0528	0.0565	0.1160	1.196	4.6	0.488
ACA1515	10.4	2.20	25.96	0.0652	0.0534	0.0595	0.1186	1.220	4.7	0.503
LSD 5%	NS	NS	NS	0.0021	NS	0.0026	NS	NS	NS	0.018
By Rate										
0	10.4	2.23	26.57	0.0698	0.0537	0.0621	0.1234	1.300	4.6	0.502
600	10.4	2.21	26.01	0.0662	0.0527	0.0582	0.1190	1.256	4.6	0.489
1200	10.3	2.21	25.29	0.0649	0.0520	0.0552	0.1169	1.249	4.7	0.472
2400	10.7	2.27	26.13	0.0662	0.0553	0.0590	0.1215	1.199	4.8	0.486
3600	10.4	2.22	25.40	0.0618	0.0521	0.0581	0.1139	1.188	4.6	0.511
4800	10.4	2.22	25.06	0.0611	0.0522	0.0583	0.1132	1.171	4.6	0.515
9600	10.3	2.21	24.83	0.0591	0.0512	0.0568	0.1103	1.156	4.6	0.517
12000	10.3	2.21	25.43	0.0599	0.0521	0.0592	0.1119	1.151	4.6	0.531
LSD 5%	NS	NS	NS	0.0034	NS	NS	0.0059	0.049	NS	0.030
Over All Surfactants & Rates										
ACA 1513 0	9.7	2.24	25.82	0.0678	0.0515	0.0603	0.1193	1.319	4.7	0.506
600	10.4	2.20	25.98	0.0672	0.0541	0.0620	0.1213	1.241	4.5	0.513
1200	10.3	2.17	24.81	0.0621	0.0496	0.0547	0.1118	1.257	4.7	0.493
2400	10.9	2.29	25.27	0.0636	0.0539	0.0612	0.1174	1.183	4.7	0.521
3600	10.8	2.30	25.50	0.0612	0.0522	0.0568	0.1134	1.175	4.7	0.504
4800	10.6	2.32	25.36	0.0615	0.0535	0.0585	0.1150	1.150	4.5	0.509
9600	10.0	2.23	24.31	0.0590	0.0504	0.0604	0.1094	1.171	4.3	0.553
12000	10.1	2.17	24.25	0.0577	0.0487	0.0590	0.1064	1.187	4.5	0.557
ACA 1514 0	10.4	2.23	26.45	0.0692	0.0537	0.0579	0.1229	1.289	4.4	0.472
600	10.3	2.20	25.62	0.0649	0.0519	0.0548	0.1167	1.252	4.6	0.473
1200	10.3	2.24	25.26	0.0634	0.0520	0.0528	0.1155	1.222	4.4	0.458
2400	10.6	2.27	26.78	0.0681	0.0564	0.0582	0.1245	1.210	5.0	0.468
3600	10.4	2.26	25.84	0.0623	0.0527	0.0589	0.1151	1.184	4.7	0.510
4800	10.4	2.20	24.75	0.0596	0.0516	0.0581	0.1112	1.156	4.6	0.522
9600	10.2	2.20	24.08	0.0555	0.0487	0.0520	0.1042	1.143	4.7	0.503
12000	10.8	2.25	26.43	0.0622	0.0557	0.0592	0.1180	1.117	4.6	0.506
ACA1515 0	10.9	2.23	27.43	0.0722	0.0558	0.0679	0.1280	1.294	4.8	0.532
600	10.4	2.23	26.44	0.0666	0.0523	0.0579	0.1189	1.274	4.7	0.490
1200	10.2	2.23	25.78	0.0691	0.0544	0.0579	0.1235	1.270	4.9	0.470
2400	10.6	2.25	26.35	0.0670	0.0556	0.0575	0.1226	1.207	4.5	0.469
3600	9.9	2.12	24.85	0.0617	0.0516	0.0586	0.1133	1.202	4.3	0.522
4800	10.2	2.14	25.07	0.0621	0.0514	0.0584	0.1135	1.208	4.7	0.514
9600	10.8	2.20	26.09	0.0629	0.0545	0.0581	0.1174	1.153	4.7	0.496
12000	10.2	2.20	25.62	0.0597	0.0518	0.0595	0.1115	1.152	4.7	0.537
LSD 5%	NS	0.10	NS	0.0059	NS	NS	0.0102	0.084	NS	0.044

Table 4. Pepper plant parameters 2 weeks after surfactant drench – individual surfactant data.

Surfactant & Rate (ppm)	Stem Length (cm)	Stem Diameter (mm)	Leaf Area (cm ²)	Leaf DW (g)	Stem DW (g)	Root DW (g)	Shoot DW (g)	Leaf Stem Ratio	True Leaf (no)	Root Shoot Ratio
ACA 1513 0	9.7	2.24	25.82	0.0678	0.0515	0.0603	0.1193	1.319	4.7	0.506
600	10.4	2.20	25.98	0.0672	0.0541	0.0620	0.1213	1.241	4.5	0.513
1200	10.3	2.17	24.81	0.0621	0.0496	0.0547	0.1118	1.257	4.7	0.493
2400	10.9	2.29	25.27	0.0636	0.0539	0.0612	0.1174	1.183	4.7	0.521
3600	10.8	2.30	25.50	0.0612	0.0522	0.0568	0.1134	1.175	4.7	0.504
4800	10.6	2.32	25.36	0.0615	0.0535	0.0585	0.1150	1.150	4.5	0.509
9600	10.0	2.23	24.31	0.0590	0.0504	0.0604	0.1094	1.171	4.3	0.553
12000	10.1	2.17	24.25	0.0577	0.0487	0.0590	0.1064	1.187	4.5	0.557
LSD 5%	NS	NS	NS	0.0051	NS	NS	0.0089	0.090	0.3	NS
ACA 1514 0	10.4	2.23	26.45	0.0692	0.0537	0.0579	0.1229	1.289	4.4	0.472
600	10.3	2.20	25.62	0.0649	0.0519	0.0548	0.1167	1.252	4.6	0.473
1200	10.3	2.24	25.26	0.0634	0.0520	0.0528	0.1155	1.222	4.4	0.458
2400	10.6	2.27	26.78	0.0681	0.0564	0.0582	0.1245	1.210	5.0	0.468
3600	10.4	2.26	25.84	0.0623	0.0527	0.0589	0.1151	1.184	4.7	0.510
4800	10.4	2.20	24.75	0.0596	0.0516	0.0581	0.1112	1.156	4.6	0.522
9600	10.2	2.20	24.08	0.0555	0.0487	0.0520	0.1042	1.143	4.7	0.503
12000	10.8	2.25	26.43	0.0622	0.0557	0.0592	0.1180	1.117	4.6	0.506
LSD 5%	NS	NS	NS	0.0070	NS	NS	NS	0.082	NS	NS
ACA1515 0	10.9	2.23	27.43	0.0722	0.0558	0.0679	0.1280	1.294	4.8	0.532
600	10.4	2.23	26.44	0.0666	0.0523	0.0579	0.1189	1.274	4.7	0.490
1200	10.2	2.23	25.78	0.0691	0.0544	0.0579	0.1235	1.270	4.9	0.470
2400	10.6	2.25	26.35	0.0670	0.0556	0.0575	0.1226	1.207	4.5	0.469
3600	9.9	2.12	24.85	0.0617	0.0516	0.0586	0.1133	1.202	4.3	0.522
4800	10.2	2.14	25.07	0.0621	0.0514	0.0584	0.1135	1.208	4.7	0.514
9600	10.8	2.20	26.09	0.0629	0.0545	0.0581	0.1174	1.153	4.7	0.496
12000	10.2	2.20	25.62	0.0597	0.0518	0.0595	0.1115	1.152	4.7	0.537
LSD 5%	NS	0.08	NS	0.0054	NS	0.0061	0.0083	0.082	NS	0.044

Table 5. Watermelon plant parameters 2 weeks after surfactant drench – main and overall effects.

Treatment	Phytoxicity Rating	Leaf Area (cm ²)	Shoot DW (g)	Root DW (g)	Whole Plant DW (g)	True Leaves (no.)	Root Shoot Ratio
By Surfactant							
ACA1513	1.25	16.85	0.1486	0.0288	0.1774	2.2	0.197
ACA1514	1.46	16.60	0.1498	0.0306	0.1813	2.2	0.204
ACA1515	1.33	16.74	0.1456	0.0297	0.1753	2.2	0.203
LSD 5%	0.14	NS	NS	NS	NS	NS	NS
By Rate							
0 ppm	1.00	17.38	0.1574	0.0345	0.1918	2.2	0.220
600	1.00	18.29	0.1659	0.0324	0.1982	2.2	0.196
1200	1.00	18.26	0.1624	0.0324	0.1948	2.3	0.203
2400	1.11	18.66	0.1617	0.0335	0.1952	2.4	0.209
3600	1.33	17.28	0.1451	0.0282	0.1733	2.2	0.196
4800	1.44	16.82	0.1409	0.0273	0.1681	2.2	0.194
9600	2.00	15.05	0.1325	0.0265	0.1591	2.3	0.201
12000	1.89	12.09	0.1182	0.0227	0.1408	2.2	0.192
LSD 5%	0.23	2.11	0.0207	0.0049	0.0239	NS	NS
Over All Surfactants & Rates							
ACA 1513 0	1.0	16.84	0.1490	0.0332	0.1822	2.2	0.239
600	1.0	19.10	0.1714	0.0304	0.2019	2.3	0.179
1200	1.0	18.88	0.1688	0.0309	0.1997	2.4	0.190
2400	1.3	18.58	0.1638	0.0317	0.1954	2.2	0.203
3600	1.0	17.82	0.1520	0.0291	0.1811	2.2	0.200
4800	1.0	15.82	0.1296	0.0256	0.1552	2.1	0.202
9600	2.0	14.37	0.1282	0.0254	0.1536	2.3	0.197
12000	1.7	13.39	0.1263	0.0240	0.1503	2.2	0.194
ACA 1514 0	1.0	17.35	0.1612	0.0353	0.1966	2.3	0.222
600	1.0	18.12	0.1672	0.0338	0.2009	2.0	0.203
1200	1.0	17.36	0.1546	0.0338	0.1884	2.2	0.221
2400	1.0	18.68	0.1659	0.0344	0.2002	2.6	0.213
3600	1.7	17.17	0.1444	0.0284	0.1728	2.1	0.201
4800	2.0	18.63	0.1624	0.0307	0.1931	2.3	0.192
9600	2.0	14.73	0.1281	0.0276	0.1557	2.3	0.215
12000	2.0	10.70	0.1139	0.0207	0.1346	2.1	0.186
ACA 1515 0	1.0	17.94	0.1619	0.0349	0.1968	2.1	0.226
600	1.0	17.65	0.1589	0.0330	0.1920	2.3	0.220
1200	1.0	18.53	0.1638	0.0323	0.1962	2.3	0.201
2400	1.0	18.71	0.1554	0.0345	0.1899	2.3	0.223
3600	1.3	16.84	0.1390	0.0270	0.1660	2.3	0.190
4800	1.3	16.00	0.1304	0.0257	0.1561	2.2	0.204
9600	2.0	16.04	0.1413	0.0266	0.1678	2.3	0.192
12000	2.0	12.18	0.1144	0.0233	0.1377	2.3	0.210
LSD 5%	0.4	3.66	0.0359	0.0085	0.0413	NS	NS

Table 6. Watermelon plant parameters 2 weeks after surfactant drench – individual surfactant data.

Surfactant & Rate (ppm)	Phytotoxicity Rating	Leaf Area (cm ²)	Shoot DW (g)	Root DW (g)	Whole Plant DW (g)	True Leaves (no.)	Root Shoot Ratio
ACA1513 0	1.0	16.84	0.1490	0.0332	0.1822	2.2	0.239
600	1.0	19.10	0.1714	0.0304	0.2019	2.3	0.179
1200	1.0	18.88	0.1688	0.0309	0.1997	2.4	0.190
2400	1.3	18.58	0.1638	0.0317	0.1954	2.2	0.203
3600	1.0	17.82	0.1520	0.0291	0.1811	2.2	0.200
4800	1.0	15.82	0.1296	0.0256	0.1552	2.1	0.202
9600	2.0	14.37	0.1282	0.0254	0.1536	2.3	0.197
12000	1.7	13.39	0.1263	0.0240	0.1503	2.2	0.194
LSD 5%	0.5	NS	NS	NS	NS	NS	NS
ACA 1514 0	1.0	17.35	0.1612	0.0353	0.1966	2.3	0.222
600	1.0	18.12	0.1672	0.0338	0.2009	2.0	0.203
1200	1.0	17.36	0.1546	0.0338	0.1884	2.2	0.221
2400	1.0	18.68	0.1659	0.0344	0.2002	2.6	0.213
3600	1.7	17.17	0.1444	0.0284	0.1728	2.1	0.201
4800	2.0	18.63	0.1624	0.0307	0.1931	2.3	0.192
9600	2.0	14.73	0.1281	0.0276	0.1557	2.3	0.215
12000	2.0	10.70	0.1139	0.0207	0.1346	2.1	0.186
LSD 5%	0.4	3.75	NS	0.0085	NS	NS	NS
ACA 1515 0	1.0	17.94	0.1619	0.0349	0.1968	2.1	0.226
600	1.0	17.65	0.1589	0.0330	0.1920	2.3	0.220
1200	1.0	18.53	0.1638	0.0323	0.1962	2.3	0.201
2400	1.0	18.71	0.1554	0.0345	0.1899	2.3	0.223
3600	1.3	16.84	0.1390	0.0270	0.1660	2.3	0.190
4800	1.3	16.00	0.1304	0.0257	0.1561	2.2	0.204
9600	2.0	16.04	0.1413	0.0266	0.1678	2.3	0.192
12000	2.0	12.18	0.1144	0.0233	0.1377	2.3	0.210
LSD 5%	0.5	2.87	0.0264	0.0097	0.0325	NS	NS

Table 7. Surfactant drench phytotoxicity ratings 1, 2, and 8 DAT and sample data 2-wk after drench on 4-wk old cabbage transplants.

Treatment	Phyto. 2/27/98	Phyto. 2/28/98	Phyto. 3/06/98	Leaf Area (cm ²)	Shoot DW (g)	Root DW (g)	Whole Plant DW (g)	True Leaves (no.)
By Surfactant								
ACA1513	2.4	3.2	3.2	13.87	0.0997	0.0294	0.1291	3.5
ACA1514	2.5	3.5	3.5	14.56	0.1046	0.0307	0.1353	3.7
ACA1515	3.0	3.7	3.6	12.87	0.0946	0.0290	0.1235	3.6
LSD 5%	0.5	NS	NS	1.24	NS	NS	NS	0.2
By Rate								
0 ppm	1.1	1.0	1.0	17.50	0.1225	0.0353	0.1578	3.7
600	1.1	1.0	1.1	17.56	0.1200	0.0351	0.1551	3.8
1200	1.4	1.8	1.6	17.65	0.1220	0.0335	0.1555	3.7
2400	2.3	3.0	3.0	15.20	0.1057	0.0312	0.1369	3.6
3600	2.1	3.1	3.7	13.87	0.0971	0.0275	0.1245	3.5
4800	2.0	3.8	4.1	13.41	0.0960	0.0294	0.1254	3.6
9600	5.0	6.6	6.1	8.22	0.0717	0.0235	0.0951	3.6
12000	5.7	7.4	7.1	6.73	0.0619	0.0223	0.0842	3.6
LSD 5%	0.8	0.7	0.8	2.03	0.0141	0.0035	0.0165	NS
Over All Surfactants & Rates								
ACA 1513 0	1.3	1.0	1.0	15.83	0.1113	0.0337	0.1450	3.5
600	1.0	1.0	1.0	16.83	0.1159	0.0339	0.1498	3.5
1200	1.3	1.3	1.3	18.68	0.1268	0.0339	0.1607	3.7
2400	2.7	2.7	2.3	15.16	0.1097	0.0314	0.1411	3.5
3600	1.7	3.3	4.0	12.84	0.0889	0.0252	0.1140	3.7
4800	1.3	3.3	4.0	14.12	0.0993	0.0300	0.1294	3.3
9600	5.3	6.0	5.7	9.37	0.0778	0.0227	0.1004	3.5
12000	4.3	7.0	6.3	8.16	0.0678	0.0245	0.0923	3.4
ACA 1514 0	1.0	1.0	1.0	18.88	0.1303	0.0380	0.1684	3.7
600	1.3	1.0	1.0	18.34	0.1288	0.0367	0.1655	3.8
1200	1.3	1.7	1.7	17.46	0.1255	0.0319	0.1574	3.6
2400	2.0	2.7	3.7	17.15	0.1161	0.0319	0.1480	3.8
3600	2.3	3.3	3.7	14.93	0.1040	0.0266	0.1306	3.8
4800	2.0	4.3	4.0	13.11	0.0938	0.0298	0.1237	3.6
9600	3.7	6.7	6.3	8.35	0.0701	0.0278	0.0979	3.8
12000	6.0	7.3	7.0	8.28	0.0682	0.0231	0.0913	3.9
ACA 1515 0	1.0	1.0	1.0	17.80	0.1258	0.0340	0.1598	3.9
600	1.0	1.0	1.3	17.52	0.1153	0.0346	0.1499	3.9
1200	1.7	2.3	1.7	16.81	0.1137	0.0347	0.1484	3.7
2400	2.3	3.7	3.0	13.29	0.0914	0.0302	0.1216	3.5
3600	2.3	2.7	3.3	13.85	0.0983	0.0306	0.1289	3.5
4800	2.7	3.7	4.3	12.99	0.0948	0.0285	0.1232	3.6
9600	6.0	7.0	6.3	6.93	0.0672	0.0200	0.0871	3.6
12000	6.7	8.0	8.0	3.73	0.0498	0.0193	0.0691	3.5
LSD 5%	1.3	1.2	1.4	3.51	0.0244	0.0060	0.0286	NS

Table 8 Within surfactant drench phytotoxicity ratings 1, 2, and 8 DAT and sample data 2-wk after drench on 4-wk old cabbage transplants.

Surfactant & Rate (ppm)	Phyto. 2/27/98	Phyto. 2/28/98	Phyto. 3/06/98	Leaf Area (cm ²)	Shoot DW (g)	Root DW (g)	Whole Plant DW (g)	True Leaves (no.)
ACA 1513 0	1.3	1.0	1.0	15.83	0.1113	0.0337	0.1450	3.5
600	1.0	1.0	1.0	16.83	0.1159	0.0339	0.1498	3.5
1200	1.3	1.3	1.3	18.68	0.1268	0.0339	0.1607	3.7
2400	2.7	2.7	2.3	15.16	0.1097	0.0314	0.1411	3.5
3600	1.7	3.3	4.0	12.84	0.0889	0.0252	0.1140	3.7
4800	1.3	3.3	4.0	14.12	0.0993	0.0300	0.1294	3.3
9600	5.3	6.0	5.7	9.37	0.0778	0.0227	0.1004	3.5
12000	4.3	7.0	6.3	8.16	0.0678	0.0245	0.0923	3.4
LSD 5%	1.4	1.0	1.3	2.13	0.0218	0.0040	0.0232	NS
ACA 1514 0	1.0	1.0	1.0	18.88	0.1303	0.0380	0.1684	3.7
600	1.3	1.0	1.0	18.34	0.1288	0.0367	0.1655	3.8
1200	1.3	1.7	1.7	17.46	0.1255	0.0319	0.1574	3.6
2400	2.0	2.7	3.7	17.15	0.1161	0.0319	0.1480	3.8
3600	2.3	3.3	3.7	14.93	0.1040	0.0266	0.1306	3.8
4800	2.0	4.3	4.0	13.11	0.0938	0.0298	0.1237	3.6
9600	3.7	6.7	6.3	8.35	0.0701	0.0278	0.0979	3.8
12000	6.0	7.3	7.0	8.28	0.0682	0.0231	0.0913	3.9
LSD 5%	1.1	1.2	1.6	3.01	0.0210	0.0068	0.0261	NS
ACA 1515 0	1.0	1.0	1.0	17.80	0.1258	0.0340	0.1598	3.9
600	1.0	1.0	1.3	17.52	0.1153	0.0346	0.1499	3.9
1200	1.7	2.3	1.7	16.81	0.1137	0.0347	0.1484	3.7
2400	2.3	3.7	3.0	13.29	0.0914	0.0302	0.1216	3.5
3600	2.3	2.7	3.3	13.85	0.0983	0.0306	0.1289	3.5
4800	2.7	3.7	4.3	12.99	0.0948	0.0285	0.1232	3.6
9600	6.0	7.0	6.3	6.93	0.0672	0.0200	0.0871	3.6
12000	6.7	8.0	8.0	3.73	0.0498	0.0193	0.0691	3.5
LSD 5%	1.4	1.4	1.5	3.22	0.0183	0.0056	0.0224	NS