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Studies on Intercropping Systems of Garlic and Green Onion to Potatoes and impact that on Growth, Yield, and Resistance Late Blight Disease

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Abstract

The study assessed the effect of intercropping Patterns on the performance of potato plants, *i.e., vegetative growth, tuber quality and yield as well as* potato late blight,*Phytophthorainfestans*disease epidemiology. Trials were carried out under a greenhouse and open field in Moshtohor and Kaha, Qalyubia Governorate, Egypt, respectively during three successive winter seasons of 2016/2017, 2017/2018 and 20178/2019. Potatowas intercropped with garlic or onion at the ratios of 1:1; 2:1 and 3:1 plant population. These treatments were compared with fungicide (Radomil gold) foliar spray and unsprayed monoculture potato plant with respect to disease development and potato tuber yield and quality. The results prevailed that, all potato-garlic ratios exhibited superior performance when compared to the fungicide unsprayed treatment. Among the proportions, 1 potato with 1 garlic intercropped plots showed significantly low disease development and high tuber yield. Moreover, at 1:1 combination of garlic (or onion) to potato, the land equivalent ratio (LER) was greater than 1 and the monetary values were high at both testing sites. The study also demonstrated that fungicide treatment provided significant low disease development and higher potato tuber yield when compared to the untreated monoculture control treatment. The findings of this study suggested garlic as a potential intercropping plant for the management of potato late blight disease under Egyptian condition. In winter growing season, the extracts of garlic or onion plants reduced the disease severity of late blight. The effect of competition among the two different *Allium* species in potato intercropping and the economic viability of intercropping potato with garlic or onion compared to its sole cropping were studied under natural late blight infestation. Generally, the present study concludes that intercropping of potato with garlic and onion may affect yield and disease resistance, competition between the 2 species (*Solanumtuberosum and Allium spp.*), and economics of mixtures as compared to monoculture of the same species. Although *Allium* crops had lower yield in mixture but are more expensive in markets, solitary planting of them would not reach the profitable level gained with potato under our trials condition

Key words: *Potato, Garlic, Onion, intercropping, competitive, late blight*

Introduction

Potato tubers (*Solanumtuberosum* L.) have been eaten since time immemorial. The current cultured potatoes have been spread 160 countries worldwide from their origin the Andes of South America. Egypt produces about 5 million MT of potatoes. Egypt is Africa's largest potato producer, produces about 5 million MT of potatoes, and ranks 14th in the world in terms of potato production as well as fifth largest exporter for potatoes. It also produces about 700,000 – 800,000 MT of local seed potatoes from imports which go into crop production the following season (**GAIN, 2018**). On the other hand, Egypt is major exporter of ware potatoes, (exported over 759,200 MT of ware potatoes in 2018). Supplying primarily the Russian Federation (48 %) and to a lesser extent the EU-18 (25 %) and United Arab Emirates (UAE) (7 %) markets. Presently, the EU is not Egypt's largest export destination for Egyptian ware potatoes. So, it is well known that potato is considered as one of the most valuable vegetable crops all over the world as it follows rice and wheat as a food for human consumption (**Camire*et al.*, 2009**). Potato is a high yielding carbohydrate-rich crop and its protein constituents is justly low but has an exceptional biological importance of 90–100, an excellent source of potassium, vitamins C and B6. Moreover, many composites in potatoes subsidize antioxidant activities like flavonoids, carotenoids and phenolic compounds. Accordingly, it can be used as dietary supplements and as protective agents against common tumor types such as breast and prostate cancer. Unfortunately, it has been reported that potato could be infect by many plant diseases. Late blight caused by *Phytophthorainfestans* (Mont.) de Bary is the most widespread throughout the world and causes serious tuber losses globally (**Erwin and Ribeiro, 1996; Fry and Goodwin, 1997; Garrett *et al.*, 2001**). In Egypt, the late blight disease is the most destructive and economical disease on potato. The only effective fungicides against late blight, caused by *Phytophthorainfestans*, in organic farming are copper based with a maximum permitted application of 3 kg pure copper per ha and season (**Tamm *et al.*, 2004**). Copper is a heavy metal that remains in the environment (**Brümmer*et***

***al*., 1986**). Therefore, there is a need for alternative strategies for disease control (**Tamm *et al*., 2004**). However, the use of self-sustaining low input technologies has been suggested as a sustainable approach, with minimum use of external inputs. Of the various options available, cropping systems, other than so many advantages related to intercropping mentioned elsewhere (**Okigbo, 1979**), disease problems is low in an intercropping production systems compared to sole cropping production system (**Batra, 1962** and **Nickel, 1973**). For pathogens like Phytophthora (**Robinson, 1976** and**Neiderhauser, 1991**), interrupting with none host crop for a disease may physically interfere and be able to entrap the spores, thereby reduce the available inoculum (**Garret and Munndit, 2000**). **Skelsey*et al*. (2005)** in his report also showed the influence of host diversity on the development of epidemic. Mixture of potato with garlic could also reduce the spread of late blight through inoculums dilution and /or inhibitory effects of volatile compounds (**Cizcova*et al*., 2002**) that possibly could create an environment hostile to the development of late blight in potato. Hence, primarily, garlic is widely grown as a crop mainly for market; secondly, intercropping can help reduce the disease effect and probably the volatile oil which the crop emits can change the micro climate to be hostile to the pathogen. Therefore, this study assessed the effect of intercropping potato with garlic or onion (at different proportions) as well as their extractions spray on potato late blight epidemic factors and tuber yield under field conditions. Among the objectives, determine the effect of competition between the two different *Allium* species (garlic, *Allium sativum*L. and onion, *Allium cepa*) in potato intercropping; as well as study the economic viability of intercropping potato with garlic and onion compared to its sole cropping under natural late blight infestation.

Materials and Methods

The field study was conducted in open field of Kaha research Farm , Hort. Res. Instit, ARC, Qalyoubia Governorate, Egypt during the two seasons of 2017/2018 and 2018/2019 in addition to a pots experiment as an initial trial was carried out in a previous season of 2016/2017 under a greenhouse of Moshtohor Agric. Faculty, Benha University, Moshtohor, Toukh, Qalyoubia Governorate using an artificial infection to study the Efficacy of intercropping between potato and green onion or garlic and spraying with onion extract or garlic extract on late blight incidence of potato plants under greenhouse conditions before application in the open field. Potato tubers cv. Cara, garlic cv. Sid-40, and onion cv. Giza 20 were obtained from Dept., of Vegetables Crop Research, Agricultural Research Centre, Giza, Egypt. Potato was intercropped with *Allium* species; Garlic and Onion in different systems as shown in Fig-1.

Greenhouse trial:

Potato tubers and onion seedlings or garlic cloves were planted in plastic pots (30 cm diameter) containing autoclaved sandy loam soil under greenhouse conditions according to the methods described by **Van Wees*et al*. (2000)**. The soils were autoclaved twice for 20 min with a 24 h interval under greenhouse conditions (18-25ºC). Each treatment replicated 3 times. The arrangements of the replicates were randomized completely. Before planted into the pot, the potato tuber, onion seedlings and garlic cloves were cleaned with tap water first, and then washed with autoclaved water for three times. The pot experiments were conducted with ten treatments (Figure-1) as follows:

- (1:1) = potato/garlic (or onion) companion cropping (one potato tuber grew with one garlic clove or onion seedling in the same pot, with distance 15 cm between potato tuber and garlic or onion seedling).
- (2:1&3:1) = one garlic clove or one onion seedling grown alone in pot beside two or three Inoculated potato plant grown in two or three pots individually.
- In four treatments of monoculture potato plants, 4^{th}-5^{th} old leaves of inoculated potato plant sprayed with 30 ml/L from prepared garlic and onion extracts as well as 2g/L Ridomil Gold MZ 68 % WG fungicide (positive control) and water tap (negative control) individually four times with a 10 days interval.

All potato plants in all treatments of greenhouse trial were inoculated with sporangia suspension ($2x10^4$ sporangia/ml) of *phytophthorainfestans*after 30 days from planting. Water was applied daily in order to maintain soil moisture at field capacity. Data collected included blight disease incidence and severity.

Pathogenic isolate *Phytophthorainfestans* the causal agents of late blight disease, was kindly obtained from Plant Pathology Dept., National Research Centre, Giza, Egypt. Meanwhile. Sporangia suspension of *P. infestans* was prepared by inoculated sterilized PDA medium (**Cohen *etal*., 1991**) with disk of fungal growth (6 mm diameter) taken from 10 days old cultures of *P.infestans*. Plates were incubated at 25 or 18˚C. Sporangia suspension ($2x10^4$ sporangia /ml) of *P.infestans* was prepared.

Fresh plant material *i.e.* garlic (*Allium sativum*) and onion (*Allium cepa*) were brought from the local market of Moshtohor then, transferred to lab. of plant pathology Dept., Fac. Agric. Moshtohor, washed in tap water and then in distilled water. In this respect, 100g of garlic and onion bulbs were grounded using sterilized vertical grinder by adding

100 mL of sterile water (1:1 w/v). The extracts of garlic and onion bulbs were filtered through 2 folds of cheesecloth, then through Whitman No.1 filter paper and then centrifuged at 5000 rpm for 15 min. The resultant crude extract of each plant material (garlic and onion) was considered as 100% stock solutions then they stored at 4ºC for further using.

Open fieldtrials:

Two experimental trials included 10 treatments (6-intercrops and 4 monocultures) were conducted in a Randomized Complete Block Design with three replicates under natural infestation with blight disease. The six intercrops treatments were planted in two spatial arrangements, *i.e.* alternating side in the same row or alternating rows. Therefore, six intercropping patterns including different potato and garlic or onion proportional areas:

1): Intercropping system of 1:1; since planting one side of potato (75 cm wide) alternated with garlic or onion (10 cm wide) in the other side of the same row (85 cm wide), referred as intercropping system 1.

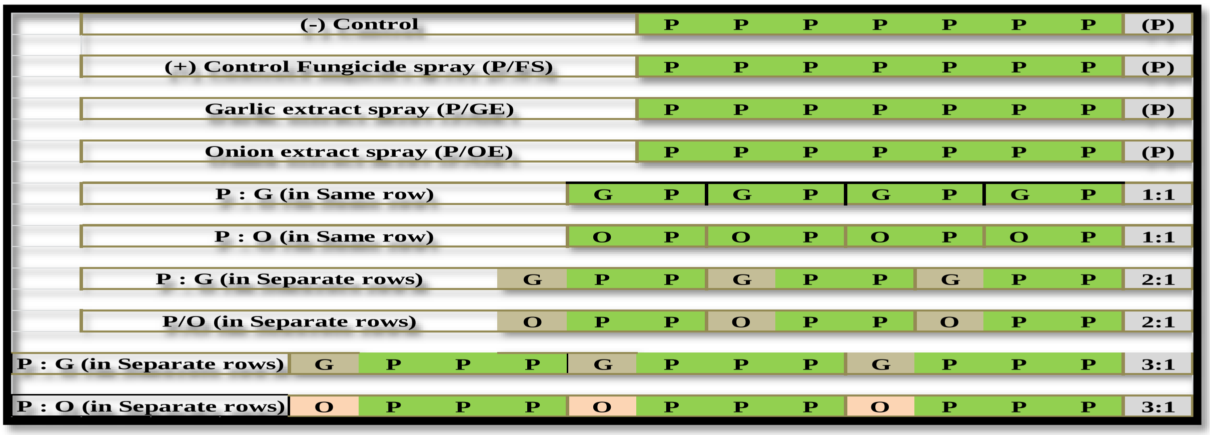

Fig. 1. Schematic diagram of different intercropping patterns between potato (P) and garlic (G) or onion (O).

2): Intercropping system of 2:1; since planting 2 rows (150 cm wide) of potato alternated with 1 row of garlic or onion (75 cm wide), referred as intercropping system 2.

3): Intercropping system of 3:1; since planting 3 rows (225 cm wide) of potato alternated with 1 row of garlic or onion; referred as intercropping system 3.

4): Four monoculture system of potato as follow (Figure 1):

- Potato plant sprayed with water tap as referred to (P, negative control)
- Potato plant sprayed with 2g/L Ridomil Gold MZ 68 % WG fungicide as referred to (P+FC, positive control)
- Potato plant sprayed with garlic extract (30 ml/l) as referred to (P+GE)
- Potato plant sprayed with onion extract (30 ml/l) as referred to (P+OE)

The inter-row spacing was 25 cm for potato and 10 cm for garlic or onion. The intercropping area ratios occupied by potato and garlic (or onion) were 8.2%: 11.8%, 66.7%: 33.3% and 75%: 25%, respectively for the three respective patterns. The plots area was 13.5 m^2 (3-rows×0.75 m wide×6 m long) for sole potato and intercropping respective patterns except 1: 1 in which the plot area was 15.3 m^2. In both years, potato, garlic and onion were sown by hand at the second week of October, the first October and middle of November, respectively. All agricultural practices necessary for the production of potatoes have been implemented as followed by the technical recommendations of the Ministry of Agriculture, *i.e.*, plowing, fertilizers application, irrigation and weed control. Garlic and onion extracts were sprayed separately four times through the season with 10 days interval from 5th week into 9th one. Physical and chemical properties of the experimental soil were measured according to the procedures described by **(Jackson, 1973)** asshown in Table 1.

Table 1. Physical and chemical properties of the experimental soil

physical properties (%)			chemical properties (ppm)		
	1st season	2nd season		1st season	2nd season
Sand	19.5	19.5	N	58.98	72.38
silt	18.1	20.1	P	7.4	6.93
clay	62.1	60.3	K	190.51	203.9
			PH	7.7	7.8

Data recorded:

a) Vegetative growth characteristics :

A random sample consists of five plants was taken from each experimental plot at 75 days after planting (DAP) to measure the growth traits, *i.e.*, Plant height (main stem length), number of leaves /plant, number of main stems plant as well as fresh and dry weight of plant foliage.

b) Total yield and its components:-

At harvest (120 days after planting), all plants in each experimental plot were pulled and the potato tubers were collected to calculate yield and it's attributed traits, *i.e.,* bothnumber and weight of tubers per plant and total yield of tuber per feddan (ton) in addition to both dry matter (%) and starch content of tubers according to **A.O.A.C. (1990)** and specific gravity (%) as **Murphy and Goven (1959),**

Tubers chemical constituents:-

To determine the chemical constituents, 100 g. of tubers were oven dried at 65˚C for 72h till constant weight to determine the dry matter content. The different measured chemical constituents were estimated in the dry matter of the different plant parts. In the digested dry matter of each plant foliage and tubers, total nitrogen was determined according to the method described by **Pregl (1945)**. Phosphorus was determined according to **Murphy** and**Riely (1962)** as modified by **John (1970)**. Potassium was evaluated flame photometrically as mentioned by **Brown** and **Lilleland (1946).**

Disease Assessment:

Late blight scale from 0 to 4 according to **Cohen *etal*., (1991)** was followed, whereas 0 = No leaf lesions; 1 = 25% or less; 2 = 26-50 %; 3 = 51-75 % and 4 = 76-100 % infected area of plant leaf. Diseases symptoms were recorded after 20 days of infestation. The following formula was used to calculate disease severity:

$$\textit{Severity}\,\% = \frac{\sum(\textit{Each category} \times \textit{leaves in each category})}{\textit{Ttotal leaf number} \times \textit{highest category}} \times 100$$

The Efficacy of each treatment in reducing severity was calculated as a percentage using the formula of **Derbalah*et al*. (2011):**

Efficacy% = [(DSC-DST)/DSC]×100

Where; DSC: Disease severity under control, DST: Disease severity under treatment.

Leaf Biochemical activity of the potted experiment:

Potato leaves (45 days of planting) of the different treatments grown under greenhouse conditions were used to determine total phenols and some related enzymes of resistance, *i.e.* peroxidase, polyphenol oxidase and chitinase. Following the colorimetric method of analysis using Folin- phenol reagent at 650 nm, the total phenols were estimated according to the method adopted by **Bray and Thorpe (1954**). Orthodihydirc phenols (OD) were measured spectrophotometrically at 515 nm wave length as described by **Arnow (1937).** Enzymatic activity ofPeroxidase, polyphenol-oxidase and chitinase activities were determined spectrophotometrically according to **Allam and Hollis (1972)**, **Matta and Dimond (1963)** and **Boller and Mauch (1988),** respectively in leaf extracts prepared according to the method of **Tuzun *et al*. (1989)**. Phenylalanine ammonia lyase (PAL) activity was determined as described by **Dickerson *et al*., (1984)**. Enzyme activity was expressed as µmol trans-cinnamic acid /min/g protein.

Protein extraction and one-dimensional SDS-PAGE(pathogenesis-related protein)***:***

Polyacrylamide gel electrophoresis (PAGE) was used to determine the qualitative changes in the soluble proteins of potato leaves (healthy or infected with late blight diseases) as a result of companion cropping with onion or garlic and sprayed with onion or garlic extract. Protein extraction was carried out according to **Bollag and Edelstein (1993)** using 2-3 of potato leaves collected after 72 h of inoculation with sporangia suspension of *P. infestans*. Total proteins were determined using bovine serum albumin as a standard following the spectrophotometric method by **Bradford (1976)**. Twenty-microliters (40 µg of protein) of leaves samples were subjected to electrophoresis in 15% polyacrylamide prepared in 0.1% ***Sodium dodecyl sulfate*** (SDS), **(Bollag and Edelstein, 1993)** and stained with silver nitrate according to **Sammons *et al*. (1981**). Obtained protein gels were scanned for band Rf using gel documentation system (AAB Advanced American Biotechnology). Different molecular weights (MW) of bands were determined against protein marker 69, 57 and 24 kDa. The gel analyzed by Gel-Analyzer 3 is software (**Alzohairy 2008).**

The competitive relationship:

1). Land equivalent ratio (LER) is an index of intercropping advantage that indicated the amount of interspecific competition or facilitation in an intercropping system (**Fetene 2003**). It was calculated as follows (**Willey, 1979**): **LER = $(Y_{ab}/Y_{aa}) + (Y_{ba}/Y_{bb})$.**

2). Land Equivalent Coefficient (LEC) is a measure of interaction concerned with the strength of relationship (**Adetiloye*et al*., 1983**). It is calculated as **LEC = $L_a \times L_b$,**

A yield advantage is obtained if LEC value exceeds 0.25).

3). Competitive ratio (CR); the competitive ratio (CR) was used to evaluate which one crop competes with the other in an intercropping system (**Willey &Rao 1980; Wahla*et al*. 2009)**, and can be calculated by following the formula (**Bhatti*et al*. 2006**). It was calculated as follows:

$CR = CR_a + CR_b$, Where:

CR_a (competitive ratio of intercrop a, potato) = $(L_a/L_b) \times (Zb_a/Z_{ab})$

CR_b (competitive ratio of crop b, garlic or onion) = $(L_b/L_a) \times (Z_{ab}/Z_{ba})$.

4). Relative crowding coefficient (RCC) was calculated as (**DeWit, 1960**):

$$RCC = K_a \times K_b$$

Where K_a and K_b are relative crowding coefficient for potato and garlic (or onion) intercrop, respectively.

$$K_a = Y_{ab} \times Z_{ba} / [(Y_{aa} - Y_{ab}) \times Z_{ab}];$$

$$K_b = Y_{ba} \times Z_{ab} / [(Y_{bb} - Y_{ba}) \times Z_{ba}.$$

5). Aggressivity index compares the yields between intercropping and sole cropping, as well as their respective land occupancy (**Wahla*et al*. 2009**) and it was calculated (**McGilchrist, 1965**) as:

$$Agg._{ab} = [Y_{ab}/(Y_{aa} \times Z_{ab})] - [Y_{ba}/(Y_{bb} \times Z_{ba})]$$

$$Agg._{ba} = [Y_{ba}/(Y_{bb} \times Z_{ba})] - [Y_{ab}/(Y_{aa} \times Z_{ab})]$$

Where:

Y_{aa}= Pure stand yield of crop a (potato), Y_{bb} = Pure stand yield of crop b(garlic or onion),

Y_{ab} representing the yield of intercrop a (potato) in combination with b (garlic or onion), Y_{ba} the yield of intercrop b (garlic or onion) in combination with a (potato).

Z_{ab} representing the sown proportion of intercrop a (potato) in combination with b (garlic or onion) and Z_{ba} representing the sown proportion of intercrop b (garlic or onion) in combination with a (potato). L_a = LER of crop a; L_b = LER of crop b.

Economic evaluation:

Gross return of intercropping cultures= Price of potato yield/fed + price of garlic (or onion) yield/fed (L.E.). Net return/fed = Total return – (fixed costs of potato + variable costs of garlic (or onion) according to market prices (2017/2018 and 2018/2019). One kilo of potato or garlic was L.E. 5 and L.E. 4.5 for onion. Monetary advantage index **(MAI)** was determined according to the equation described by **Willey (1979)** to measure the productivity and profitability of intercropping as compared to solid planting of the associated component crops as follows: **MAI = value of combined intercrop yield × (LER-1)/LER**. Where, LER: abovementioned in the competitive relationship.

Statistical analysis:

Analysis of variance was done on the two-year data for a Randomized Complete Block Design according to **Gomez and Gomez (1984).** Means were compared by Least Significant Difference (LSD) at 5% level of significant.

Results and Discussion

Open field trials:

Disease incidence and severity of potato plants:

Effect of spraying or companion cropping treatments on disease incidence and severity of potato plants inoculated with sporangia suspension of P. infestans the causal agents of late blight disease under the greenhouse and open field conditions are shown in Table 2.

Results obtained under the greenhouse conditions indicate that all investigated treatments reduced significantly disease severity and incidence of *P. infestans* inoculation on potato plants as compared to the control treatment, especially “P+GE”, “1P+1G”, “P+OE” and “1P+1O” treatments (Fig. 3). Likewise, significant variations in disease incidence and severity were recorded for the used treatments under open field (Table 2) reveals that all the investigated treatments reduced significantly disease incidence and severity during both seasons of study.

The most efficient treatment was “P+FC” one which decreased disease severity and incidence by approximately 40% or more. In the first season, 1P+1G as well as P+GE recorded comparable results as “P+FC”. These finding agree with those of **Skelsey*et al.* (2005**) who indicated that host diversity reduced the development of epidemic, through generating little amount of spores (intercropped treatments) compared to broad lesions as it happened in monoculture potato without fungicide protection. Probably the explanation for this could be related to population increment of none host plant to the pathogen and increment of concentrations of the volatile oils that come out from garlic plant in the field which probably hindered the growth of the pathogen. Similar results were stated by **Cizcova*et al*. (2002**) which highlighted the reductions in numbers of rotten potato tubers by placing garlic extract at the corner of storage facilities. These results agree with those reported by **Krebs *et al.* (2006)** who found that the extracts of medicinal plants reduced effectively foliar blight of potato plants. In this concern, the volatile antimicrobial allicin is produced in garlic (**VanEtten*et al*., 1994** and **Mansfield, 2000**) that react with free thiol groups in proteins (**Ankri and Mirelman, 1999 and Miron*et al*., 2002)** inhibiting SH-containing enzymes such as succinic dehydrogenase, urease, papain, xanthine oxidase, choline oxidase, hexokinase, cholinesterase, glyoxylase, both triose phosphate and alcohol dehydrogenase and cysteine proteases (**Ankri*et al*., 1977** and **Wills, 1956**). Additionally, **Focke*et al*. (1990), Rabinikov*et al*., (1998)** and **Miron*et al*., (2000)** provided evidence for specific inhibition of acetyl-CoA synthetase (E.C.6.2.1.1) by allicin which decomposes into various products, one of which, ajoene, results from the conjugation of three allicin molecules (**Block, 1985).** This product has been reported to have antifungal activity (**Singh *et al*., 1990).** Moreover, Allicin in garlic extracts shows disease reduction for *Phytophthorainfestans*-infected potato tubers by decreasing *P. infestans* spore germination *in vitro* (**Curtis *et al*. 2004**).

Table 2. Effect of pre-sprayed and intercropping system treatments on disease incidence and severity on potato plants under experimental field, in two growing seasons.

Treatments	2016/2017		2017/2018		2018/2019	
	Disease Severity (GH)	Disease Incidence (GH)	Disease Severity (OF)	Disease Incidence (OF)	Disease Severity (OF)	Disease Incidence (OF)
P	80.83	100.00	55.83	100.00	75.83	100.00
P+FC	26.67	63.33	16.67	53.33	20.83	56.67
1P+1G	25.00	66.67	26.67	60.00	24.17	63.33
2P+1G	37.50	73.33	30.83	70.00	29.17	73.33
3P+1G	37.50	76.67	31.67	70.00	30.83	76.67
P+GE	19.17	53.33	26.67	56.67	23.33	60.00
1P+1O	28.33	70.00	29.17	70.00	28.33	73.33
2P+1O	33.33	76.67	32.50	70.00	32.50	76.67
3P+1O	46.67	90.00	36.67	73.33	43.33	80.00
P+OE	33.33	70.00	27.50	66.67	31.67	70.00
LSD	11.93	14.80	5.97	6.36	7.12	12.91

GH: greenhouse inoculated potato plants OF: open field infested potato plants

Plant growth parameters and yield components of potato plants

Effect of spraying or companion cropping treatments on plant growth parameters and yield components of potato plants infested with *P. infestans*under the field conditions illustrated in Table 3. All studied intercropping as well as both fungicides and extracts foliar spray treatments significantly increased all plant growth parameters over monoculture potato “P” treatment with no significant differences between them in number of leaves and stems per plant in both seasons. However, the highest increments in most vegetative traits were achieved for the garlic and onion extracts followed by 1P+1G (or onion) and 2P+1G (or onion) intercropping patterns, in descending order. Likewise, all extracts and intercropping treatments exhibited significant increments over control (monoculture potato) for all studied yield traits, *i.e.*, tubers number, tuber yield/plant, dry matter, total yield/fed, starch content and specific gravity of potato plants under open experimental field (Table 4). Extracts and both 1P:1G and 1P:1O intercropping patterns showed the highest effect on yield/plant and yield /fed with no significant differences between extracts and 1P:1O in both seasons.As for number of tubers, no significant differences between all treatments were observed in both seasons except P+FC fungicide foliar spray and both 2P:1O and 3P:1O intercropping ratio in the 1st season. However, 1P:1G intercropping proportion recorded the highest increases in tubers number in both seasons. P+GE and each of P+OE, 1P+1G and 2P+1G in 1st season and as average of both seasons for starch, dry matter and gravity. **Abd-El-Khair*et al.*, (2007)** evaluated aqueous extracts of sun–dried samples of garlic bulbs (*Allium sativum*) and onion seeds (*Allium cepa*) against *P. infestans* in vivo and vitro and found that these extracts reduced significantly the disease severity of late blight, while increased potato growth parameters and tuber yield. These results suggested that medicinal plant extracts may play important roles in controlling the potato blight diseases. Thus the enhancing effect of intercropping systems on plant growth may be due to the compounds secreted by garlic roots (vitamins B1, B2, B6 and C) which played significant roles in improving physiological status of plants such as absorbing macro and microelements and, in turn, reflected the significant increases that took place in plant growth. **Imran *et al*. (2013)** founding's confirmed also such interpretation. Moreover, **Cizcova*et al*. (2002**) mentioned that intercropping potato with garlic reduced the spread and development of late blight. These results can be attributed to the beneficial effect of garlic root secretions on plant growth, as discussed previously, and there is another explanation, which may be that the reason is that garlic root secretions improved the absorption of the potato plant's nutrients, leading to a positive competition between them (**Willey, 1979**). Thus planting potatoes with garlic as companion crops can effectively reduce the severity of late blight, and provide a suitable growing environment that increases the yield of tubers (**Kassa and Sumartia 2006**).

Plant growth parameters and yield of garlic and onion plants:

Effect of companion cropping treatments on plant growth parameters and yield of garlic and onion plants infested with P. infestans under the field conditions illustrated in Figure 2.

Table 3. Effect of spraying and intercropping system treatments on the vegetative growth parameters of potato plants under experimental field, in two growing seasons.

Treatments	Plant Height (cm)	Number		Fresh weight (g)		Dry weight (g)	
		Stems	Leaves	Stems	Leaves	Stems	Leaves
				2017/2018			
P	43.78	3.22	32.44	103.5	130.9	7.87	20.42
P+FC	50.11	5.22	43.11	165.10	246.62	11.22	27.18
1P+1G	60.11	6.00	49.44	180.84	339.40	18.37	33.57
2P+1G	55.11	5.44	47.00	188.80	308.4	18.26	30.14
3P+1G	66.33	5.33	44.55	167.02	271.1	13.37	27.14
P+GE	60.11	6.44	50.22	192.51	349.40	19.11	36.23
1P+1O	53.33	5.66	47.44	184.61	307.07	19.01	32.64
2P+1O	50.44	5.44	46.44	175.88	292.45	18.62	28.33
3P+1O	48.77	5.11	45.33	161.4	262.45	18.25	27.15
P+OE	58.22	6.33	48.77	192.00	350.88	20.04	36.60
LSD	7.25	1.34	8.66	50.12	54.73	3.32	6.15
				2018/2019			
P	43.11	3.11	30.11	106.77	155.83	7.47	21.34
P+FC	61.44	5.11	49.11	196.00	280.15	13.05	27.46
1P+1G	65.44	5.67	53.55	199.67	344.07	17.28	35.05
2P+1G	64.33	5.44	52.33	189.1	332.30	16.31	34.23
3P+1G	59.33	5.55	50.55	179.64	332.96	15.58	34.15
P+GE	68.33	5.78	58.78	201.28	364.72	18.41	36.54
1P+1O	65.22	6.33	58.44	181.95	360.65	17.17	36.72
2P+1O	65.33	6.00	53.33	176.29	358.82	17.07	34.01
3P+1O	60.88	5.00	48.22	161.34	334.57	16.38	35.20
P+OE	68.33	6.33	58.66	197.35	363.03	18.31	36.15
LSD	12.55	1.52	10.56	36.66	40.21	2.64	3.37

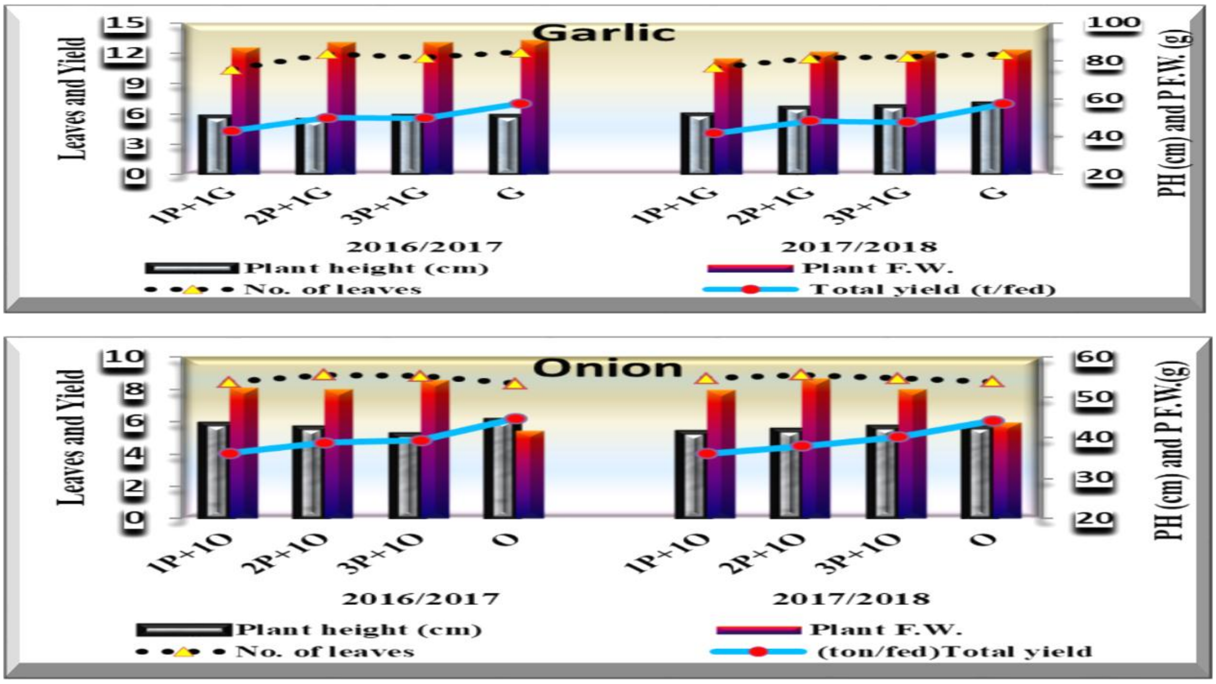

Fig.2. Effect of companion cropping treatments on vegetative growth parameters and total yield of garlic (upper) and onion (down) plants under experimental field, in two growing seasons.

Table 4. Effect of spraying and intercropping system treatments on No. of tubers, tuber yield/plant, dry matter, total yield, starch content and specific gravity of potato plants under experimental field, in two growing seasons.

Treatments	Number of Tubers/plant	Total Yield g/plant	Total Yield ton/fed.	Dry matter (g)	Starch (%)	SpecificGravity (g/cm^3)
			2017/2018			
P	5.39	435.87	9.494	17.64	10.86	1.054
P+FC	8.22	510.00	11.463	19.47	13.29	1.058
1P+1G	10.33	558.31	12.474	22.49	15.87	1.072
2P+1G	10.11	526.24	11.828	21.23	15.26	1.063
3P+1G	9.11	524.75	11.750	21.61	14.93	1.057
P+GE	10.22	591.29	13.215	22.30	16.04	1.081
1P+1O	9.00	592.50	13.231	21.09	14.60	1.082
2P+1O	8.66	559.50	12.484	20.91	14.75	1.073
3P+1O	8.33	547.63	12.296	20.42	14.21	1.061
P+OE	9.11	626.70	14.078	22.98	16.48	1.074
LSD	1.42	67.39	1.122	1.80	1.57	0.055
			2018/2019			
P	5.33b	407.11	9.691	18.91	10.15	1.059
P+FC	7.11	528.78	11.844	20.01	13.81	1.067
1P+1G	9.11	569.71	12.761	22.12	15.72	1.079
2P+1G	7.66	541.51	12.075	22.18	15.77	1.070
3P+1G	7.33	540.15	12.099	21.67	15.32	1.066
P+GE	8.33	603.10	13.509	22.15	16.28	1.090
1P+1O	8.33	563.85	12.779	21.02	15.11	1.089
2P+1O	7.11	544.81	12.203	21.04	14.71	1.082
3P+1O	7.00	537.84	12.047	21.38	14.69	1.069
P+OE	8.44	613.66	13.745	22.19	15.48	1.082
LSD	1.48	46.39	1.011	2.64	2.12	0.055

All growth parameters were depressed with intercropping systems except number of leaves and Plant fresh weight of onion in which insignificant and significant increment over corresponding monoculture (control) treatment, respectively in both seasons. The highest growth values were found with pure stand of garlic or onion. No significant differences between (2P+1G) and (3P+1G) intercropping treatments were observed in all growth and yield traits except plantheight of garlic as well as both plant fresh weight and yield of onion in 1st and both seasons, respectively and number of leaves in both seasons. However, within intercropping treatments, the highest yield/fed trait were achieved for 2P+1G followed by 3P+1G intercropping patterns, in descending order for garlic and reverse trend for onion. Obtained results are in agreement with those of **Kassa and Sommartya (2006)**.

NPK contents in potato

Effect of spraying or companion cropping treatments on NPK contents in potato plants infested with *P. infestans,* the causal gents of late blight disease, under the field conditions are presented in Table 5. All treatments raised significantly NPK contents within different plant parts as compared to the control treatment during both seasons of study. Although, N-content in leaves, stems and tubers did not vary significantly among the studied treatments during the first growing season; yet significant variations occurred in N-content in leaves owing to these treatments in the second growing season. In the second growing seasons, P content did not vary significantly among all treatments; however, there values were still higher than the control. The highest increases in K content in leaves, stem and tubers were attained for “P+OE” which also recorded comparable increases with all the studied treatments in K-content in different plant parts, except for the control and “P+FC” treatments during the first growing season. These two treatments also recorded the least values of K in leaves, stems and tubers in the second growing one, while “P+OE” recorded the highest K-increases in this concern.

Table 5. Effect of spraying and intercropping system treatments on NPK contents within the different parts of potato plants under experimental field, in two growing seasons.

Treatments	Nutrient contents in potato plants, %								
	N			**P**			**K**		
	Leaves	Stems	Tuber	Leaves	Stems	Tuber	Leaves	Stems	Tuber
2017/2018									
P	1.63	0.86	1.30	0.124	0.124	0.124	1.63	1.57	1.60
P+FC	2.72	2.21	2.17	0.134	0.135	0.135	2.16	2.16	2.15
1P+1G	2.63	2.61	2.62	0.135	0.135	0.135	2.29	2.30	2.33
2P+1G	2.60	2.32	2.50	0.135	0.136	0.135	2.26	2.31	2.28
3P+1G	2.53	2.48	2.43	0.134	0.135	0.136	2.24	2.26	2.26
P+GE	2.67	2.78	2.65	0.136	0.135	0.136	2.34	2.34	2.37
1P+1O	2.59	2.58	2.65	0.135	0.134	0.136	2.42	2.35	2.40
2P+1O	2.51	2.56	2.51	0.134	0.134	0.135	2.40	2.35	2.37
3P+1O	2.37	2.30	2.25	0.135	0.135	0.135	2.40	2.34	2.37
P+OE	2.68	2.76	2.74	0.135	0.135	0.135	2.52	2.37	2.47
LSD	0.67	0.98	0.860	0.002	0.009	0.001	0.31	0.18	0.17
2018/2019									
P	1.28	0.80	1.43	0.124	0.128	0.124	1.60	1.61	1.65
P+FC	2.42	2.26	2.04	0.135	0.135	0.135	2.14	2.18	2.22
1P+1G	3.21	2.58	2.61	0.135	0.135	0.135	2.24	2.27	2.37
2P+1G	2.61	2.57	2.41	0.135	0.136	0.135	2.26	2.32	2.31
3P+1G	2.54	2.33	2.46	0.136	0.136	0.135	2.20	2.33	2.32
P+GE	3.49	2.62	2.65	0.135	0.136	0.136	2.36	2.34	2.41
1P+1O	2.95	2.72	2.63	0.135	0.135	0.135	2.54	2.41	2.42
2P+1O	2.28	2.56	2.54	0.135	0.136	0.135	2.37	2.37	2.44
3P+1O	2.40	2.59	2.65	0.135	0.136	0.135	2.38	2.37	2.44
P+OE	2.94	2.71	2.77	0.135	0.135	0.135	2.50	2.35	2.53
LSD	0.65	1.18	0.55	0.001	0.009	0.001	0.086	0.032	0.052

***Greenhouse experiments*:**

Effect of spraying or companion cropping treatments on phenol content and enzyme activities of potato plants inoculated with sporangia suspension of *P. infestans* the causal gents of late blight disease under the greenhouse conditions are presented in Table 6 and Fig.3. All treatments raised significantly the total, free and conjugate phenols when compared to the control treatment. The highest increases were detected by “P+GE” and “1P+1G” treatments then “P+OE” and “1P+1O” treatments. Such treatments also raised ignificantly the activities of plant defense enzymes *i.e.*chitinase, polyphenol oxidae, peroxidase and phinilamnilase.

Also, “P+GE” then “P+OE” treatments recorded the highest increases in activities of such enzymes. **Cao and Forrer (2001)** and **Cao and van-Bruggen (2001)** tested the activity of garlic extract, against *Phytophthorainfestans* and potato late blight; in addition to any directly antimicrobial effects of allicin on pathogens in plant and found that this extract induced systemic acquired resistance (SAR) in host plants. Probably, this extract increased the accumulation of molecular markers such as mRNA for pathogenesis related (PR) proteins and salicylic acid **(Uknes*et al.*, (1992)**.

It is well known that total phenolics and ortho-dihydric phenols are two important components that induceresistance of plants against pathogens, *e.g.* phenols are oxidized to highly toxic ortho-dihydric phenols by enzymatic action (polyphenol-oxidase) which penetrate the microorganisms and cause considerable damage to the cell metabolisms (**Kalaichelvan and Elangovan,1995**).

Con.F.: Inoculated potato plant sprayed with fungicide Ridomil Gold
Con.W.: Inoculated potato plant sprayed with tab water
G. Ex.: Inoculated potato plant sprayed with garlic extract
O. Ex.: Inoculated potato plant sprayed with onion extract

1P+1G: potato/garlic clove companion cropping (one potato tuber grew with one garlic clove in the same pot).
1P+1O: Inoculated potato plant / onion seedling companion cropping (one potato tuber grew with one onion seedling in the same pot).

Fig. 3. Effect of spraying and intercropping system treatments on potato plants inoculated with sporangia suspension of *P. infestans*the causal agents of late blight disease under the greenhouse conditions.

However, the first step of plant defense system against pathogen attack involves the rapid accumulation of phenols at the infection sites (**Matern and Kneusal, 1988)**, which acts as mobilized defense system which can be translocate by plants and enzymatically converted into defensive substance at the site of the attack. All the studied treatments induced the activities of chitinase, peroxidase and polyphenyl oxidase (PPO) enzymes as compared with the control or even the fungicide treatment. Such increases were Significantly higher in potato plants spraying with garlic extract “P+GE” or onion extract “P+OE” and intercropping with garlic “1P+1G”or onion “1P+1O” treatments rather than the single ones. Peroxidases also, catalyse the final polymerisation step of lignin synthesis, and this may increase the ability of tissue to lignify which may restrict the fungal penetration in addition to Chitinase and β-1, 3 glucanase enzymes play important roles in inducing plant defense against fungi by hydrolyzingtheir cell walls (**Gorovitsa and Czosnek, 2008**).

Table 6. Effect of spraying and intercropping system treatments on phenol content and enzyme activities of infected potato plants.

Treatments	Phenols Content **%**			Enzymes activity **(µmol/min/g)**			
	Total Phenols	**Free Phenols**	**Conjugated Phenols**	**Chitinase**	**Polyphenol oxidase**	**Peroxidase**	PAL*
P	0.243	0.148	0.095	0.596	0.279	0.633	0.066
P+FC	0.491	0.280	0.211	0.799	0.422	0.855	0.074
1P+1G	1.180	0.497	0.683	1.240	0.502	1.324	0.265
2P+1G	0.906	0.412	0.494	0.960	0.470	1.113	0.200
3P+1G	0.790	0.312	0.478	0.790	0.461	1.026	0.131
P+GE	1.265	0.625	0.640	1.280	0.551	1.678	0.375
1P+1O	0.901	0.404	0.497	0.895	0.472	1.143	0.205
2P+1O	0.554	0.293	0.261	0.885	0.406	1.040	0.148
3P+1O	0.497	0.293	0.204	0.748	0.387	1.015	0.093
P+OE	1.040	0.596	0.444	1.030	0.445	1.350	0.205
LSD	**0.012**	**0.014**	**0.089**	**0.071**	**0.012**	**0.015**	**0.10**

* Phenylalanine ammonia lyase

Induction of new proteins:

Induction of new proteins in spraying or companion cropping treatments on potato plants inoculated with sporangia suspension of *P. infestans* the causal agents of late blight disease are presented in Table 7 and illustrated in Fig (4). Results of SDS-PAGE exhibited that new protein bands (of different molecular weights) were detected as a result of spraying potato plants with either garlic or onion extracts and also as a result of intercropping. On contrary, no new proteins were detected in untreated infected plants or those sprayed with Ridomil Gold fungicide. Probably, plants induced formation of new protein bands with low molecular weight which may lessen disease severity of late blight. In this concern, most new exhibited bands lied between 69, 57 and 24 kDa. These protein bands were detected against late blight when plants sprayed with garlic extract or potato/garlic seed intercropping (*i.e.* “1P+1G”, or “2P+1G”). The two protein bands, detected at 69 and 24 kDa, position against late blight when potato/garlic seed companion cropping (3P+1G) and/or plant sprayed with onion extract (P+OE) were used. Meanwhile one new protein was detected at 69 kDa position against late blight when potato/onion seedling companion cropping inoculated potato plant (“1P+1O” or “2P+1O”) as shown in Table 7 and Fig 4.These new proteins with the same or probably close molecular weights can lead us to the explanation that limited number of genes control late blight disease under the effect of investigated treatments. Thus, it may be deduced that in resistance against late blight disease, the accumulated intercellular proteins forms the first line of defense which have antifungal and antibacterial activities according to **Mauch and Staehelin (1989) and Van-Loon *et al*.(1994).** Other workers such as **Becto*et al*. (2000),** concluded also the induction of plant resistance with chemical inducers which were associated with accumulation of pathogensis-related proteins. These promising results lead us to guarantee plant spray and/or intercropping with either onion or garlic as protective control means with no ecological restrictions since they are environmentally safer, economically cheaper and easy to use than synthetic fungicides.

Table 7. Induced new proteins in spraying and intercropping system treatments on potato plants inoculated with sporangia suspension of *P. infestans*the causal agent of late blight disease.

MW KDa	P Lane 1	P+FC Lane 2	P+GE Lane 3	1P+1G Lane 4	2P+1G Lane 5	3P+1G Lane 6	P+OE Lane 7	1P+1O Lane 8	2P+1O Lane 9	3P+1O Lane 10
245										
180										
154	154	154	154	154	154	154	154	154	154	154
135										
122	122	122	122	122	122	122	122	122	122	122
101	101	101	101	101	101	101	101	101	101	101
100										
79	79	79	79	79	79	79	79	79	79	79
69			69	69	69	69	69	69	69	
63										
57			57	57	57					
55	55	55	55	55	55	55	55	55	55	55
48										
42	42	42	42	42	42	42	42	42	42	42
38	38	38	38	38	38	38	38	38	38	38
35										
31	31	31	31	31	31	31	31	31	31	31
25										
24			24	24	24	24	24			
23	23	23	23	23	23	23	23	23	23	23
17	17	17	17	17	17	17	17	17	17	17
13	13	13	13	13	13	13	13	13	13	13
11	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

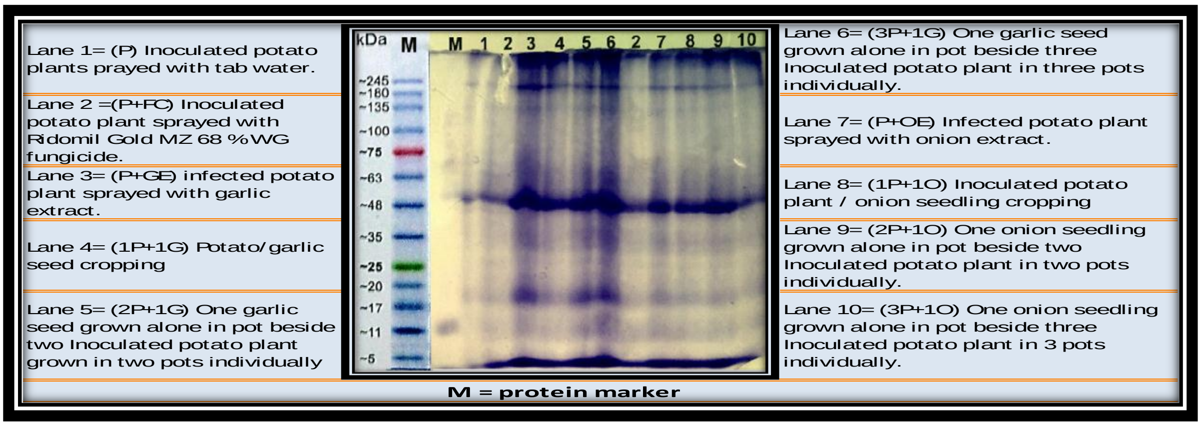

Fig. 4. SDS-PAGE analysis of total protein extracted from treated potato leaves with different treatments before inoculated with sporangia suspension of *P. infestans* the causal of Late Blight disease in potato.

Competitive relationships:

Land equivalent coefficient (LEC) is used to determine the strength of the intercropping interaction which referred to as the productivity index because it is a more superior index in evaluating crop mixture performance in terms of mixture productivity (**Adetiloye*et al*., 1983**). The study showed that the LEC was generally greater than 25% in all the treatments (Table 8 and Fig. 5). Potato-Garlic intercropping patterns demonstrated more productivity as was demonstrated by higher LEC values as compared to Potato-onion in both seasons (Fig. 5).

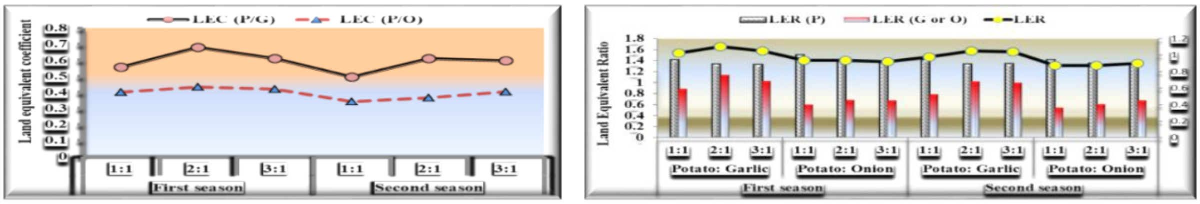

Fig.5. Land equivalent coefficient (LEC) for average both seasons and Land equivalent ratio (LER) for two seasons in potato–garlic and potato-onion intercropping system

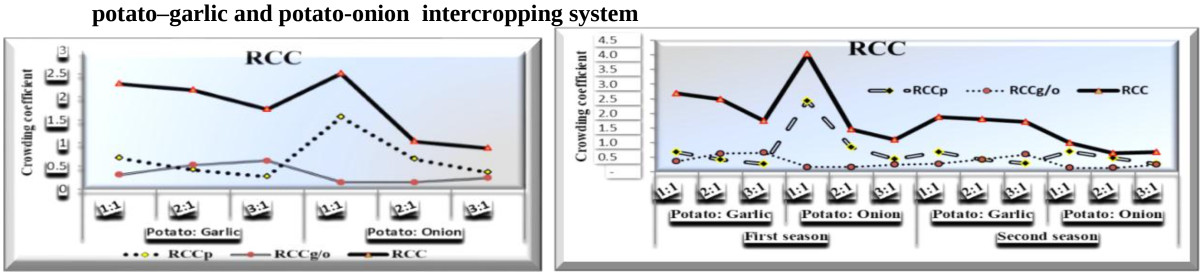

Fig. 6. Relative crowding coefficients (RCC) for average both seasons and two seasons in potato–garlic and potato-onion intercropping system

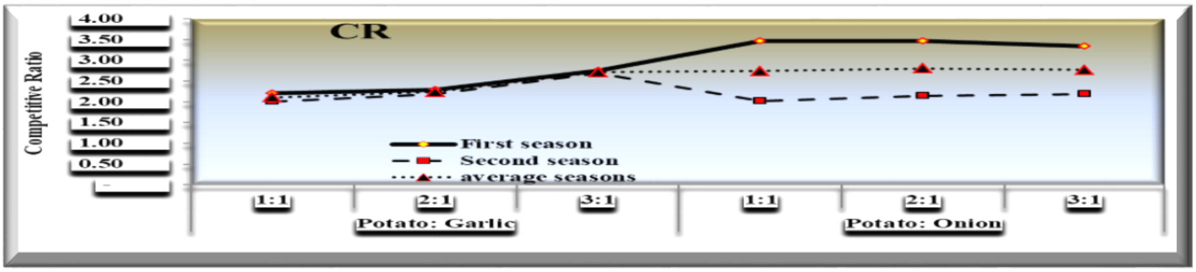

Fig. 7. Competitive ratio of potato (CR) for average both seasons and two seasons in potato–garlic and potato-onion intercropping system

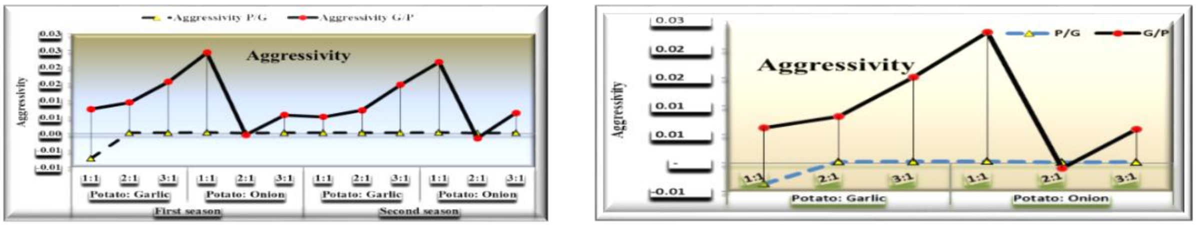

Fig. 8. Aggressivity values in potato–garlic or onion intercropping system in two and average seasons

The results demonstrated that intercropping had yield advantage over sole cropping and potato-garlic intercropping was to be more productive. Data on Likewise, LER (land equivalent ratio) is an index of intercropping advantage that indicated the amount of interspecific competition or facilitation in an intercropping system (**Fetene 2003**) are presented in Table 8 and Fig. 5. Obtained data revealed that the LERs for the intercrop yields of both potato and garlic were increased as their proportions were increased up to 2:1 in the studied intercropping patterns. Values of potato were higher than those of garlic or onion at equal proportion or equalization of their proportions in the intercropping systems. This means that potato was the dominant crop and garlic (or onion) was the dominated one. The highest LER_a value in both seasons for potato (1.0, 0.95) & (0.94, 0.94) in 1st and 2nd season, respectively was obtained with "1 potato : 1 onion" and "1 potato: 1 garlic", respectively and that for $LER_b$of garlic were 0.76 and 0.68 in the first and second seasons, respectively and onion were 0.46 in both seasons, which were obtained with 2 potato :1 garlic (or onion) intercropping system. Results concerning the LER for the combined intercrop yield presented in Table 8 and Figure 3 showed that the highest values were 1.7 and 1.6 in the first and second season, respectively, which were obtained with 2 potato: 1garlic intercropping system. This means that 70% (0.7 fed) in case of intercropping with garlic and both 40% and 30% with onion, more land area in sole cropping pattern would produce the same yield as in the intercropping system of potato and garlic (or onion). These results indicated that the 2P:1G pattern had the most yield advantage compared to other patterns. These findings were also in agreement with the results of LER and the other competition indices. Similarly, **Ghosh (2004)** found that when the LER and RCC where higher there is also significant economic benefit expressed with higher MAI values Similar results were also reported by **Yadav and Yadav (2001), Muhammad *et al*. (2008) and Yayeh*et al*. (2014a)** who reported yield advantage in crop mixtures than equivalent sole crops on the same land area. Intercropping systems with constantly higher LERs well-above one are considered more resource-use efficient than mono crops (**Willey, 1979**).

Table 8. Effect of cropping pattern on land equivalent ratio (LER) and Coefficient (LEC), aggressivity, competitive ratio (CR) and relative crowding coefficient (RCC) during 2017/2018 and 2018/2019 seasons.

Intercropping patterns		LEC	LER ratio			Aggr*.		CR	RCC
			LER	LER_a	LER_b	Ab	Ba		
2017/2018									
Potato : Garlic	1:1	0.6	1.5	0.94	0.59	-0.007	0.0074	2.20	2.4
	2:1	0.7	1.7	0.90	0.76	0.0003	0.0094	2.29	2.6
	3:1	0.6	1.6	0.89	0.69	0.0003	0.0156	2.75	1.7
Potato: Onion	1:1	0.4	1.4	1.00	0.40	0.0004	0.0243	3.46	4.0
	2:1	0.4	1.4	0.94	0.46	0.0002	-0.0004	3.46	1.4
	3:1	0.4	1.4	0.93	0.45	0.0002	0.0056	3.34	1.1
2018/2019									
Potato: Garlic	1:1	0.5	1.5	0.94	0.52	0.0002	0.0051	2.00	1.9
	2:1	0.6	1.6	0.89	0.68	0.0003	0.0070	2.18	1.8
	3:1	0.6	1.6	0.90	0.67	0.0003	0.0147	2.68	1.7
Potato: Onion	1:1	0.3	1.3	0.95	0.36	0.0003	0.0215	2.01	0.99
	2:1	0.4	1.3	0.90	0.46	0.0002	-0.0014	2.14	0.64
	3:1	0.4	1.3	0.89	0.45	0.0002	0.0063	2.18	0.69

Aggr*. ab: potato/garlic (or onion) Aggr*. ba: garlic (or onion)/potato LER_a: (Potato) LER_b: (garlic or onion)

Results presented in Table 8 and Fig. 6 showed the effect of intercropping patterns between potato and either garlic or onion on their relative crowding coefficients (RCC). Obtained results revealed that all values of potato (RCC_p) were higher than those of onion of all ratios and garlic of 1:1 ratio which indicated that potato was the dominant crop whereas onion or garlic was the dominated one. The highest coefficients of potato were found with the intercropping systems 1potato: 1onion while those of garlic or onion wereobtained with 3 potato : 1garlic or onion in both seasons. Relative crowding coefficients (RCC) revealed again the superiority of 1:1 pattern of intercropping potato with either garlic or onion, followed by those of 2:1 one in average of both seasons. While potato/onion of 3:1 ratio resulted in the lowest value (Fig. 6). This was attributed to effectual competition of potato were its RCC coefficients were very high to those of two crops. In addition all values of the coefficient products were higher than one which indicated that there were yield advantages, *i.e.*, the combined intercrop yield was higher than expected **(Willey, 1979)**. Similar results were obtained by **Abd El-lateef*et al*. (2011).** Likewise,the competitive ratio of potato (CR) in different potato/garlic (or onion) intercropping patterns always exceeded 1.0 in two seasons and thus were higher than the competitive ratios of garlic (or onion) relative to potato during. Meanwhile, the average CR_{pg} and CR_{po} value over two seasons was also higher than 1.0 for each intercropping configuration. In contrast, the average $CR_{gp}$and CR_{op} values were less than 1, suggesting that potato had greater competitive intensity relative to garlic or onion in potato/garlic or potato/onion combination (Fig 7). Also, our results suggest that potato is the dominant crop in potato/garlic or onion combination, at least under the current experimental settings, as indicated by the higher RCCp, competitive ratios and positive aggressivity. This reveals that potato intercropped with garlic or onion utilized the resources more aggressively, and its production was the major factor that determined the overall yields. Aggressivity of intercrop potato on garlic or onion was pronounced especially under 2:1 intercropping pattern of potato with garlic and 1:1 pattern of potato/onion. The aggressivity values of potato were positive revealing the prevailing effect of potato. Finally, all competition relations indicated that potato was dominant and both garlic and onion were dominated (Fig.8).

Economic advantage of intercropping

Most intercropping indices mainly give the agronomic and yield advantages of intercropping, and do not take into account the economic and absolute yield comparisons (**Tamado and Mulatu, 2000; Yayeh*et al*., 2014b**). Nevertheless, it is desirable to evaluate yield advantage on monetary basis following **Willey (1979)** formula. Monetary values of the combined intercrop yield of potato and (garlic or onion) were calculated according to their price in local market for wholesale after the harvest season (2017/2018). The intercropping potato with garlic or onion showed that MAI was positive in all the intercropping systems and higher above one (Table 9). Obtained values shown in Table (9) indicated that the highest cash advantage was achieved from intercropping system ratios 1potato: 1garlic, 2 potato: 1 garlic and 1potato: 1onion, in descending order under late blight natural infestation. For farmers interested in getting maximum income, using 1potato: 1garlic intercropping system would be the best treatment (gave 10.358 thousand pounds advantage as average of both seasons) without any fungicids treatments. While For farmers interested in getting high income and the highest yield of garlic, using 2 potato : 1 garlic would be recommended. This indicates that the intercropping systems were more economically feasible weighed compare to monoculture. This conforms to similar results by **Dutta*et al*. (1994**) on maize-rape seed combinations.

Table 9. Effect of intercropping patterns on monetary advantage (thousand L.E) during 2017/2018 and 2018/2019 seasons.

	1st season		2nd season		Average both seasons	
Intercropping patterns	P: G	P: O	P: G	P: O	P: G	P: O
1:1	10.598	9.616	10.083	7.427	10.358	8.525
2:1	10.276	7.590	9.627	5.944	9.965	6.776
3:1	9.460	7.526	9.860	6.902	9.663	7.216

P: potato G: garlic O: onion

Conclusion

The present study concludes that intercropping of potato with garlic and onion may affect yield and disease resistance, competition between the 2 species (*Solanumtuberosum and Allium spp.*), and economics of mixtures as compared to monoculture of the same species. Regardless of various varieties, potato-garlic or potato-onion intercropping had the yield advantages of intercropping and optimum exploitation of the environmental resources as opposed to other intercropping systems. Additionally, these 2 intercropping systems were observed to be the most profitable. Furthermore, onion intercropped with potato was more competitive than garlic. Generally, potato was the dominant species in all mixtures. Although *Allium* crops had lower yield in mixture but are more expensive in markets, solitary planting of them would not reach the profitable level gained with potato or other crops cited in literature. On the other hand, mixtures with potato and garlic resulted in significant advantages of intercropping as confirmed by the economic and land use efficiency values. Potato tuber, Cara cv., intercropped with green garlic, Sids-40 cv., presented the greatest monetary advantage. Such a system can be easily practiced especially by peasants from the lower and Upper Egypt regions in ARE, as well as in other countries that have similar climate. Therefore, with a higher socio-economic return for farming system, as well as soil conservation can be improved in such environments.

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دراسات على نظم تحميل الثوم والبصل الأخضرعلى البطاطس وتأثيرذلك على النمو والمحصول ومقاومة مرض اللفحة المتأخرة

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اجريت هذه التجارب الحقلية لدراسة تأثيرنظم الزراعة البينية او التحميل على أداء نباتات البطاطس سواء النمو الخضري او جودة وعائد محصولالدرنات وكذلك المقاومة لمرض اللفحة المتأخرة في نبات البطاطس خلال ثلاثة مواسم متتالية ونفذ الموسم الاول (2017/2016) تحت الصوب الزراعية كموسم اولى للدراسات المعملية ثم تلاها التنفيذ الحقلى بمزرعة قها كحقل مفتوح 2018/2017 و 2019/2018 وتمت زراعة البطاطس مع الثوم والبصل بنظم تحميل مختلفة بنسب 1:1 (البطاطس والمحصول المحمل كل على جانب فى نفس الخط)؛ 2:1 (2 خط بطاطس مقابل خط واحد ثوم او بصل) و 3:1 (3 خطوط بطاطس : خط من المحصول المصاحب). قورنت هذه المعاملات مع مبيد الفطريات (Radomil gold)الموصى به كرش ورقي على البطاطس المنزرعة فرديا بالاضافة الى معاملة نبات البطاطس الأحادي الزراعة بدون رش بالمبيد لدراسة تطور المرض ومحصول درنات البطاطس وصفاتها. أظهرت النتائج أن جميع نسب البطاطس والثوم أظهرت أداءً فائقًا عند مقارنتها بالزراعة الفردية بدون مبيد.

من بين النسب المستخدمة، أظهرت 1 بطاطس : 1 ثوم نقص معنوي مرغوب فى تطور المرض وإنتاجية عالية للدرنات علاوة على ذلك ، عند زراعة 1: 1 من الثوم (أو البصل) إلى البطاطس ، كانت نسبة الأرض المكافئة (LER) أكبر من 1 وكانت القيم النقدية عالية في كلا الموسمين. أظهرت الدراسة أيضًا أن المعاملة بمبيدات الفطريات أدى إلى انخفاض معنوي في تطور المرض وزيادة محصول درنات البطاطس مقارنةً بمعاملة التحكم الأحادي غير المعاملة. كما أدت نتائج هذه الدراسة إلى اقتراح أن الثوم له جدوى (كنبات تحميل) لإدارة مرض اللفحة المتأخرة في البطاطس تحت الظروف المصرية. كان ايضا من ضمن اهداف هذه الدراسة، تقييم الرش بالمستخلصات النباتية لفصوص الثوم، وبصيلات البصل على نباتات البطاطس المصابة بـP. infestans في الزراعات المفتوحة في موسم النمو الشتوي فى تخفيض حدة المرض. تمت دراسة تأثير المنافسة بين نوعي Allium المختلفين في الزراعة البينية للبطاطس والجدوى الاقتصادية لزراعة البطاطس مع الثوم والبصل مقارنة بمحصولها المفرد تحت الإصابة الطبيعية باللفحة المتأخرة. بشكل عام ، خلصت الدراسة الحالية إلى أن زراعة البطاطس مع الثوم والبصل تؤثرايجابيا على المحصول ومقاومة الأمراض ، والمنافسة بين النوعينSolanumtuberosumو .Allium spp ، واقتصاديات التحميل مقارنة بالزراعة الأحادية من نفس النوع. على الرغم من أن محاصيل Allium كانت ذات إنتاجية أقل في التحميل ولكنها أكثر قيمة تسويقية وأن الزراعة المنفردة منها لن تصل إلى المستوى المربح المكتسب مع البطاطس في ظل ظروف التجارب الحالية.