INVASIVE *Solanum elaeagnifolium* CAV. WEED CHEMICAL CONTROL WITH SPECIAL REFERENCE TO ADDITIVES

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ABSTRACT

Solanum elaeagnifolium Cav. is an invasive perennial weed that causes a high degree of loss in crop productivity, and it is difficult to control. Therefore, some experiments were conducted to optimize the efficacy of the used herbicides via some additives and other herbicides against *S. elaeagnifolium*. In the fig fields, the efficacy of glyphosate showed better control when applied with additives and other herbicides that could be ranked as follows; fluroxypyr ≥ pyraflufen-ethyl ≥ metribazine ≥ bromoxynil-octanoate. Applied glyphosate with additives can sever as a substitute to other herbicides combination in the early growth to give a better weed control, while glyphosate with pyraflufen-ethyl, fluroxypyr, and metrabzine in the presence of additives delayed the revegetation times of weed from 70 up to 85 days. Application in August was proved to reduce the fruiting and subsequently their future infection of *S. elaeagnifolium*. Accordingly, these mixtures of herbicides led to remarkable timing reduction effects in soil microbe's counts and activity diminished within four weeks after application whereas, fungi were the most restrained microorganisms to herbicides treatments. Among the selective herbicides, pyraflufen-ethyl, and fluroxypyr could be used to suppress the weed growth in the emergency of growing *Triticum aestivum* and *Zea mays* respectively. Finally, promoting the effectiveness of the herbicides was profitable by choosing the proper time of application and the suitable mixtures, thus must be devoted to an integrated program for better weed control.

Keywords: *Solanum elaeagnifolium,* herbicides, additives, weed control efficiency, soil microorganisms.

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INTRODUCTION

Silverleaf nightshade (*Solanum elaeagnifolium* Cav.) is one of the worst invasive alien plants worldwide (Brunel, 2011). Whereas, invasive plants are considered a major risk to biodiversity and can disturb the nutrient dynamics and water balance in affected ecosystems (Ehrenfeld, 2003) and social values are widely acknowledged (Pimentel, 2002). *S. elaeagnifolium* Cav. is an invasive perennial plant species of North, Central, South American origin (Henderson, 2001). It invaded all countries of the Mediterranean Basin (Mekki 2007) and Egypt (Täckholm 1974; Boulos 2009, Balah 2011, Balah 2015, Balah and Abdelrazek 2020). *S. elaeagnifolium* is hard to control once they are established (Chauhan *et al*.

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2012), especially with the current cultural, mechanical, chemical, and biological control means (EPPO, 2007). *S. elaeagnifolium* harms crops, causing up to 75% yield loss, as well as an indirect impact by harboring plant pests and diseases (Uludag *et al.* 2016). High economic losses are caused in cotton, grain sorghum, wheat, and lucerne by *S. elaeagnifolium* infestation (Boyd and Murray, 1982; Lemerle and Leys, 1991) and interfere with peanuts growth (Hackett *et al.* 1987). *S. elaeagnifolium* is an alternative host for phytophagous insects and plant diseases (Heap & Carter, 1999). Weed populations of *S. elaeagnifolium* in the Jordan Valley probably act as alternative hosts for different agricultural pests (Qasem, 2012).

Integration of knowledge of weed emergence could be used to improve weed control strategies (Grundy, 2003). The growth and reproduction of *S. elaeagnifolium* were affected significantly by the time of emergence (Zhu *et al*. 2013d). *S. elaeagnifolium* reproduces sexually (Cooley & Smith, 1972) and asexually which regeneration can occur in root fragments (Fernandez & Brevedan, 1972) and creeping lateral roots (Cuthberston *et al*. 1976), whereas seeds are viable for at least six years (Stanton *et al*. 2009). *S. elaeagnifolium* is a very adaptable plant to high summer temperatures (20-34^{o}C), low annual rainfall (250-600 mm), drought, and saline soil conditions (Brunel, 2011). It is a drought-tolerant invasive weed (Garcia-Fortea *et al.* 2019). Alternating temperatures are basic requirements of *S. elaeagnifolium* seed germination while it seems a moderate tolerance to salinity and drought stresses (Balah *et al.,* 2021). It has a high level of genetic diversity within and between populations (Dekker, 1997, Hawker *et al.* 2006). *S. elaeagnifolium* is a problematic weed pose that exhibited distinct morphological variations due to a high level of genetic diversity and is difficult to control ((Zhu *et al*. 2013a, Tsaballa *et al*. 2015, Qasem *et al*. 2019). and the morphological variation influences the herbicide efficiency (Brewer *et al*. 1991, Kraemer *et al.* 2009).

Preventing weeds is usually easier and less costly than controlling them after severe infestation, whereas, invasive weeds are difficult to control once it established (Chauhan *et al*., 2012). It is very difficult to eradicate as new sprouts can generate from creeping lateral roots, root fragments and rhizomes (Stanton and Lemerle, 2011; Westerman and Murray, 1994). If *S. elaeagnifolium* is not controlled at all or not controlled at an early stage, it will spread rapidly in the following years and can drastically reduce yield (Green *et al.* 1988). Mechanical, herbicidal, and biological methods often fail because of *S. elaeagnifolium* Cav. network of creeping horizontal and deep vertical roots (Olckers *et al*. 1995). Under dry conditions, deep cultivation may reduce but not eradicate an infestation (Parsons and Cuthbertson, 1992). Suppression using competition from cultivated pastures offers a possible solution (Viljoen, 1988). Sustainable management of *S. elaeagnifolium* will require coordination, education and support across the affected countries (Uludag *et al*. 2016). On the other hand, the extensive root system limited the efficacy of mechanical management (Stanton *et al.* 2011). Glyphosate is recommended for *S. elaeagnifolium* non-selective control (Eleftherohorinos *et al*. 1993; Baye and Bouhache, 2007; Ensbey, 2011). Glyphosate is a foliar systemic herbicide (Tomlin, 2006). It is absorbed across the leaves and translocated throughout the plant phloem (Roberts, 1998).The combination of glyphosate with ammonium sulfate and mechanical control allowed a reduction of density (> 92%) and biomass (> 94%) of *S. elaeagnifolium* Cav. (Zaki *et al.* 1995). The most appropriate timing for glyphosate application is the green berries growth stage (Sayari & Mekki, 2017). While translocation of the herbicide glyphosate within *S. elaeagnifolium* is much greater in spring and autumn compared to summer (Greenfield, 2003), two applications of glyphosate (early plus midseason) significantly reduced stem number but would be more expensive than a single application. Three applications provided even greater control at an increased cost (Choudhary and Bordovsky, 2006). 2, 4-D, triclopyr and glyphosate were effective in suppressing the growth and seed production of *S. elaeagnifolium* (Qasem, 2014). An application at early flowering followed by a late application in autumn is necessary to effectively control the seedset (seed bank) and the root regrowth (root bank) of *S. elaeagnifolium* (Wu *et al.* 2016). Glufosinate and glyphosate were found to be reliable options for control of *S. elaeagnifolium* when applied at either weed growth stage; tembotrione could be also another reliable option, however, when applied only at an early vegetative stage (Gitsopoulos *et al*. 2017). However, sustainable management of *S. elaeagnifolium* will require coordination, education and support across the affected countries (Uludag *et al*. 2016). Herbicides can be considered the most active tools in invasive weed control. However, there are many environmental considerations and safety complications. On the other side, many tools can be used to maximize their effectiveness toward these intractable weeds. In *S. elaeagnifolium* case, none of the previous studies attempt to compare the use of herbicide efficiency via additives and/or other mixtures of herbicide. Therefore, the work aims to compare the glyphosate biological activity in the presence of additives and other herbicide mixtures against *S. elaeagnifolium* to develop an integrated management program lead to prevent their invasion.

MATERIALS AND METHODS

Plant and chemical materials

Seeds of silver nightshade (*S. elaeagnifolium*) were collected from the invaded regions of the western north coast of Egypt after maturing berries and preserved at Desert Research Center. After crushed berries, the obtained seeds were soaked in running water for 48 h, and dried by air at room temperature, then kept until use. Glyphosate 48%WSC (Round up), Fluroxypyr 20%EC (Stryne), Pyraflufen-ethyl 2%EC (Ecopart), Bromoxynil octanoate 24%EC (Borminal), Bentazon 48% AS (Basgran), Tribenuron-methyl 75%DF (Ganstar), Metribuzin 70% WP (Cynozed). Nonionic surfactant (Tween 20%) and sticking agent (Arabic gum) supplied from El-Gomhouria Chemicals, Egypt).

2-Greenhouse trails efficiency

Solanum elaeagnifolium was planted in plastic pots filled with sandy soil collected from Borg El Arab district, Egypt. The soil is sandy loam to loamy sand with pH 8.2, EC 0.73 ds/m respectively and with soluble cations (meq/l) 1.530 (Na^+), 1.06 for (K^+), 2.230 for (Ca^{++}), 2.040(Mg^{++}) and soluble anions (meq/100 g) 1.630 (Cl^-), 1.070 ($SO4^-$) and 2.11(HCO_3^-) respectively. These pots were gently and periodically irrigated each 3 days intervals with appropriate amounts of water. Then and at the 5 to 7 leaves stage, the pots were arranged in a Complete Randomized-Block Design before treating with herbicides mixtures without and with additives. After three weeks from application, the vegetative parts fresh and dry weights of the plants were calculated, while, untreated control was used in the comparison. The reduction was calculated according to following formula; R (%) = Control- treatment/ Control x 100.

3-Laboratory studies of physicochemical properties

The solutions of herbicides mixtures additives were shaken thoroughly to make them homogeneous. Then, pH meter (Model Thermo Orion 25 star Instruments, USA), was used to measure pH values at 25±2°C. While the electrical conductivity was determined using an electrical conductivity meter. Viscosity was measured by Brookfield programmable DV-11+Viscometer: 60RPM where $cm^2 s^{-1}$ is the unit of viscosity measurement**.** Surface tension (ST) using droplet weight methods in dyne cm^{-1} was measured according to ST = W x 980.7/2 x π x D, where W is the maximum weight (g), 980.7 is the factor of convert gravitational force and D represents the diameter of the ring.

4- The selective broadleaved herbicides evaluation using crops and *S. elaeagnifolium*

Silver nightshade (*S. elaeagnifolium*), maize (*Z. mays*), wheat (*T. aestivum*), and Egyptian clover (*T. alexandrinum)* were used to evaluate the activity of selective broadleaved herbicides. In plastic pots containing the collected sandy soil, five seeds of these plants were sowed each pot. The pots were placed in the greenhouse under Randomized Complete Block Design with five replications. Pots were gently irrigated regularly each 3-day intervals with suitable amounts of water until the 5 to 7 leaves stage of plant growth. The herbicides of bentazon, pyraflufen-ethyl, fluroxypyr and metrabzine at the recommended dose were applied to the crop plants after one month from germination. After two weeks of application; lengths, vegetative fresh and dry weights were recorded.

5-Field trial efficacy

Glyphosate was mixed with pyraflufen-ethyl or fluroxypy or bromoxynil-octanoate or metribazine at a half dose in the presence of additives (Nonionic surfactant and sticking agent) compared with glyphosate at recommended dose alone. Using a knapsack sprayer (Matabi 20 L), these mixtures were applied to fig farms infected with *S. elaeagnifolium* at May and August, respectively. Each treatment was established on two plots of fig fruits, while each plot area was 4 ×20 m in length. These applications were repeated in three nonadjacent farms infected with *S. elaeagnifolium* during the same growing season whereas, the recommended cultural practices were followed on fig plantation. After three weeks from application, total fresh and dry weights of vegetative parts were estimated. The weed control efficiency (WCE) was calculated according to Mani *et al* (1976) using the following formula; WCE (%) = Weed dry weight of weedy check- Weed dry weight of treatment/ Weed dry weight of weedy check x 100.

6- The effect of herbicides +additives on soil microorganisms

The screening was done in the soil using five g soil samples from fig farm after treating with glyphosate- herbicides mixtures. A sampling of soil was taken randomly at 0 times, 1, 3, 7, 14, 28 days from the top (0-5) centimeters with five replicates, stored at -4^{0}C and subsequently used for microbiological analysis from the initial herbicide application to four weeks. On nutrient agar, total bacterial counts were incubated at 30^{0}C for 24hours. (Jacobs and Gerstein, 1960). Actinomycetes counts were on starch agar at 28-30^{0}C/24hr – 7 days. Waksman and Lechevalier, (1962). Fungi were counted on potato dextrose agar after incubation at 28-30^{0}C for 7 days (Riker and Riker, 1936). According to (Caldwell, 2005) dehydrogenase enzyme was determined.

7-Statistical analysis

Experiments were designed in Randomized Complete Block Design. All data were statistically analyzed by ANOVA with SPSS software and treatment means were compared using the LSD test at a 5% level of probability according to **Snedecor and Cochran (1990).**

RESULTS

1-Efficiency and spray tank physicochemical properties of herbicides -additives mixtures

The highest effectiveness presented from glyphosate with additives at complete doses on S*. eleaegnifolium* yielded a reduction in dry weight by 56.97% as compared with the control. At microdoses (half-dose), the reduction efficacy was 45.0 and 49.22% (glyphosate plus pyraflufen-ethyl without and with additives), 44.86 and 49.69% glyphosate plus triclopyr-butotyl without and with additives, 43.27 and 45.42% (glyphosate plus fluroxypyr in the absence and the presence of additive), 35.98 and 41.03% (glyphosate plus metribazine alone and with additives), 32.53 and 34.58% glyphosate plus bentazon without and with additives, 36.95 and 39.07% (glyphosate plus bromoxynil-octanoate with and without additives) in dry weight reached respectively as compared with the control (Table 1).

Concerning physicochemical properties at full doses, glyphosate alone and glyphosate plus additives (1% arabic gum and 0.05% tween 20) were achieved values reached 2.50 and 2.45 (EC; m mohs/m), 5.34 and 5.12 (pH), 7.57 and 5.75 (Viscosity; $cm^2 s^{-1}$), 56.43 and 40.62 (surface tension; dyne /cm), respectively. At half-dose, glyphosate plus bentazon without and with additives were 0.72 and 1.29 (EC), 6.80 and 6.83(pH), 6.33 and 5.30 (viscosity; $cm^2 s^{-1}$), 40.31 and 41.98(surface tension) respectively. Glyphosate plus pyraflufen-ethyl without and with additives were recorded 1.65 to 1.61 (EC), 6.05 and 5.84 (pH), 6.59 and 5.21(viscosity; $cm^2 s^{-1}$), 55.44 and 43.06 (surface tension) respectively. Glyphosate plus fluroxypyr in the absence and the presence of additives were 1.94 and 1.89 (EC), 5.83 and 5.76 (pH), 6.33 to 5.33 (viscosity; $cm^2 s^{-1}$), 43.70 and 35.88 (surface tension) respectively. Glyphosate plus triclopyr-butotyl without and with additives were 2.00 and 2.09 (EC), 6.63 and 6.56 (pH), 5.26 and 5.11 (viscosity; $cm^2 s^{-1}$), 42.7 and 37.88 (surface tension) respectively. The treatments of glyphosate plus bromoxynil-octanoate without and with additives were recorded 1.49 and 1.47(EC), 5.93 and 5.43 (pH), 6.77 and 6.14 (viscosity; $cm^2 s^{-1}$), 44.20 and 37.81 (surface tension) respectively. Glyphosate plus metribazine without and with additive were 1.94 and 1.27(EC), 5.59 and 6.92 (pH), 6.77 and 6.14 (viscosity; $cm^2 s^{-1}$), 46.38 and 43.13 (surface tension) respectively (Table 1).

Table (1) Efficiency and physicochemical properties of used herbicides against *Solanum eleaegnifolium*

			Efficacy			Physicochemical properties			
	Treatments	Rate of Herbicide application (Active ingredient (g)/ hectare)	Fresh weight)g/plant(	Dry weight)g/plant(	Survival % 3WAT	**EC (mmohs/cm)**	**pH**	**Viscosity ($cm^2 s^{-1}$)**	**Surface tension dyne/cm**
1	Control		3.60±0.07	1.39±0.06	100.0±0.0				
2	Glyphosate	2880 g ai	2.00±0.18	0.75±0.02	13.33±5.8	2.50±0.03	5.34±0.01	7.57±0.42	56.43±0.17
3	Glyphosate + Additives	2880 g ai	1.76±0.04	0.60±0.03	6.67±5.8	2.45±0.01	5.12±0.00	5.75±0.86	40.62±1.53
4	Bentazon	1152 g ai	2.86±0.02	1.24±0.05	100.0±0.0	0.65±0.00	6.38±0.00	5.68±0.18	44.45±0.70
5	Bentazon + Additives	1152 g ai	2.78±0.07	1.13±0.02	100.0±0.0	0.72±0.00	6.80±0.06	5.30±0.24	40.31±0.00
6	Bentazon + Glyphosate	576 +1440 g ai	2.58±0.18	0.94±0.02	33.33±5.8	1.29±0.03	5.83±0.00	6.33±0.37	41.98±0.45
7	Bentazon + Glyphosate + Additives		2.35±0.20	0.91±0.03	26.67±5.8	1.27±0.01	5.33±0.00	5.39±0.21	33.70±0.01
8	Pyraflufen-ethyl	48 g ai	2.30±0.09	0.92±0.04	33.33±5.8	1.53±0.02	6.09±0.03	5.83±0.05	53.34±0.65
9	Pyraflufen-e	48 g ai	2.19±0.04	0.83±0.04	13.33±5.8	1.58±0.02	5.64±0.00	5.08±0.06	44.42±1.15
10	Pyraflufen-e + Glyphosate	24 +1440 g ai	2.12±0.04	0.77±0.05	0.00±0.0	1.65±0.01	6.05±0.11	6.59±0.19	55.44±0.02
11	Pyraflufen-e + Glyphosate + Additives		1.87±0.01	0.71±0.02	0.00±0.0	1.61±0.02	5.84±0.11	5.21±0.10	43.06±0.01
12	Fluroxypyr	19.2 g ai	2.28±0.02	0.88±0.02	33.33±5.8	1.42±0.02	6.15±0.03	5.40±0.31	54.25±0.67
13	Fluroxypyr + Additives	19.2 g ai	2.23±0.06	0.82±0.04	26.67±5.8	0.02±1.49	0.00±5.68	0.20±4.58	0.00±0.31
14	Fluroxypyr + Glyphosate	9.6 +1440 g ai	2.18±0.09	0.77±0.02	0.00±0.0	1.94±0.02	5.83±0.00	6.33±0.37	43.70±0.01
15	Fluroxypyr + Glyphosate + Additives		1.88±0.09	0.70±0.02	0.00±0.0	1.89±0.03	5.76±0.03	5.33±0.31	35.88±0.02
16	Triclopyr-butotyl	18 g ai	2.21±0.02	0.85±0.05	0.00±0.0	1.50±0.02	6.7±0.03	5.30±0.30	51.25±0.52
17	Triclopyr-b + Additives	18 g ai	2.13±0.04	0.81±0.04	0.00±0.0	1.52±0.02	6.48±0.00	4.27±0.23	36.31±0.20

18	Triclopyr-b + Glyphosate	9 + 1440 g ai	2.08±0.06	0.79±0.03	0.00±0.0	2.0±0.02	6.63±0.00	5.26±0.33	42.70±0.11
19	Triclopyr-b + Glyphosate + Additives		1. 9±0.08	0.76±0.02	0.00±0.0	2.09±0.03	6.56±0.03	5.11±0.22	37.88±0.15
20	Bromoxynil octanoate	576 g ai	2.67±0.06	1.13±0.01	100.0±0.0	0.85±0.00	6.48±0.00	6.45±0.08	44.95±0.70
21	Bromoxynil-o + Additives	576 g ai	2.59±0.09	0.99±0.02	93.33±5.8	0.92±0.00	7.06±0.04	6.02±0.01	40.81±0.00
22	Bromoxynil-o + Glyphosate	288 +1440 g ai	2.09±0.07	0.88±0.02	66.67±5.8	1.49±0.03	5.93±0.00	6.77±0.19	44.20±0.01
23	Bromoxynil-o + Glyphosate + Additives		1.99±0.05	0.85±0.01	53.33±5.8	1.47±0.01	5.43±0.00	6.14±0.06	37.81±0.30
24	Metribazine	504 g ai	2.31±0.07	1.07±0.07	93.33±5.8	1.44±0.00	5.97±0.04	6.17±0.07	49.45±0.00
25	Metrabizin + Additives	504 g ai	2.26±0.02	0.97±0.01	86.67±5.8	1.57±0.03	5.79±0.00	5.83±0.21	40.81±0.00
26	Metrabzine + Glyphosate	252 + 1440 g ai	1.99±0.03	0.89±0.02	0.00±0.0	1.94±0.02	5.59±0.00	6.77±0.19	46.38±0.02
27	Metrabzine + Glyphosate + Additives		1.86±0.04	0.82±0.01	0.00±0.0	1.27±0.01	6.92±0.00	6.14±0.06	43.13±0.13
	F		85.224	84.454	66.462	2053.05	590.6	18.48	433.04
	P value		0.000	0.000	0.000	0.0000	0.000	0.000	0.000

ai = active ingredient g =gram WAT = Week after treatment

3- Selective broadleaved herbicides evaluation under greenhouse condition

The selective broadleaved herbicides of bentazon, pyraflufen-ethyl, fluroxypyr and metrabzine at the full doses provided low effective when applied singly in *S. elaeagnifolium*. This response appeared in the measured fresh and dry weights, total chlorophyll and shoot lengths in the infected crops of *T. aestivum, Z. mays, T. alexandrinum* in greenhouse. The highest control efficiency was achieved from fluroxypy and pyraflufen-ethyl followed by metribazine and finally bentazon. The interactions effect between the herbicides and target plants were significant for fresh weights ($F=99.95$, $p < 0.02$) and dry weight ($F=3.92$, $p < 0.01$), chlorophyll ($F=137.21$, $p < 0.000$) of *S. elaeagnifolium.* Based on the findings, it may depend on fluroxypy in *Z. mays* and pyraflufen-ethyl in *T. aestivum* at the full doses to suppress *S. elaeagnifolium* growth with a promising crop protection degree. (Table 2).

Table (2). Selective herbicide evaluation on *Solanum elaeagnifolium* and crops under greenhouse conditions.

Crops	Herbicides at the full doses	Fresh weight (g/ plants)	Dry weight (g/ plants)	chlorophyll (SPAD)	Shoot length (cm)
S. elaeagnifolium	Control	2.053 ±0.13	0.900±0.10	18.00±1.00	15.00±1.00
	Bentazon 48%AS	1.668±0.13	0.758±0.13	17.90±0.85	12.00±1.00
	Pyraflufen-ethyl 2% EC	1.284±0.01	0.563±0.13	3.32±0.03	10.00±0.00
	Fluroxypyr 20%EC	0.883±0.13	0.553±0.13	3.92±0.03	10.00±0.00
	Metribazine 70%WP	0.928±0.08	0.758±0.13	5.52±0.03	11.00±1.00
T. alexandrinum	Control	0.841±0.07	0.175±0.01	25.33±0.58	13.30±0.58
	Bentazon 48%AS	0.747±0.08	0.114±0.00	19.00±1.00	11.60±1.15
	Pyraflufen-ethyl 2% EC	0.654±0.09	0.107±0.00	17.52±0.03	11.00±1.00
	Fluroxypyr 20%EC	0.775±0.10	0.107±0.00	17.02±0.03	10.30±0.58
	Metribazine 70%WP	0.652±0.08	0.091±0.00	17.26±0.55	11.00±1.00
T. aestivum	Control	2.188±0.13	0.453±0.01	30.00±1.00	28.10±1.04
	Bentazon 48%AS	1.798±0.13	0.412±0.01	26.47±0.45	28.00±1.00
	Pyraflufen-ethyl 2% EC	2.998±0.13	0.453±0.00	29.66±0.58	28.60±0.58
	Fluroxypyr 20%EC	2.926±0.13	0.414±0.00	29.00±1.00	28.30±1.53
	Metribazine 70%WP	1.558±0.13	0.336±0.01	27.33±0.58	27.30±1.53
Z. mays	Control	6.442±0.13	0.321±0.01	32.33±0.03	31.0±1.00
	Bentazon 48%AS	6.146±0.01	0.278±0.00	19.83±0.03	30.3±1,53
	Pyraflufen-ethyl 2% EC	6.188±0.07	0.209±0.02	15.43±0.2	29.3±0.58
	Fluroxypyr 20%EC	6.283±0.06	0.313±0.01	30.73±0.2	27.7±0.58
	Metribazine 70%WP	5.883±0.06	0.251±0.01	28.33±0.01	31.0±1.00
Statistics	F (p value)				
	Target plants	9091.20(0.00)	246.68(0.00)	732.86(0.00)	603.87(0.00)
	Herbicide treatments	113.935(0.00)	6.91(0.00)	290.70(0.00)	3.65(0.00)
	Target plants x Herbicide treatments	99.957(0.02)	3.92(0.01)	137.21(0.00)	2.5(0.05)

4-Weed control management of *Solanum elaeagnifolium* in Fig orchards.

The invasive *S. elaeagnifolium* weed was treated during the early vegetative growth in May and at the flowering stage in August in the field of fig. Overall, weed control efficiency should be better controlled when glyphosate at the full doses with additive (surfactant and staking agent), this treatment gave reduction reached 71.52 % to 66.87% of dry weight in May and August respectively. The highest weed control efficiency (WCE) has achieved from the half dose of glyphosate + fluroxypy + additives by 79.65 and 74.52% in May and August respectively. A similar result of WCE achieved from the half dose of glyphosate + pyraflufen-ethyl + additives reached 77.9 and 74.2% in May and August respectively. A moderate WCE% has achieved from the half dose of glyphosate + bromoxynil-octanoate + additives by 75.28 and 64.47% and glyphosate + metribazine + additives by 75.27 and 63.33% in May and August respectively. The lowest WCE was observed from glyphosate herbicides alone at the full dose without additives by 55.9% to 53.42% in May and August respectively. The most efficacy treatments in delaying the revegetation time were glyphosate with each of pyraflufen-ethyl, fluroxypyr, and metrabzine reached up to 70 to 85 days (Table 3).

Table (3). Selected herbicides mixtures evaluation against *Solanum elaeagnifolium* in fig fields.

			May treatments						August treatments					
			Fresh weight		Dry weight		Fruit number	Reveg. (days)	fresh weight		Dry weight		Fruit numbers	Reveg. (days)
	Treatments	Rate of herbicides application (Active ingredient (g)/ hectare)	Weight (g m^2)	WCF%	Weight (g m^2)	WCF%			Weight (g m^2)	WCF%	Weight (g m^2)	WCF%		
1	Control		2395.93^a	0.00	341.48^a	0.00	378±20	0.0	2462.03^a	0.00	297.39^a	0.00	380.0±13	0.0
2	Glyphosate alone	2880 g ai h	640.88^b	73.25	150.60^b	55.90	364±5	50.0±7	662.38^b	73.10	138.51^b	53.42	60.0±8	48.0±2
3	Glyphosate + Additives	2880 g ai h	459.55^c	80.81	97.26^c	71.52	335±7	60.0±3	582.38^c	76.35	98.51^d	66.87	50.0±10	60.0±3
4	Glyphosate + Pyraflufen-e + additives	24 +1440 g ai	334.49^d	86.03	75.47^d	77.90	317±3	85.0±2	471.97^d	80.83	76.73^e	74.20	40.0±6	80.0±2
5	Glyphosate + Fluroxypy + Additives	9.6 +1440 g ai	330.18^d	86.21	69.50^d	79.65	320±9	85.0±4	453.06^d	81.60	75.77^e	74.52	39.0±7	80.0±2
6	Glyphosate + Bromoxynil-o + Additives	288 +1440g ai	436.27^c	81.79	84.40^d	75.28	345±4	70.0±2	556.62^c	77.39	105.65^c	64.47	55.0±4	70.0±4
7	Glyphosate + Metribazine + Additives	252 + 1440g ai	459.67^c	80.81	84.46^d	75.27	328±8	75.0±2	578.22^c	76.51	109.05^c	63.33	52.0±8	70.0±4
	F		36207.9		162.9		2.3	15.32	1026.6		98.011		342.0	38.011
	P value		0.000		0.000		0.05	0.020	0.000		0.000		0.000	0.001

Reveg. = Revegetation by days after treatment

5-Examine the effect of herbicides on soil microorganism and Dehydrogenase activity

The effects of selected herbicides on soil microorganisms were greater in the microbial count at the beginning of treatment. Accordingly, this harmful effect could be diminished within four weeks after treatment. Then, the total microbial counts increased slowly from 9, 5, 6, 5, 6, 9, x10^3 CFU/ml after the first days to reach 33, 32, 32, 32, 31, 33, 30 x10^5CFU/ml at 28 days of glyphosate alone, glyphosate + additives, glyphosate + metribazine + additives, glyphosate + fluroxypy + additives and glyphosate + pyraflufen-ethyl + additives, respectively. While, the number of fungi increased slowly from 1, 0, 0, 0, 1, 0 x10^2 CFU/ml after first days to 7,6,7,5,7, 6 x10^2 CFU/ml at 28 days from glyphosate alone, glyphosate with additives, glyphosate + metribazine + additives, glyphosate + fluroxypy + additives and glyphosate + pyraflufen-ethyl + additives, respectively. Also, the Actinomycetes counts were increased slowly from 0,0,0,0,0,0 x10^3 CFU/ml after first days to reach 25, 24, 24, 25, 26, 26 x10^2 CFU/ml at 28 days form glyphosate alone, glyphosate with additives, glyphosate + metribazine + additives, glyphosate + fluroxypy + additives and glyphosate + pyraflufen-ethyl + additives, respectively. On the other hand, soil dehydrogenase activity was affected significantly by all treatments due to low microbial activity especially from glyphosate plus metribazine or bromoxynil-octanoate than other treatments. In general, glyphosate + metribazine + additives, glyphosate + fluroxypy + additives and glyphosate + pyraflufen-ethyl + additives at half dose were affected microbial count negatively as compared with the control. Whereas, the effect of glyphosate alone was lower than glyphosate with additive in microbe counts (table 4). It could be concluded that the presence of additives may increase the impacts of the herbicides on soil microorganisms.

Table (4) Influences of selected herbicides on total microbial counts and Dehydrogenase activity.

			Full doses		Half doses					
	Days	Control	Glyphosate alone	Glyphosate + additives	Glyphosate + pyraflufen-ethyl + additives	Glyphosate + fluroxypy + additives	Glyphosate + + bromoxynil + additives	Glyphosate + metribazine + additives	F (P value)	Interaction (Herbicides* time) F (P value)
Total Bactrial count (10^5 CFU/gm dry soil)	0	34.00	34.00	33.00	32.00	33.00	34.00	34.00	6.117 (0.052)	1.67 (0.173)
	1	34.00	9.00	5.00	6.00	5.00	6.00	9.00		
	3	35.00	9.00	6.00	9.00	7.00	6.00	14.00		
	7	36.00	23.00	22.00	24.00	21.00	29.00	16.00		
	14	35.00	32.00	28.00	26.00	27.00	30.00	23.00		
	28	36.00	33.00	32.00	32.00	31.00	33.00	30.00		
Fungi (10^2 CFU/ gm dry soil)	0	5.00	600	5.00	6.00	7.00	6.00	7.00	3.33 (0.044)	1.24 (0.67)
	1	6.00	1.00	0.00	0.00	0.00	1.00	0.00		
	3	7.00	1.00	1.00	0.00	0.00	1.00	0.00		
	7	6.00	1.00	3.00	2.00	1.00	1.00	1.00		
	14	6.00	3.00	4.00	5.00	4.00	4.00	3.00		
	28	7.00	7.00	6.00	7.00	5.00	7.00	6.00		

Dehydrogenase (g TPF/g dry soil/24 h)	0	0.025	0.023	0.027	0.029	0.026	0.027	0.027	12.961 (0.046)	2.54 (0.051)
	1	0.025	0.010	0.001	0.012	0.001	0.014	0.001		
	3	0.026	0.012	0.010	0.014	0.001	0.012	0.010		
	7	0.027	0.014	0.012	0.018	0.050	0.013	0.012		
	14	0.028	0.022	0.019	0.024	0.012	0.018	0.016		
	28	0.028	0.027	0.025	0.027	0.024	0.023	0.022		
Actinomycetes (10^3 CFU/ gm dry soil	0	25.00	26.00	25.00	24.00	24.00	25.00	26.00	7.095 (0.015)	1.42 (0.432)
	1	24.00	0.00	0.00	0.00	0.00	0.00	0.00		
	3	24.00	14.00	7.00	2.00	1.00	8.00	0.00		
	7	26.00	14.00	14.00	13.00	7.00	11.00	3.00		
	14	24.00	17.00	19.00	19.00	19.00	20.00	15.00		
	28	26.00	25.00	24.00	24.00	25.00	26.00	26.00		

DISCUSSION

Invasive *S. elaeagnifolium* is one of the most difficult weeds to control; therefore, more than one application of herbicide is needed during the same season. The experiments took into account the differences in the activity of the applied dose, time of application and conditions. Therefore, choosing suitable herbicide mixtures and additives of stickers and spreaders or wetting agents were used to make glyphosate more effective and increase its biological performance against intractable invasive weed of *S. eleaegnifolium*. It is clear from the greenhouse results that the mixtures of glyphosate with pyraflufen-ethyl, fluroxypyr, triclopyr-butotyl and metrabzine at the half dose in the presence of additives achieved complete suppression of *S. eleaegnifolium* compared to glyphosate at a full dose with additives. While, the role of additives on spray tank physicochemical properties and consequence the activity was remarkable. These treatments resulted in zero survival of populations after three weeks from application. Based on the above findings, the used mixtures at the micro-dose reduced viscosity and surface tension properties. However, EC and pH values were increased with varying levels based on the chemical mixture. In general, great changes in physicochemical properties were measured when the additives were added but at various levels. So, it can be considered that glyphosate bio-efficacy was a function of the used herbicides and selected additives. The control of SOLEL (*S. elaeagnifolium*) using translocated herbicides was reported (Eleftherohorinos *et al.*, 1993; Westerman and Murray, 1994). However, one application of glyphosate gave poor control of *S. elaeagnifolium* (Choudhary and Bordovsky 2006). Therefore, available control techniques need to be strengthened to reduce the impact of *S. elaeagnifolium* and prevent its spread (Uludag *et al.*, 2016). While, the activity of glyphosate was linked with the used doses and the additives (Balah, 2011). Surfactants play an important role in accelerating the penetration of the herbicide across the cuticle (Devendra *et al*., 2004). Nelson *et al*., (2002) reported the synergistic effect of different adjuvants on the herbicidal activity and performance of glyphosate herbicide. Adding an appropriate adjuvant can decrease the amount of applied herbicide and lower total costs for weed control (Green 2001). On the other hand, the lower response of some *S. elaeagnifolium* individuals may be due to physiological and morphological differences in response to the applied herbicide. The addition of adjuvants to glyphosate may increase herbicide uptake by acting on the leaf surface, on the cuticle and within the internal tissues (Travlos *et al*., 2017, Leaper and Holloway 2000).

Synergistic effects were found in glyphosate mixtures with pyraflufen-ethyl, fluroxypyr, triclopyr-butotyl and metribazine based on their activity at the 5-7 leaves stage of *S. elaeagnifolium* in the field condition. Whereas, there are a variety of practices that can be used before herbicides in the integrated system to strengthen *S. elaeagnifolium* management. These results are in agreement with Balah (2011) who found the combination of glyphosate at micro rate + glue + glycerin + monoleate was more suitable for intractable weeds control including *S. elaeagnifolium*. The field application rate of glyphosate has little effect on soil microbial communities (Basse *et al*., 1990). Absorption, translocation, or metabolism of glyphosate can be affected by mixing with another herbicide (Meyer *et al*., 2020).

Thus, the tested combinations are very helpful to establish effective and extended control of *S. elaeagnifolium.* While the additives (Arabic gum + Tween 20) are helpful to obtain the optimized glyphosate (Balah 2011). These additives resulted from physicochemical properties changes depending on the type of additive and the interaction with the used herbicides which influenced the control behavior. In general, the additives decreased the viscosity and surface tension as well as EC values, while the pH varied depending on the type of herbicide. Surfactants are the most widely used and probably the most important of all adjuvants (Miller and Westra, 1998). The use of a non-ionic surfactant leads to a decrease in the size of droplets and an increase in drift values (Al Heidary *et al*., 2014). Deposition agents such as guar gum can reduce surface tension while increasing the viscoelasticity of the droplets (Bergeron *et al*., 2000). Spreading agents (surfactants) lower surface tension in the spray droplet and can function as activator adjuvants (Hazen, 2000). The surface tension and viscosity parameters are considered the most important factors affecting spray drift (Hilz and Vermeer 2013). Spraying was most successful when the plants were fresh after rainfall, not stressed, and not dormant (Kidston *et al.*, 2006).

The impact of herbicides on soil microorganism's count was measured by the total count of bacteria, fungi, actinomycetes and dehydrogenase activities during four weeks, these effects started high and gradually decreased to diminish within four weeks whereas, fungi were the most restrained microorganisms to herbicides treatments. The field application rates of glyphosate have little effect on soil microbial communities (Basse *et al.,* 1990, Balah, 2011). There was a significant short-term (2 months) effect of glyphosate on both fungal and bacteria counts at the 0.54kg ha^{-1} treatment (Chakravarty and Chatarpaul, 1990). Herbicides application may do significant changes in the microorganism's populations, their activities, and microbial ecological balance in the soil and affect the productivity of the soils. It decreased the population of all the bacteria counted. This effect was stronger with the increasing concentration of the herbicides. Concentrations recovered within 30 days to reach populations not significantly different from the control treatments (Latha and Gopal 2010). The toxic effect of herbicides on non-target soil microorganisms which do help in the remediation of nitrogen, organic matter, and nutrient recycling and decomposition necessary to be considered. The decreasing of the bacterial population for five, ten and fifteen days after treatment (Adakai and Akyeampong, 2016). Glyphosate is directly degraded by microbes, even at high application rates, without directly affecting microbial activity (Haney *et al*., 2017).

In the invaded crops, there is a possibility of using selective herbicides of pyraflufen-ethyl in *T. aestivum*, fluroxypyr in *Z. mays* respectively at the full dose to suppress *S. elaeagnifolium* growth, while the effect of metribazine, bentazone and bromoxynil-octanoate were slightly and not enough to control the weed. Meanwhile, all the selective herbicides were not able to achieve the complete control of *S. elaeagnifolium* without glyphosate. It is necessary to control *S. elaeagnifolium* before fruiting to avoid the replenishment of the soil seed bank. The timing of herbicide application on *S. elaeagnifolium* is very important to clarify the effective control. It's needed more than one application during the year especially before and after the flowering during the season. Therefore, multiple applications are needed to keep *S. elaeagnifolium* under continuous control to reduce their fruiting numbers (table 3). In general, *S. eleaegnifolium* fruiting number is very high while, treating with herbicides in August (flowering stages) affected significantly the fruiting number. However, treating in May did not affect significantly the fruiting number. Meanwhile, a rapid recovery was observed from glyphosate alone (50 days after treatment) as compared with glyphosate at the full dose with additives (60 days after treatment), respectively. However, the mixture with other tested herbicides at the half dose achieved complete suppression. While the use of these mixtures not only increases the control efficacy but also increased the time before revegetation. While improving efficiency should be extended suppress times to reduce the use of herbicides and prevent fruiting formation during the same season. Minimum tillage techniques should be encouraged in areas with *S. elaeagnifolium* infestations. Whereas, short root fragments adhered to machinery are capable of starting a new infestation in a clean field (Stanton *et al.*, 2011). Treating SOLEL before flowering reduces seed and after flowering to reduces root growth (Snell, 2003). The seasonal timing was the major factor influencing absorption and translocation rates (Greenfield, 2003). Applying glyphosate late in the season didn't effectively control the population (Choudhary and Bordovsky, 2006). Early application of glyphosate can effectively control silverleaf nightshade populations and can increase yield when compared to no application or a late application (Choudhary and Bordovsky, 2006). The optimum efficiency *S. elaeagnifolium* is much greater in the early vegetative stage and it is preferable to repeat the treatment after revegetation in the summer to prevent them from forming fruits. Therefore, the efficacy of glyphosate depends on the used herbicide mixture, the presence of additive forms, and weed stage or time of treatment

Finally, the glyphosate activity was enhanced through other herbicides in the presence of some additive as a powerful tool for controlling *S. elaeagnifolium* to reduce the used quantity of herbicides. The mixtures of glyphosate with fluroxypy or pyraflufen-ethyl, metribazine, bentazone and bromoxynil-octanoate resulted in synergistic effects for *S. elaeagnifolium* weed. According to the above findings, pyraflufen-ethyl can be used in *T. aestivum*, and fluroxypyr at the full dose can be used in *Z. mays* effectively to control *S. elaeagnifolium*. Other selective herbicides such as bentazone, or metrabazine had a lower efficiency alone on their crop, but none of them were able to kill *S. elaeagnifolium* completely. According to this research, these mixtures are more effective than using glyphosate alone, and it's important to use additives such as surfactants and stickers to control *S. elaeagnifolium.* In general, the bio-efficacy depends on the used herbicides, additive types, and time of application. While, a variety of variables such as weed age, applied doses and type of chemical mixtures should be taken into account for good control. However, repeated applications are needed for extended control during the same season and in the flowering stage to reduce fruit numbers. Integrated management packages must be fully considered to suit each infestation resource and minimize the root and seed bank of *S. elaeagnifolium*. A great control efficiency in *S. elaeagnifolium* weed came from integrated approaches that included culture methods with chemical mixtures providing good and successful control when used properly and on time.

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