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Evaluation of Some Adjuvants in Improving Foliar Fertilizers Efficiency

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Abstract: A series of lab and field experiments were carried out to evaluate the possibility of using some substances as adjuvants added to the foliar fertilizer tank to improve fertilizer application and enhance use efficiency. Each of the suggested substances was prepared in 10 concentrations treatments, ranging between 0.05 and 2g/L. The effect of each concentration on static surface tension and static contact angle in liquid/air/glass and solid plant leaves/air interface were used to evaluate and find out the optimum concentration of each substance to be used as an adjuvant. An Adjmix-D1 was prepared using 0.6g/L Triethanolamine and 0.6g/L liquid soap as surfactants, 0.6g/L glycerin as a humectant, 0.6 g/L Arabic gum as a sticker and 0.6g/L urea as a penetrator. The obtained results showed that fruit yield as well as N, K, Fe, Zn and Mn contents in white eggplants and cucumber leaves are positively increased by the applications of improved foliar fertilizers (IFF). This increase can be arranged in the following descending order: Adjmix-D1 > Adjmix-D2 > Liquid soap > Rixi film > Triethanolamine. It could be concluded that the Adjmix-D1 can be used as an effective adjuvant for improving foliar fertilizer application efficiency.

1 Introduction

Several methods were recently used in delivering nutrients for plants including soil and foliar methods. Foliar nutrition is considered one of the most common methods, which is used to deliver the needed nutrients to plants in adequate concentrations and improve plant nutritional status as well as increase the crop yield and quality (Smoleń 2012). Fertilizer management is very important due to its role in plant growth and development in addition to its role in biochemistry and plant disease control (Dordas 2009).

The applied nutrients can enter the leaves through many steps by penetrating the cuticle or entering through the stomata before entering the plant cell where they are used in metabolism (Oosterhuis and Weir 2010).

The main dilemma of foliar nutrient application is that the waxy cuticle, covering the surfaces of all plant foliage, is an effective barrier to the penetration of exogenous chemicals into the underlying tissues (Heywood 1970). Thus, it is apparent that many of the principles of formulation employed with foliar-applied systemic pesticides also may be used to advantage for foliar fertilizer application. The most common way of improving the interaction of spray droplets and plant leaf surfaces is by modifying the surface tension of the droplet. Somervaille and Betts (2011) mentioned that droplets with a high surface tension bounce off target surfaces, while those with a low surface tension tend to spread on contact and retain.

The ability of foliar sprays to stick to leaves is essential to enable the uptake of nutrients. Many plant species showed to have low wettability due to leaf surface roughness, which is caused, by waxes and hairs (De Ruiter et al 1995). To overcome these issues, additives were added to the spray tank e.g. adjuvants including surfactants to improve leaf wetting, stickers to minimize fertilizer wash and humectants to prolong the time of nutrient absorption (Fernández and Eichert 2009). A large number of adjuvants are commercially available for use in combination with agrochemicals, however, their effectiveness with foliar-applied fertilizers is often unknown (De Assunção et al 2019).

It has been also suggested to use a surfactant as an adjuvant for improving the wetting properties of foliar fertilizer on leaves (i.e., low surface tension and low contact angle), which might increase the rate of uptake of foliar-applied fertilizers (Fernández and Eichert 2009). It follows that poorer wetting (higher surface tension and contact angles) will result in lower uptake rates of the nutrients from different fertilizer formulations. Even though the addition of an adjuvant will increase the surface area of the sprayed solution, there seems to be an optimal concentration for both economic and effective coverage (Rasmussen 2016).

In fact, effective spray applications are required to help reduce operational costs with adequate spraying coverage for large acreage operations. By adding adjuvants to the spray solution, the droplet dispersion on leaf surfaces as well as the surface area of the droplets might increase, creating a larger coverage area per volume. This larger surface area can also increase the evaporation speed of the solution through the heat exchange between the environment and the plant, but the plant will have a greater opportunity to absorb the solution before evaporation (Ortiz et al 2007).

The main purpose of this investigation is to evaluate the ability of some selected substances to act as adjuvants (that improve the performance of foliar fertilizers) can be added to foliar fertilizer tank (six-laboratory grade and two commercial) to improve nutrient use efficiency by plants. The subsequent short-term uptake of foliar applied N, K, Fe, Zn and Mn as a reflection of foliar fertilizer use efficiency was taken under consideration.

2 Materials and Methods

A series of lab and field experiments were carried out to evaluate the possibility of using some substances as adjuvants added to the foliar fertilizer tank for improving foliar fertilizer application and use efficiency.

2.1 Suggested substances as adjuvants

The suggested adjuvants included Triethanolamine (TEA), liquid soap (prepared by mixing 7 parts of cottonseed oil with 1 part of KOH and 10 parts of H_2O) as surfactants, glycerin as a humectant, Arabic gum, molasses as stickers and urea as a penetrator. Citric acid was used to adjust the pH of the final foliar fertilizer solution to about seven. Camina red food color is also used in 0.1g/L to make the spray solution clearer in vision. Rixi film (25% Sodium laurel ether sulfate) is used as a commercial adjuvant for comparison. Each of the suggested substances was prepared in 10 concentrations treatments, i.e., 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 1, 1.25, 1.5, and 2g/L. The effect of each concentration on static surface tension (SST) and static contact angle (SCA) in liquid/air/glass and solid plant leaf/air interface were used to evaluate and find out the optimum concentration of each substance to be used as an adjuvant which had the highest effects on reducing SST and SCA.

The optimum concentrations of the suggested six substances mixed each alone or in combination with the final foliar fertilizer solution tank in addition to the pH adjuster and color were all determined. The commercial adjuvant (Rixi film) and pure water were also used by mixing each alone with the final foliar fertilizer solution tank as control treatments without any other additives. The SST was determined at room temperature using the drop weight method as described by Soni (2019) and by using the capillary tube method described by Harkins and Brown (2019). The SCA was measured using a smart cellphone as described by Lamour et al (2010). The SCA measurements were made on the adaxial (top) side of leaves taken at the vegetative stage of white eggplants and cucumber plants as varied in their leaf surface roughness.

2.2 Field experiments using improved foliar fertilizers

Two field trials were conducted on clay loam soils at Aboelnaga, Basos, Qaluobia Governorate at the location of (30° 07’ 4 8.6’’ N, 31° 13’ 40.5’’ E) for cucumber and in Elmanawat, Aboelnomros, Giza Governorate at the location of (29.9° 17.1’ 95.0’’ N, 31.2° 45.7' 75.0'' E) for white eggplants. Crops in these locations were irrigated by a surface flooding irrigation system using fresh water delivered from the Nile river (EC is about 0.43 dS/m). All field experiments were designed and statistically analyzed in a complete randomized block design.

Un-improved foliar fertilizer (UIFF) alone or in combination with the suggested adjuvants treatments were used for improving foliar fertilizer (IFF) in addition to control treatments either Rixi film and pure water were sprayed weekly for 4 times in sequence applications on the test plants using a low-pressure sprayer. The first applications of IFF or UIFF and control treatments began just before the fruiting stages of each crop. No negative interaction was observed between any of the suggested adjuvants with foliar fertilizers.

Crop types, cultivars, dates of Planting, dates of the applications of foliar fertilizer treatments and age of plants at each crop harvesting or leaves sampling are presented in **Table 1**. Chemicals used for preparing the stock solutions of the different foliar fertilizer's formula (K1, K1.5, K2 and K3) are shown in **Table 2**. Nutrient contents in the final foliar fertilizers solutions using two cm^3/l from the stock solutions are presented in **Table 3**.

To evaluate the effects of the IFF on nutrient use efficiency, foliage plant samples were collected after one week from each application of the improved and UIFF. The collected plant foliage was prepared for chemical analyses to determine N, K, Fe, Zn and Mn contents using methods described by Jones (2001).

3 Results and Discussion

3.1 Effects of the suggested adjuvants on static surface tension

Results in **Table 4** indicated that the lowest values of SST determined by drop weight method were 45.4, 19.7, 48.2, 50.1, 49.3 and 51.0 N/m at 33ºC for TEA, liquid soap, glycerin, Arabic gum, molasses and urea. These lowest values of surface tension were taken at the concentrations of 0.6, 1.0, 0.6, 1.0, 0.8 and 0.8g/L respectively. The lowest value of surface tension for the commercial adjuvants (Rixi film) was 28.8 N/m at the concentrations of 0.4g/L respectively. The SST value of pure water determined under similar conditions was 74.7 N/m at 33ºC.

These results are in agreement with that of Tu and Randall (2003) who mentioned that surfactants are the most widely used products of the chemical industry and probably the most important group of all adjuvants for foliar application. However, the most common types of activator adjuvants are surfactants (Penner 2000) such as TEA, and liquid soap. Due to the special structure of surfactants, their presence at the surface is more beneficial, and therefore the surface tension can be efficiently reduced (Rosen and Kunjappu 2012). The term 'surfactant' is derived from 'surface active agent' and should not be mixed up with the term 'adjuvant' since adjuvants are not limited to surfactants (Penner 2000).

Data in **Table 5** show the effects of the different suggested adjuvant concentrations on the average values of SST determined by the drop weight method and capillary tube methods in N/m. Results indicated that the lowest values of SST determined by the capillary tube method were 43.1, 20.4, 41.0, 37.5, 27.4 and 60.2 N/m at 25ºC for TEA, liquid soap, glycerin, Arabic gum, molasses and urea respectively.

These lowest values of SST were taken at the concentrations of 0.6, 0.8, 0.6, 0.8, 0.8 and 0.8g/L respectively. The lowest value of SST for the commercial adjuvant (Rixi film) was 15.9 N/m at a concentration of 0.6g/L. The SST value of pure water was 72.3 N/m at 25ºC. It is worth mentioning that the SST value determined by the drop weight method at 33ºC was higher than that determined by the capillary tube method at 25 by about 12.6%. Despite this difference, similar trends were observed for the effect of adjuvant treatments on SST values particularly the concentrations of each adjuvant at the lowest values of SST. This result agrees with that of Park et al (1999) who found a linear relationship between SST and temperature. A similar trend with very few differences was observed between SST values determined by the drop weight method (**Table 4**) and capillary tube method (**Table 5**). The average of both values to represent the effects of different suggested adjuvants for improving foliar fertilizer on its SST values was taken under consideration. Therefore, it was observed that the average lowest SST values were taken at concentrations of 0.6, 0.8, 0.6, 0.8, 0.8, 0.8 and 0.6g/L for TEA, liquid soap, glycerin, Arabic gum, molasses, urea and Rixi film. The corresponding average values obtained for SST were 43.1, 20.4, 41.0, 37.5, 27.4, 60.2 and 15.9 N/m respectively. The average value of SST for pure water was 73.5 N/m. These results are in agreement with that observed by Chen et al (2018).

Table 1. Crop types and cultivars, planting date, date of foliar fertilizer treatments applications, date of fruit crop harvesting, and the foliar fertilizer (FF) formula used

Crop types and cultivar	Planting dates	Beginning date of the 1St Spray of FF	Sampling time, dates and plant ages			
			1	2	3	4
White eggplants Apastra CV.	5-3-2020	14-5-20 at 70 days old FF formula	21-5-20 77 days *K2	28-5-20 84 days K3	4-6-20 91 days K3	11-6-20 98 days K3
Cucumber Hayel CV.	26-8-2020	4-10-20 at 59 days old FF formula	11-10-20 46 days K1.5	18-10-20 53 days K2	25-10-20 60 days K3	1-11-20 67 K3

* K1.5, K2 and K3 are K_2O:N ratios in FF's, i.e. 1:1, 1:1.5, 1:2 and 1:3 respectively

Table 2. Chemicals used for preparing the stock solutions of the different used foliar fertilizers formulae

Foliar Fert's formulae	AN	KN	MgS	FS	ZS	MS	N	K_2O	MgO	Fe	Zn	Mn
	g/L in stock foliar fertilizer solutions						g/L in stock foliar fertilizer solutions					
K1.5	2.9	4.3	0.6	1.9	0.9	0.9	10.0	18.8	7.20	2.06	0.95	1.04
K2	2.6	5.2	0.5	1.8	0.9	0.9	6.81	22.7	6.52	2.00	0.95	1.06
K3	2.0	5.9	0.4	1.8	0.9	0.9	1.79	25.6	4.91	1.99	0.89	1.00

AN: Ammonium nitrate (33% N), KN: Potassium nitrate (13% N, 46% K_2O), MgS: Magnesium sulfate (16.8% MgO), FS: Iron sulfate (18.2 Fe), ZS: Zinc sulfate (19.9% Zn), MS: manganese sulfate (17.7% Mn).

Table 3. Nutrient contents in the final foliar fertilizer solutions

Foliar Fert's formulae	$N/K_2O/MgO/Fe/Zn/Mn$ Ratios	N	K_2O	MgO	Fe	Zn	Mn
		Nutrient concentrations in the final FF solutions using 2 cm^3/L					
K1.5	1/1.5/0.2/0.1/0.05/0.05	58	86	11.5	3.7	1.9	1.8
K2	1/2/0.2/0.1/0.05/0.05	52	104	10.4	3.6	1.9	1.9
K3	1/3/0.2/0.1/0.05/0.05	39	118	7.8	3.6	1.8	1.8

Table 4. Effects of the different adjuvant concentrations suggested for improving foliar fertilizer on SST determined by drop weight method at 33°C in kg/S^2

Adjuvant Conc. g/L	Adjuvants suggested for improving foliar fertilizers							SST at 33°C
	TEA	Liquid soap	Glycerin	Arabic gum	Molasses	Urea	Rixi film	
Pure water	74.7	74.7	74.7	74.7	74.7	74.7	74.7	74.7
0.05	56.6	41.1	53.0	54.5	52.0	57.0	57.1	53.2
0.1	46.1	40.9	52.1	56.4	50.4	54.8	55.2	50.2
0.2	45.7	42.5	48.5	50.5	52.0	53.4	47.1	47.5
0.4	47.3	28.7	48.5	50.7	52.4	54.2	28.8	43.3
0.6	45.4	24.0	48.2	50.8	52.4	54.7	29.2	42.3
0.8	47.6	21.6	48.2	51.1	49.3	51.0	29.3	41.5
1.0	46.6	19.7	49.0	50.1	55.8	53.6	29.3	42.4
1.25	46.2	19.9	49.0	50.4	55.4	53.3	28.9	42.1
1.5	45.9	19.8	49.6	50.5	57.8	54.0	29.7	42.7
2.0	45.6	20.0	50.6	50.3	54.1	53.6	29.4	42.2
Mean	47.3	27.8	49.7	51.5	53.2	53.9	36.4	44.7

Table 5. Effects of the different adjuvant concentrations suggested for improving foliar fertilizer on SST determined by capillary tube method at 25°C in N/m

Adjuvant Conc. g/L	Adjuvants suggested for improving foliar fertilizers							SST at 25°C
	TEA	Liquid soap	Glycerin	Arabic gum	Molasses	Urea	Rixi film	
Pure water	72.3	72.3	72.3	72.3	72.3	72.3	72.3	72.3
0.05	48.8	40.3	54.4	51.0	53.3	61.8	23.8	44.7
0.10	48.8	40.8	48.8	51.1	57.9	69.8	21.5	44.9
0.20	46.5	40.0	43.1	40.8	40.9	69.2	20.4	40.6
0.40	47.7	30.6	43.1	46.0	40.9	66.4	20.4	39.0
0.60	43.1	22.1	41.0	40.8	34.1	64.8	15.9	35.1
0.80	49.4	20.4	52.3	37.5	27.4	60.2	17.0	35.9
1.00	49.4	20.4	47.8	47.8	34.1	69.4	17.0	38.0
1.25	49.4	20.4	43.3	42.7	36.5	68.8	17.0	37.0
1.50	51.1	21.1	43.2	41.0	38.8	69.5	18.2	38.3
2.00	54.6	22.1	43.3	39.3	41.2	65.6	17.0	37.7
Mean	48.9	27.8	46.0	43.8	40.5	66.5	18.8	39.1

The high SST values of urea, glycerin, Arabic gum and molasses even at the lowest SST values compared with that of the tested commercial adjuvant (Rixifilm) were expected. The reason could be that not all these tested adjuvants acted as surfactants for increasing fluid spreading rate but acted as a penetrator, humectant, and sticker respectively. However, these differences may be attributed to the unknown components of such commercial adjuvants which may contain several surfactants acting together in reducing SST and consequently increasing the spreading rate of fluids on solid surfaces.

In general, all the suggested adjuvants can used to improve foliar fertilizers and have lower SST values compared with that of pure water (Prado et al 2016). The calculated net reduction in SST of the tested adjuvants compared with that of pure water was about 42, 62, 45, 35, 27 and 12.1 for TEA, liquid soap, glycerin, Arabic gum, molasses and urea respectively. The net reduction in SST was more pronounced for liquid soap than the other adjuvants or even the commercial adjuvants under investigation.

3.2 Effects of the suggested adjuvants on static contact angle

The SCA measurements made on the adaxial (top) side of leaves taken at the vegetative stage of white eggplants and cucumber plants varied in leaf surface roughness. Results presented in **Table 6** revealed that the lowest SCA values at the air/glass interface were observed at concentrations of 0.4, 0.4, 0.6, 0.4, 0.4, 0.6 and 0.4 g/L for TEA, liquid soap, glycerin, Arabic gum, molasses, urea and Rixi film, respectively. The corresponding values of contact angle were 15.0, 14.8, 15.8, 14.3, 15.1, 17.3 and 15.7° at 25°C in the same order.

The lowest SCA values for Air/eggplant leaf interface were 20.6, 16.9, 14.2, 22.1, 18.9, 23.4 and 13.6° at concentrations of 0.4, 0.6, 0.6, 0.4, 0.8, 0.6 and 0.4g/L respectively, and for Air/cucumber leaf interface were 22.8, 15.7, 27.6, 25.9, 19.7, 23.2 and 14.3° at concentrations of 0.8, 0.8, 0.8, 0.6, 0.6, 0.8 and 0.6g/L for cucumber using TEA, liquid soap, glycerin, Arabic gum, molasses, urea and Rixi film respectively. These results are in agreement with those obtained by Santos et al (2019).

It could be concluded that the efficiency of adjuvant concentration in reducing SCA and in consequently increasing the spreading rate of foliar fertilizers sprayed on plant foliage are more pronounced for white eggplants than for cucumber. This is a fact even for the commercial adjuvant under investigation (Rixifilm).

This may ascribed to the high roughness of cucumber leaves compared with that of white eggplants. Nairn et al (2013) reported that despite no standardized method for quantifying leaf surface roughness has yet been established, it is well known that surface roughness is a dominant factor in spray droplet adhesion. However, droplet spreading generally decreases with increasing leaf roughness (Gaskin et al 2005). Hence, the ability of foliar sprays to stick to leaves is essential to enable the uptake of nutrients. Many plant species including wheat have been shown to have low wettability due to leaf surface roughness which is caused by waxes and hairs (De Ruiter et al 1995).

Data in **Table 7** summarized the highly effective adjuvant concentrations in reducing SST and SCA under different conditions taken from **Tables 4, 5 and 6**. These concentrations are used to prepare adjuvant mixtures for improving the efficiency of foliar fertilizers.

Table 6. Effects of different adjuvants suggested for improving foliar fertilizers on the contact angle of adjuvant and glass, white eggplants, and cucumber leaf interface

Adjuvant Concentrations g/L	**Adjuvant treatments**						
	TEA	**Liquid soap**	**Glycerin**	**Arabic gum**	**Molasses**	**Urea**	**Rixifilm**
	Contact angle Air/glass interface in degree (º)						
0.05	16.4	25.7	17.4	17.4	16.9	28.2	16.1
0.1	15.9	25.7	18.0	15.1	15.6	25.4	17.2
0.2	15.7	23.6	18.9	18.5	18.4	24.6	20.9
0.4	15.0	14.8	17.5	14.3	15.1	26.1	**15.7**
0.6	15.0	15.3	15.8	16.8	16.6	17.3	16.1
0.8	19.1	16.8	16.6	17.9	15.4	21.5	22.9
1.0	18.5	17.0	18.4	19.2	18.2	21.1	16.8
1.25	16.0	18.8	21.8	18.0	16.1	25.7	16.8
1.5	17.6	23.8	17.2	19.4	15.5	22.5	23.5
2.0	19.1	15.3	16.1	18.2	16.0	29.7	20.2
	Contact angle of Air/Eggplant leaf interface in degree (º)						
0.05	27.4	31.1	23.8	31.6	24.4	23.9	24.1
0.1	27.3	32.3	21.0	26.2	30.6	27.7	22.4
0.2	25.1	25.6	29.8	22.9	32.1	30.5	23.5
0.4	20.6	24.1	15.5	22.1	30.5	28.0	13.6
0.6	21.8	16.9	14.2	24.7	23.9	23.4	15.8
0.8	26.7	23.4	14.6	28.1	18.9	27.1	17.1
1.0	25.9	31.2	15.7	27.6	20.1	29.9	19.0
1.25	23.5	20.7	19.3	33.7	24.7	23.8	16.1
1.5	28.1	24.2	20.7	24.1	25.7	23.7	15.3
2.0	25.0	31.3	21.4	26.7	24.6	25.4	15.5
	Contact angle of Air/Cucumber leaf interface in degree (º)						
0.05	32.3	35.7	30.1	32.7	29.1	20.5	30.2
0.1	32.1	25.8	29.6	32.1	26.9	31.0	25.1
0.2	27.3	21.7	33.5	30.5	22.8	28.1	25.2
0.4	25.5	19.7	28.4	27.7	22.2	24.8	22.3
0.6	26.6	17.9	28.1	25.9	19.7	25.7	14.3
0.8	22.8	15.7	27.6	27.0	21.2	23.2	25.1
1.0	27.0	17.9	31.3	26.8	24.6	23.3	25.2
1.25	29.9	17.8	30.2	35.0	20.1	25.3	18.8
1.5	32.6	17.2	29.5	31.9	22.8	27.4	22.2
2.0	26.7	16.7	27.8	29.5	23.9	30.3	26.1

Table 7. Summary of the highly effective adjuvant concentrations in reducing SST and SCA under different conditions

Treatments	**Adjuvant treatments**						
	TEA	**Liquid soap**	**Glycerin**	**Arabic gum**	**Molasses**	**Urea**	**Rixifilm**
	Effective adjuvant concentrations in reducing of SST and contact angle - g/L						
ST at 33ºC	0.6	1.0	0.6	1.0	0.8	0.8	0.4
ST at 25ºC	0.6	0.8	0.6	0.8	0.8	0.8	0.6
$CA_{Air/Glass}$	0.4	0.4	0.4	0.4	0.4	0.6	0.4
$CA_{Air/Eggplant}$	0.4	0.6	0.6	0.4	0.8	0.6	0.4
$CA_{Air/Cucumber}$	0.8	0.8	0.8	0.6	0.6	0.8	0.6
Mean	0.56	0.72	0.60	0.64	0.68	0.72	0.48
	The suggested adjuvant mixtures suggested to use for improving foliar fertilizers – g/L						
Adjmix-D1	0.6	0.6	0.6	0.6	--	0.6	--
Adjmix-D2	0.6	0.6	0.6	--	0.6	0.6	--

According to the average of the effective adjuvant concentrations shown in **Table 7**, two adjuvant mixture were prepared to consist of some adjuvants act as a surfactant, humectant, sticker and penetrator as follow: Adjmix-D1 contains 0.6g/L TEA and 0.6g/L liquid soap as surfactants, 0.6g/L glycerin as a humectant, 0.6g/L Arabic gum as a sticker and 0.6 g/L urea as a penetrator in addition to Adjmix-D2 contains 0.6g/L TEA and 0.6g/L liquid soap as surfactants, 0.6g/L glycerin as a humectant, 0.6g/L Molasses as a sticker and 0.6g/L urea as a penetrator.

To evaluate the efficiency of using the suggested adjuvants each alone or in combination as Adjmix-D1 and Adjmix-D2 for improving foliar fertilizers, a series of field experiments were carried out by spraying some vegetable crops weekly for 3 to 4 sequence applications. The tested plants were sprayed with the tested adjuvants each alone or in combination with Adjmix-D1 or Adjmix-D2 with its optimum concentration to evaluate its efficiency on nutrient contents and crop yield.

3.3 Effects of the improved foliar fertilizers (IFF) on some nutrient contents

White eggplant plants sprayed with foliar fertilizers improved by mixing with the recommended concentrations of the suggested adjuvants each alone or in combinations as Adjmix-D1 and Adjmix-D2. Concerning the changes in nutrient contents in white eggplant leaves at the different sampling periods along to growth stage. The effects of the tested adjuvants used for improving foliar fertilizers each alone or in combination (Adjmix-D1 and Adjmix-D2) added in four sequence applications on some nutrient contents in white eggplants and cucumber leaves and its relative effects to that of the first date of sampling =100 is presented in **Tables 8 and 9**, respectively.

Data in **Table 8** show some nutrient contents in white eggplant leaves as affected by IFF in four sequences applications relative to that of the first date of harvesting (i.e., 21-5-2020) equal to 100.

Results revealed that the increases in the relative N and K contents in eggplant leaves during the four sequence foliar fertilizer applications ranged between 111 and 114% for N and 106 and 124% for K. Similar increases were also observed for Fe, Zn and Mn contents in white eggplant leaves as affected by the improved foliar fertilizer (IFF) as shown in **Table 8**. These increases ranged between 109 and 117% for Fe, 107 and 126% for Zn and 113 and 128% for Mn relative to the first sampling equal 100.

Data in **Table 9** show some nutrient contents in cucumber leaves as affected by IFF in four sequences applications relative to that of the first date of harvesting (11-10-2020) equal to 100. Results revealed that the increases in the relative N and K contents in cucumber leaves during the four sequence foliar fertilizer applications ranged between 103-111% for N and 108-111% for K. Similar results were also observed for Fe, Zn and Mn contents in white eggplant leaves as affected by the IFF as shown in **Table 9**. The increases in Fe, Zn and Mn contents in white eggplant leaves ranged between 115 and 140 % for Fe, 116 and 127% for Zn and 125 and 132% for Mn relative to the first sampling equal 100.

It observed the increases in N, K, Fe, Zn and Mn contents in cucumber leaves as affected by the application of the IFF more pronounced than that in white eggplants. These increases in N, K, Fe, Zn and Mn contents in cucumber leaves may be attributed to the positive effect of the high degree of roughness of cucumber leaves on reducing the losses of the nutrient content added in foliar fertilization by slipping. This leads to an increase in the efficiency of plant utilization of the foliar fertilizer content (De Ruiter et al 1995).

Data summarized in **Table 10** show some nutrient contents in white eggplants and cucumber leaves as affected by different adjuvant treatments used for improving foliar fertilizer and relative values to that of UIFF = 100. Nitrogen content in white eggplant leaves increased by the applications of IFF to about 124, 120, 115 and 115 % for Adjmix-D1, Adjmix-D2, liquid soap and Rixifilm, respectively, relative to UIFF = 100.

Nitrogen content in cucumber leaves increased by improving foliar fertilizers using TEA, liquid soap, urea, Rixifilm, Adjmix-D1 and Adjmix-D2 to about 4.42 (118%), 4.1 (109), 4.45 (119), 4.11 (111), 4.45 (119) and 3.89% (104%), respectively, relative to UIFF = 100.

Table 8. Nutrient contents in white eggplant leave as affected by different adjuvant treatments used for improving foliar fertilizer in four sequence applications

Adjuvant treatments	N	K	Fe	Zn	Mn	N	K	Fe	Zn	Mn
	%		ppm			%		ppm		
	Sampled date: (1) 21-5-2020					**Sampled date: (2) 28-5-2020**				
Pure water	4.03	3.02	115	25.4	143	4.19	4.08	110	27.8	145
UIFF	4.31	3.63	122	31.7	178	4.21	4.14	123	32.1	173
TEA	4.55	4.43	135	36.5	201	4.85	4.39	143	35.7	195
Liquid soap	4.84	4.54	133	35.3	195	4.90	4.42	144	36.6	196
Glycerin	4.39	4.29	137	33.7	187	4.76	4.34	137	32.5	190
Arabic gum	4.57	4.39	131	33.8	191	4.72	4.38	137	32.4	189
Molasses	4.45	4.32	132	32.0	175	4.46	4.18	128	27.4	183
Urea	4.59	4.28	131	31.5	174	4.63	4.37	137	31.6	189
Rixi film	4.56	4.68	136	36.9	203	4.86	4.37	142	37.3	202
Adjmix-D1	5.65	4.72	138	38.5	227	5.02	4.54	148	38.9	214
Adjmix-D2	5.54	4.64	131	36.4	224	4.83	4.33	147	36.8	207
Mean-IFF	4.82	4.50	134	35.4	200	4.78	4.37	140	34.4	196
Relative to UIFF	112	124	110	112	113	114	106	114	107	113
Relative to P. water	120	149	116	140	140	114	107	127	124	135
$LSD_{0.05}$	0.25	0.9	13.0	3.3	17.0	0.6	0.19	19.0	3.6	23.0
	Sampled date: (**3**) 4-6-2020					Sampled date: (**4**) 11-6-2020				
Pure water	4.18	3.66	113	25.8	136	4.10	3.67	105	23.9	141
UIFF	4.32	3.75	119	29.6	154	4.35	3.94	120	27.9	150
TEA	4.89	4.23	126	38.7	195	4.68	4.76	141	38.2	197
Liquid soap	4.90	4.37	136	39.0	205	5.17	4.83	147	39.2	202
Glycerin	4.71	4.11	120	30.0	183	4.73	4.63	127	33.3	193
Arabic gum	4.65	4.26	127	33.2	186	4.64	4.48	133	34.2	178
Molasses	4.36	4.17	125	32.4	179	4.65	4.25	123	27.4	172
Urea	4.57	4.34	123	33.5	170	4.66	4.42	135	33.6	191
Rixi film	5.05	4.62	134	38.6	195	5.24	4.65	148	36.8	202
Adjmix-D1	5.08	4.63	140	40.7	207	5.52	4.86	159	38.4	203
Adjmix-D2	5.03	4.46	138	39.6	204	5.25	4.67	146	36.5	198
Mean-IFF	4.80	4.35	130	36.2	192	4.95	4.62	140	35.3	193
Relative to UIFF	111	116	109	122	124	114	117	117	126	128
Relative to P. water	115	119	115	140	140	121	126	133	148	137
$LSD_{0.05}$	0.57	0.55	15.0	9.0	40.0	080	0.70	26.0	8.5	43.0

Table 9. Nutrient contents in cucumber leaves as affected by different adjuvant treatments used for improving foliar fertilizer in four sequence applications

Adjuvant treatments	N	K	Fe	Zn	Mn	N	K	Fe	Zn	Mn
	%		ppm			%		ppm		
	Sampled date: (1) 11-10-2020					Sampled date: (2) 18-10-2020				
Pure water	2.90	2.86	41.6	26.7	54.3	3.02	2.68	46.7	26.9	52.8
UIFF	3.50	3.10	49.8	37.8	61.2	3.64	3.04	53.1	30.6	60.3
TEA	4.20	3.48	69.8	49.0	84.3	4.81	3.13	71.9	40.4	87.9
Liquid soap	4.11	3.40	72.9	50.1	82.2	3.97	3.45	78.6	42.5	88.1
Glycerin	3.64	3.55	60.0	38.1	71.6	3.78	3.45	57.9	41.2	73.7
Arabic gum	3.73	3.42	54.2	43.1	77.4	3.73	3.13	52.7	39.7	76.5
Molasses	3.45	3.24	52.1	40.1	69.9	3.97	3.26	44.7	35.3	69.9
Urea	4.34	3.15	61.6	36.1	71.3	3.78	3.44	39.0	24.2	71.3
Rixi film	3.78	3.49	74.9	46.1	86.5	4.01	3.49	76.2	45.9	81.3
Adjmix-D1	4.11	3.40	71.9	55.8	80.9	4.53	3.71	74.3	45.7	83.1
Adjmix-D2	3.55	3.14	65.4	38.2	75.9	3.83	3.29	71.7	42.4	82.0
Mean-IFF	3.89	3.35	63.5	43.8	76.7	4.05	3.36	61.3	38.9	79.1
Relative to UIFF	111	108	127	116	125	111	111	115	127	131
Relative to P. water	134	117	153	164	141	134	125	131	145	150
$LSD_{0.05}$	0.6	0.3	22.0	12.0	19.0	0.19	0.40	21.0	11.5	18.0
	Sampled date: (**3**) 25-10-2020					Sampled date: (**4**) 1-11-2020				
Pure water	3.96	3.07	44.5	27.2	53.4	3.33	3.20	45.3	29.1	51.4
UIFF	3.92	3.51	53.6	34.5	60.9	3.92	3.56	54.8	37.6	63.9
TEA	4.20	3.87	81.5	44.4	88.6	4.48	4.08	83.2	49.3	90.5
Liquid soap	4.01	4.12	81.58	46.4	86.1	4.29	4.14	86.1	45.1	89.3
Glycerin	4.01	3.54	63.4	41.7	75.0	4.11	3.64	66.1	41.1	74.2
Arabic gum	3.83	3.49	61.6	44.0	81.2	4.01	3.60	70.1	41.7	84.1
Molasses	3.73	3.73	65.5	41.1	69.9	3.92	3.67	58.0	41.2	69.9
Urea	4.20	3.92	86.0	42.0	71.3	5.46	3.77	71.2	53.2	71.3
Rixi film	4.48	4.12	75.0	47.0	88.5	4.39	4.33	81.6	53.1	90.2
Adjmix-D1	4.25	4.48	83.8	48.3	86.6	4.53	4.19	79.2	47.5	86.7
Adjmix-D2	4.01	4.07	76.2	41.1	82.2	4.15	4.01	75.9	45.7	81.2
Mean-IFF	4.03	3.90	75.0	43.6	80.1	4.37	3.89	73.7	45.6	80.9
Relative to UIFF	103	111	140	127	132	111	109	134	121	127
Relative to P. water	120	127	169	160	150	131	121	163	157	157
$LSD_{0.05}$	0.25	0.6	28.0	11.9	21.0	0.35	0.45	24.0	9.0	22.0

Table 10. Nutrient contents in white eggplant and cucumber leaves as affected by different adjuvant treatments used for improving foliar fertilizer and relative values (RV) to UIFF=100

Adjuvant treatments	Nutrient contents in white eggplant leaves					Nutrient Contents in Cucumber leaves				
	N	K	Fe	Zn	Mn	N	K	Fe	Zn	Mn
	%		ppm			%		ppm		
Pure water	4.12	3.61	111	25.7	141	3.15	2.95	44.5	27.5	53.0
%	96	93	92	85	86	84	89	84	78	86
UIFF	4.30	3.86	121.0	30.3	164	3.75	3.30	52.8	35.1	61.6
RV %	100	100	100	100	100	100	100	100	100	100
TEA	4.75	4.45	136	37.3	197	4.42	3.64	76.6	45.8	87.8
RV %	110	115	113	123	120	118	110	145	130	143
Liquid soap	4.95	4.54	140	37.5	200	4.10	3.78	79.8	46.0	86.4
RV %	115	117	116	124	122	109	114	151	131	140
Glycerin	4.65	4.34	130	32.4	188	3.89	3.55	61.8	40.5	73.7
RV %	108	112	108	107	115	104	107	117	115	120
Arabic gum	4.64	4.38	132	33.4	186	3.83	3.41	59.7	42.1	79.8
RV %	108	113	109	110	113	102	103	113	120	130
Molasses	4.48	4.23	127	29.8	177	3.77	3.47	55.1	39.4	69.9
RV %	104	110	105	98	108	101	105	104	112	113
Urea	4.62	4.38	132	32.9	183	4.45	3.57	64.5	38.9	71.3
RV %	107	113	109	108	112	119	108	122	111	116
Rixi film	4.93	4.58	140	37.4	200	4.17	3.86	76.9	48.0	86.6
RV %	115	119	116	123	122	111	117	146	137	141
Adjmix-D1	5.32	4.60	143	38.4	211	4.35	3.95	77.3	49.3	84.3
RV %	124	119	118	126	129	116	120	146	141	137
Adjmix-D2	5.16	4.52	141	37.3	208	3.89	3.63	72.3	41.8	80.3
RV %	120	117	116	123	127	104	110	137	119	130
Mean – IFF	4.83	4.45	136	35.1	195	4.10	3.67	70.2	44.2	80.4
Relative to UIFF	112	115	112	116	119	110	111	133	126	131
Relative to pure water	117	123	122	134	138	130	124	158	161	152
$LSD_{0.05}$	0.30	0.5	10.1	3.2	22.7	0.32	24.8	12.5	5.4	8.5
%	7.0	13.0	8.3	10.6	13.8	8.5	7.6	23.7	15.5	13.8

Results revealed in **Table 10** showed that the highest values and relative increase in K content in white eggplant leaves were 4.60 (119), 4.58 (119), 4.54 (117), 4.52 (117) and 4.45% (115%) for Adjmix-D1, Rixifilm, liquid soap, Adjmix-D2 and TEA, respectively comparing with that of UIFF which was 3.56% (100%), respectively. Similar increases were also obtained for K content in cucumber leaves as affected by the application of different adjuvants each alone or in combination for improving foliar fertilizer. These increases reached about 3.64 (110), 3.78 (114), 3.57 (108), 3.86 (117), 3.95 (120) and 3.63% (110%), respectively relative to UIFF=100.

Regarding the effects of the tested substances, either alone or in combination used as adjuvants for improving foliar fertilizer on some micronutrient's contents in white eggplant and cucumber leaves, results in **Table 10** indicated similar positive effects, particularly for Adjmix-D1, Adjmix-D2, Rixifilm, liquid soap and TEA that give the highest relative increases in Fe, Zn, and Mn contents. For white eggplant, these increases were about 143ppm (118), 141 (116), 140 (116), 140 (116) and 136 ppm (113%) for Fe, 38.4 (126), 37.3 (123), 37.4 (123), 37.5 (124) and 37.3 ppm (123%) for Zn and 211 (129), 208 (127), 200 (122), 200 (122) and 197 ppm (120%) for Mn, respectively compared with that of UIFF=100.

These results illustrated the higher positive effect of surfactants (i.e., TEA and liquid soap) as adjuvants on the spreading rate of the improved foliar fertilizer (IFF) on leaves leading to increased nutrient uptake as illustrated by Czarnota and Thomas (2010).

For cucumber, the increases were about 77.3 (146), 72.3 (137), 76.9 (146), 79.8 (151), and 76.6 ppm (137%) for Fe, 49.3 (141), 41.8 (119), 48.0 (137), 46.0 (131) and 45.8 ppm (130%) for Zn and 84.3 (137), 80.3 (130), 86.6 (141), 86.4 (140), and 87.8 ppm (143%) for Mn by using Adjmix-D1, Adjmix-D2, Rixi film, liquid soap and TEA for improving foliar fertilizers, respectively.

These results illustrated the higher positive effect of surfactants (i.e., TEA and liquid soap) as adjuvants on the spreading rate of the IFF on leaves leading to an increase in the nutrient uptake efficiency as declared by Czarnota and Thomas (2010).

The average and relative increases in N, K, Fe, Zn and Mn contents as affected by the tested adjuvants each alone or in combination in four sequence applications were about 4.83% (112), 4.45% (115), 136 ppm (112), 35.1 ppm (116%) and 195 ppm (119%) for white eggplant leaves respectively relative to that of UIFF=100 (**Table 10**). The increase in N, K, Fe, Zn and Mn contents reached to about 117, 123, 122, 134 and 138% for white eggplant and 130, 124, 158, 161 and 152% for cucumber respectively relative to that of pure water=100 (**Table 10**). However, these increases are more pronounced for cucumber than white eggplant. This may be attributed to the differences in the roughness properties of plant leaves (De Ruiter et al 1995).

It is worth mentioning that the highest increase in N, K, Fe, Zn and Mn contents in white eggplant leaves as affected by the IFF applied in four sequence weekly applications were obtained by using Adjmix-D1 in improving the foliar fertilizers (**Table 10**). These increases were about 5.32% (124), 4.6% (119), 143 ppm (118), 38.4 ppm (126) and 211 ppm (129%) for white eggplant and 5.35, (116), 3.95% (120%), 77.3 ppm (146), 49.3 ppm (141) and 84.3 ppm (137%) for cucumber, respectively **Table 10**. The highly positive effect of Adjmix-D1 to improve foliar fertilizers can be due to the combined effect of its adjuvant components in increasing spreading rate, sticking, humectant, and penetrating which together act to increase the efficiency of plant utilization of IFF.

However, surfactants such as TEA, and liquid soap and stickers such as Arabic gum, and molasses are often added to adjuvants to improve the spreading and sticking of the fertilizer on the leaf surface and increase the area of leaf interacting with the fertilizer (Fernández and Eichert 2009).

In addition, the ability of foliar sprays to spread and stick to leaves is essential to enable the uptake of nutrients. Many plant species including cucumber have been shown to have low wettability due to leaf surface roughness which is caused by waxes and hairs (De Ruiter et al 1995).

3.4 Effects of the improved foliar fertilizers (IFF) on fruit crop yields

To evaluate the efficiency of using the suggested adjuvants (each alone or in combination) for improving foliar fertilizers, two field experiments were carried out by spraying white eggplants and cucumber crops in sequence weekly applications to evaluate their efficiency on fruit yield and nutrient contents.

Data in **Table 11** show the average effect of the IFF by using the different adjuvant treatments on the fruit yield of eggplants and cucumbers relative to pure water treatment = 100 or relative to UIFF=100.

In general, the obtained results revealed that the IFF increased fruit yield by 23% relative to pure water treatment and 8% relative to UIFF treatment. These results demonstrated the importance of foliar fertilizers application and the IFF for increasing fruit yield.

Data in **Table 11** show the average fruit yield as affected by the IFF using the different suggested adjuvants relative to UIFF=100. Data indicated that the highest increase in fruit yield of the tested crops was observed at the application of the improved foliar fertilizer using Adjmix-D1. This increase was about 42% relative to pure water treatment =100 or 27% relative to UIFF treatment =100.

It could be also observed that the application of molasses treatment for improving foliar fertilizer caused a reduction in fruit yield to about 87% relative to UIFF=100. This reduction may be ascribed to the possible adverse effects of some additives to molasses such as sulfur dioxide (sulfured molasses), which acts as a preservative, preventing the molasses from spoiling (El-Geddawy et al 2012, McDonell 2020).

Table 11. Average effects of IFF using the different suggested adjuvants on relative fruit yield to pure water =100 or relative to UIFF=100

Adjuvant treatments	Crop yield relative to pure water or UIFF=100- %			
	White eggplants		Cucumber	
Pure water	85	100	92	100
UIFF	100	118	100	109
TEA	113	134	102	111
Liquid soap	123	145	116	127
Glycerin	108	127	100	109
Arabic gum	107	127	97	106
Molasses	81	96	92	100
Urea	109	129	102	111
Rixi film	119	141	110	120
Adjmix-D1	128	151	129	140
Adjmix-D2	114	135	110	120
Mean	110	130	106	116

Data in **Table 12** show the fruit yield of white eggplants as affected by adjuvants treatments used for improving foliar fertilizers during four sequence applications. Data indicated that the highest increase in fruit yield of eggplants was obtained with the application of adjmix-D1 followed by adjmix-D2. These increases were about 28 and 14%, respectively.

Results indicated that the fruit yield of white eggplants as affected by the application of the improved foliar fertilizer treatment could be arranged in the following descending order: Adjmix-D1 > Liquid soap > Rixi film > Adjmix-D2. Similar results were also obtained for the four sequence fruit harvestings each after 7 days from the application of pure water, IFF and UIFF treatments. No substantial changes in fruit weight in g/fruit were observed for all the tested treatments. Similar findings were obtained by Gaskin and Stevens (1993), Gaskin et al (2000) and Czarnota and Thomas (2010).

Data in **Table 13** show the fruit yield of cucumber as affected by adjuvant treatments used for improving foliar fertilizers during the sequence applications. Data indicated that the highest increase in the fruit yield of cucumber was obtained with the application of Adjmix-D1 followed by adjmix-D2. These increases were about 29 and 10%, respectively.

Data in **Table 13** indicated that the fruit yield of cucumber influenced by the application of the improved Foliar fertilizer treatment could be arranged in the following descending order: Adjmix-D1>Liquid soap>Adjmix-D2 = Rixi film. Similar results were also obtained for the four sequences of fruit harvesting each after 7 days from the application of pure water, IFF and UIFF treatment.

These results may be attributed to the effect of these adjuvants in enhancing the wettability of plant leaves with the IFF and consequently increasing nutrient uptake. These results are in agreement with those obtained by Alexander and Schroeder (1987), Brazee et al (2004) and Fernández and Brown (2013) as No substantial changes in fruit weight in g/fruit were observed for all the tested treatments.

Table 12. Fruit yield of white eggplants as affected by adjuvant treatments used for improving foliar fertilizers during four sequence applications

Adjuvant Treatments	Mean Fruit No. Fruit/plant	White eggplant fruit yield in g/plant at 4 sequence harvestings				Mean Fruit yield		Relative Fruit yield %
		21-5-20	28-5-20	4-6-20	11-6-20	g/fruit	g/plant	
Pure water	4.80	74	142	205	211	32.9	158	85
UIFF	5.61	116	152	223	257	33.4	187	100
TEA	6.27	123	184	261	277	33.7	211	113
Liquid soap	6.88	131	184	263	341	33.4	230	123
Glycerin	6.02	120	154	251	280	33.5	201	108
Arabic gum	5.92	118	174	248	262	33.9	201	107
Molasses	4.57	70.6	135	194	209	33.3	152	81
Urea	6.02	124	185	249	257	33.8	204	109
Rixi film	6.57	121	163	267	338	33.9	222	119
Adjmix-D1	7.55	163	204	299	355	33.8	255	136
Adjmix-D2	7.08	144	176	300	338	33.8	239	128
Mean	6.12	118	169	251	284	33.6	206	114
$LSD_{0.05}$	0.9	4.0	20.5	37.0	20.0	1.1	24.0	12.8

Table 13. Cucumber fruit yield as affected by different adjuvants used for improving foliar fertilizers for four sequences applications

Adjuvant Treatments	Mean Fruit No.	Cucumber fruit yield in g/plant at 4 sequence harvestings				Mean Fruit yield		Relative Fruit yield
	Fruit/plant	11-10-20	18-10-20	25-10-20	1-11-20	g/fruit	g/plant	%
Pure water	1.23	73.0	125	132	173	102	502	92
UIFF	1.33	77.2	140	149	181	103	547	100
TEA	1.37	77.1	132	157	194	102	559	102
Liquid soap	1.57	102	138	187	209	101	636	116
Glycerin	1.35	76.6	127	135	209	101	548	100
Arabic gum	1.35	50.4	141	127	213	98	531	97
Molasses	1.27	90.2	114	126	174	99	504	92
Urea	1.37	97.2	143	128	189	102	557	102
Rixi film	1.45	98.3	145	142	216	104	601	110
Adjmix-D1	1.70	110	169	197	229	104	704	129
Adjmix-D2	1.45	51.2	155	174	221	104	601	110
Mean	1.42	83.4	140	153	203	102	579	108
$LSD_{0.05}$	0.20	15.0	8.0	15.0	20.1	0.4	33.0	6.0

4 Conclusion

From the aforementioned results, it could be concluded that the Adjmix-D1 contained 0.6g/L TEA and 0.6g/L liquid soap as surfactants, 0.6g/L glycerin as a humectant, 0.6g/L Arabic gum as a sticker and 0.6g/L urea as a penetrator can be used as an effective adjuvant for improving foliar fertilizers application and use efficiency.

References

Alexander A, Schroeder M (1987) Fertilizer use efficiency: Modern trends in foliar fertilization. *Journal of Plant Nutrition* 10, 1391-1399. https://doi.org/10.1080/01904168709363671

Jones JJB (2001) Laboratory guide for conducting soil tests and plant analysis. 1st ed, CRC Press, Boca Raton London, New York Washington, DC. https://doi.org/10.1201/9781420025293

Brazee RD, Bukovac MJ, Zhu H (2004) Diffusion model for plant cuticular penetration by spray-applied weak organic acid bioregulator in presence or absence of ammonium nitrate. *American Society of Agricultural and Biological Engineers* 47, 629-635. https://doi.org/10.13031/2013.16092

Chen H, Muros-Cobos JL, Amirfazli A (2018) Contact angle measurement with a smartphone. *Review of Scientific Instruments* 89, 035117. https://doi.org/10.1063/1.5022370

Somervaille A, Betts G (2011) Adjuvants : oils, surfactants and other additives for farm chemicals. Kingston, ACT: Grains Research & Development Corporation, 48 p. https://rb.gy/aaky8

Czarnota M, Thomas PA (2010) Using surfactants, wetting agents, and adjuvants in the greenhouse. University of Georgia Cooperative Extension, Athens, Georgia B1319. https://api.semanticscholar.org/CorpusID:49571308

De Assunção HHT, Campos SFB, Sousa LA, et al (2019) Adjuvants plus phytosanitary products and the effect on the physical-chemical properties of the spray liquids. *Bioscience Journal* 35, 1878-1885. https://doi.org/10.14393/BJ-v35n6a2019-46994

De Ruiter H, Straatman KR, Meinen E (1995) Influence of two fatty amine surfactants on foliar absorption, translocation, and efficacy of 2,4-D Triethanolamine salt. *Journal of Agricultural and Food Chemistry* 43, 3093-3097. https://pubs.acs.org/doi/pdf/10.1021/jf00060a018

Dordas C (2009) Role of nutrients in controlling plant diseases in sustainable agriculture: A review. In: Lichtfouse E, Navarrete M, Debaeke P, Véronique S Alberola C. (Eds), Sustainable Agriculture. Springer, Dordrecht. pp 443–460. https://doi.org/10.1007/978-90-481-2666-8_28

El-Geddawy MMA, Omar MB, Seleim MM, et al (2012) Composition and properties of Egyptian beet molasses. *Journal of Food and Dairy Sciences* 3, 669-679. https://doi.org/10.21608/JFDS.2012.81735

Fernández V, Brown PH (2013) From plant surface to plant metabolism: the uncertain fate of foliar-applied nutrients. *Frontiers in Plant Science* 4, 289. https://doi.org/10.3389/fpls.2013.00289

Fernández V, Eichert T (2009) Uptake of hydrophilic solutes through plant leaves: Current state of knowledge and perspectives of foliar fertilization. *Critical Reviews in Plant Sciences* 28, 36-68. https://doi.org/10.1080/07352680902743069

Gaskin RE, Murray RJ, Krishna H, et al (2000) Effect of adjuvants on the retention of insecticide spray on cucumber and pea foliage. *New Zealand Plant Protection* 53, 355-359. https://doi.org/10.30843/nzpp.2000.53.3608

Gaskin RE, Steele KD, Forster WA (2005) Characterizing plant surface for spray adhesion and retention. *New Zealand Plant Protection* 58, 179-183. https://doi.org/10.30843/nzpp.2005.58.4244

Gaskin RE, Stevens PJG (1993) Antagonism of the foliar uptake of glyphosate into grasses by organosilicone surfactants. Part 2: Effects of surfactant structure and glycerol addition. *Pesticide Science* 38, 193-200. https://doi.org/10.1002/ps.2780380214

Harkins WD, Brown FE (2019) The determination of surface tension (free surface energy), and the weight of falling drops: The surface tension of water and benzene by the capillary height method. *Journal of the American Chemical Society* 41, 499-524. https://pubs.acs.org/doi/pdf/10.1021/ja01461a003

Lamour G, Hamraoui A, Buvailo A, et al (2010) Contact angle measurements using a simplified experimental setup. *Journal of Chemical Education* 87, 1403-1407. https://doi.org/10.1021/ed100468u

Heywood VH (1970) The Cuticles of plants. In: Martin JT, Juniper BE, Arnold E (Eds) Ltd., London and New York. pp 347. https://api.semanticscholar.org/CorpusID:138204850

McDonell K (2020) Everything you need to know about molasses. *Medical News Today*. https://www.medicalnewstoday.com/articles/318719

Nairn JJ, Forster WA, Van Leeuwen RM (2013) Universal spray droplet adhesion model - accounting for hairy leaves. *Weed Research* 53, 407-417. https://doi.org/10.1111/wre.12039

Oosterhuis DM, Weir BL (2010) Foliar fertilization of Cotton. In: Stewart JM, Oosterhuis DM, Heitholt JJ, Mauney JR (Eds) Physiology of Cotton. Springer, Dordrecht. pp 272–288 https://doi.org/10.1007/978-90-481-3195-2_25

Ortiz PR, Meza BIC, Requena de la Garza FR, et al (2007) Evaluation of different iron compounds in chlorotic Italian lemon trees (Citrus lemon). *Plant Physiology and Biochemistry* 45, 330-334. https://doi.org/10.1016/j.plaphy.2007.03.015

Park SY, Hannemann RE, Franse EI (1999) Dynamic tension and adsorption behavior of aqueous lung surfactants. *Colloids and Surfaces B: Biointerfaces* 15, 325-338. https://doi.org/10.1016/S0927-7765(99)00098-3

Penner D (2000) Activator adjuvants. *Weed Technology* 14, 785-791. https://doi.org/10.1614/0890-037X(2000)014[0785:AA]2.0.CO;2

Prado EP, Raetano CG, Dal Pogetto MHF, et al (2016) Effects of agricultural spray adjuvants in surface tension reduction and spray retention on *Eucalyptus* leaves. *African Journal of Agricultural Research* 11, 3959-3965. https://doi.org/10.5897/AJAR2016.11349

Rosen MJ, Kunjappu JT (2012) Reduction of Surface and Interfacial Tension by Surfactants. In: Rosen MJ, Kunjappu JT (Eds), Surfactants and Interfacial Phenomena, (4Th ed.) John Wiley, New York, NY, US. pp 235-271. https://doi.org/10.1002/9781118228920.ch5

Rasmussen HR (2016) Foliar application of iron chelated fertilizer and surfactants for management of iron deficiency chlorosis in soybeans. Phd._dissertation, North Dakota State, University of Agriculture and Applied Science. https://hdl.handle.net/10365/27708

Santos RTS, Ferreira MC, Viana RG (2019) Does the use of adjuvants alter surface tension and contact angle of herbicide spray droplets on leaves of Sida spp.?. *Planta Daninha* 37, e019185603. https://doi.org/10.1590/S0100835820193701000082

Smoleń S (2012) Foliar Nutrition: Current State of Knowledge and Opportunities. In: Srivastava A. (Eds) *Advances in Citrus Nutrition. Springer, Dordrecht* pp 41-58. https://doi.org/10.1007/978-94-007-4171-3_4

Soni M (2019) A simple laboratory experiment to measure the surface tension of a liquid in contact with air. *Journal of Pharmacognosy and Phytochemistry* 8, 2197-2202. https://rb.gy/36kpl

Tu M, Randall JM (2001) Adjuvants. In: Tu M, Hurd C, Randall JM.(Eds) Weed Control Methods Handbook: Tools & Techniques for Use in Natural Areas. The Nature Conservancy, pp 8.1-8.25.