Advances in Crop Science and Technology

Lamlom et al., Adv Crop Sci Tech 2018, 6:5
DOI: 10.4172/2329-8863.1000394

Research Article Open Access

Crop Interference Effects of Some Winter and Summer Field Crops on Egyptian Cotton Characters

Mohamed M Lamlom[1], Sherif I Abdel-Wahab[1], Tamer I Abdel-Wahab[1] and Mohamed AA Ibrahim[2]

[1]*Crop Intensification Research Department, Field Crops Research Institute, Agricultural Research Center, Egypt*

[2]*Agronomy Department, Cotton Research Institute, Agricultural Research Center, Egypt*

[*]**Corresponding author:** Sherif Ibrahim Abdel-Wahab, Crop Intensification Research Department, Field Crops Research Institute, Agricultural Research Center, Egypt, Tel: 00201006912633; E-mail: twins00twins50@yahoo.com

Rec date: June 30, 2018; **Acc date:** September 10, 2018; **Pub date:** September 19, 2018

Abstract

A two-year study was carried out at Sids Agricultural Research Station, Beni Sweif government, Agricultural Research Center (ARC), Egypt, during 2015/2016 and 2016/2017 seasons to evaluate the crop interference of Egyptian clover, faba bean, onion, wheat, cowpea and sesame crops on Egyptian cotton characters for maximizing land usage with economically efficient cropping system and good fiber quality. The treatments were the combinations between four winter cropping systems (double cropping systems of Egyptian clover and cotton, relay intercropping cotton with faba bean, onion or wheat) and three summer cropping systems (sole cotton, intercropping cowpea or sesame with cotton). The treatments were compared in a split plot design with three replications. Egyptian clover, faba bean and onion had positive effects on seed cotton yield, yield attributes and fiber quality traits. Summer crops affected significantly seed cotton yield, yield attributes and fiber quality traits. Crop interference effects of cotton+cowpea pattern improved cotton fiber quality compared with sole cotton, meanwhile cotton +sesame pattern had the opposite trend. The interaction between winter and summer cropping systems was significant for seed cotton yield plant^{-1} and lint in the first season, boll weight and 100-seed weight in the second season. Egyptian clover/cotton+cowpea achieved the highest LER and ATER followed by onion+cotton/cotton +cowpea. Onion+cotton/cotton+cowpea had higher net return and fiber quality for spinning the stronger and silkier yarns that can be woven into luxury cotton clothing than the conventional cropping system (Egyptian clover/cotton).

Keywords: Crop interference; Cropping systems; Seed cotton yield; Fiber quality; Competitive relationships; Farmers' benefit

Introduction

Always, population growth is considerable pressure on available environmental resources. About half of Egypt's residents live in urban areas, with most people spread across the densely populated centers of greater Cairo, Alexandria and other major cities in the Nile Delta. Egypt's fertile area totals about 3.3 million ha, about one-quarter of which is land reclaimed from the desert. However, the reclaimed lands only add 7% to the total value of agricultural production [1]. Even though only 3% of the land is arable, it is extremely productive and can be cropped two or even three times annually [2]. Fortunately, Egypt had four seasons during the year, but generally there are only two familiar seasons for Egyptian agriculture that is a mild winter from November to April and a hot summer from May to October. The most differences between the seasons are variations in light intensity, daytime temperatures and prevailing winds. Consequently, there are some strategic crops such as wheat (*Triticum aestivum* L.), faba bean (*Vicia faba* L.) and onion (*Allium cepa* L.) in addition to Egyptian clover (*Trifolium alexandrinum* L.) during the winter season. In the summer season, there are some other crops such as maize (*Zea mays* L.), rice (*Oryza sativa* L.), cotton (*Gossypium barbadense* L.) and sesame (*Sesamum indicum* L.) in addition to cowpea (*Vigna unguiculata*).

Recently, special attention has been directed towards increasing productivity of Egyptian cotton unit area^{-1}. Delaying cotton planting date than the suitable date (as a result of the late harvest date of some winter field crops) reducing seed cotton yield and its quality [3-7] and thereby low-income farmers. Cotton classification is the process of describing the quality of cotton in terms of such properties as cleanness, length, smoothness, color, maturity, strength and contamination. It is known that Egyptian cotton is characterized by having the longest, finest and strongest fibers, with fiber lengths exceeding 3.5 cm, some even ≥ 5.0 cm. Its fibers are generally used to manufacture high quality ring-spun yarns with end-uses including sewing thread, lace yarns and high-quality dress and shirt fabrics [8]. In this concern, Long et al. [9] reported that fiber quality is characterized by fiber length, strength and micronaire, and the textile industry has a preference for long and strong fibers of moderate micronaire for producing high-quality yarns. Fiber fineness affects processing performance and the quality of the end product in several ways. Cotton requires slower processing speeds to fibers per cross-section, which in turn produces stronger yarns. Also, color deterioration affects the ability of fibers to absorb and hold dyes and finishes. Unfortunately, the cultivated area of this important crop continuously till it reached about 571 thousand ha in 2016 [10].

Accordingly, late cotton planting date during the summer season is one of the main problems associated with the Egyptian farmers. Consequently, the cropping system adopted by the farmer in soils of the Nile Valley and Delta must be physically viable, sustainable, less exhaustive acceptable to farming community and most important thing is that it should be economical. However, most plant species are capable of influencing the quality of their environment [11] where plants may exert substantial effects on nutrient cycling [12]. On the other hand, Basra and Saha [13] mentioned that fiber maturation included four stages of growth (initiation, primary elongation, secondary wall formation and maturation). It known that cotton plant store substantial amounts of photo-assimilate as starch in stems and roots prior to flowering [14]. Therefore, it is expected that environment surrounding cotton seedling and growth could be have substantial effects on boll formation. Certainly, environmental conditions can be playing a vital role in cotton growth and development stages. The effects of climatic factors such as evaporation, sunshine duration, humidity, surface soil temperature and maximum air temperature are the important factors that affect significantly flower and boll production of cotton [15].

For edaphic factors, the mobility in soil is dependent on the chemical form of the element used. The availability of nitrogen (N), phosphorus (P), potassium (K) and water are the major constraints in cotton production in most cotton producing environments [16]. Therefore, the allelopathic effect of the winter and summer field crops on seed cotton yield and its attributes were differed due to soil N, P, K and ferulic acid contents, as well as, population density of *Bacillus* sp. in the cotton rhizosphere. Ferulic acid (4-hydroxy-3-methoxycinnamic acid) and *Bacillus* sp. could affect either negatively or positively cotton growth. Ferulic acid (phenolic compound) is a strong dibasic acid in which the first proton dissociation generates the carboxylate anion, while the second produces a phenolate anion. The anion has a high degree of resonance stabilization, which increases its acidity in comparison with similar phenolic acids [17] and could affect plant-microbe interactions that play important roles in a number of vital ecosystem processes such as nutrient cycling [18]. According to Gui-Ying et al. [19], ferulic acid inhibited the growth, enzyme activities and root activity of cotton seedlings from long term sole cotton fields.

N fixation by both symbiotic and free-living bacteria is highly sensitive to interference effects (including allelopathy) from certain plant species [20]. There are several free-living N-fixing bacteria that grow in close association with plants such as *Bacillus* sp. that is one of the predominant genera of plant growth promoting bacteria [21]. Root-colonizing species of *Bacillus* is well known for the enhancement of plant growth [22] and is responsible for the biocontrol activity in rhizosphere of cotton seedlings [23]. Consequently, if Egyptian agricultural production must be intensified, a cropping system should be followed depending on proper management to offer optimum productivity of cotton crop unit area^{-1} with regarded to crop interference effects.

Interference between plants typically refers to either competition for resources (nutrients, light and water) or chemically-mediated interference "allelopathy" [24]. Thus, relay intercropping cotton (seedling and growth stages) with wheat (reproductive stage) is a recent technology in crop intensification field, where, the crops overlap in time, growing as an intercrop, from March till May [25-27]. Moreover, summer intercrops were interfered strongly with some preceded winter crops to overcome the negative allelopathic effects [28]. The objective of this investigation was to evaluate the crop interference of Egyptian clover, faba bean, onion, wheat, cowpea and sesame crops on Egyptian cotton characters for maximizing land usage with economically efficient cropping system and good fiber quality.

Materials and Methods

A two-year study was carried out at Sids Agricultural Research Station, Beni Sweif governorate (Lat. 29°12' N, Long. 31°01' E, 32 m.a.s.l.), Egypt, during 2015/2016 and 2016/2017 seasons. Chemical analyses of the soil (0-30 cm) were done by Water, Soil and Environment Research Institute, ARC (Table 1). According to Jackson [29] and Chapman and Pratt [30] before growing of the winter crops. Soil texture is clay. Furrow irrigation was the irrigation system in the region. Cultivars of winter field crops were Giza 6 for Egyptian clover, Giza 843 for faba bean, Giza 6 improved for onion and Misr 1 for wheat. Cultivars of summer filed crops were Giza 95 " extra-long staple" for cotton, Cream 1 for cowpea and Shandweel 3 for sesame. Egyptian clover and cowpea seeds were kindly provided by Forage Crops Research Department, Field Crops Research Institute, ARC. Faba bean seeds were kindly provided by Food Legumes Research Department, Field Crops Research Institute, ARC. Onion transplants were kindly provided by Onion Research Department in Sids Agricultural Research Station, Field Crops Research Institute, ARC. Wheat grains were kindly provided by Wheat Research Department, Field Crops Research Institute, ARC. Cotton seeds were kindly provided by Cotton Research Institute, ARC. Sesame seeds were kindly provided by Oil Crops Research Department, Field Crops Research Institute, ARC.

Depth (0-30 cm)	Growing Season	
	First Season	Second Season
Chemical properties		
pH	8.1	8.55
Available N ppm	12.6	13.7
Available P ppm	26	25
Available K ppm	178	163

Table 1: Soil chemical properties of Sids location before growing the winer crops in the two seasons.

In the two winter seasons, Egyptian clover and faba bean seeds were inoculated by *Rhizobium trifolii* and *Rhizobium leguminosarum*, respectively, before seeding it and Arabic gum was used as a sticking agent. In the two summer seasons, cowpea seeds were inoculated by *Rhizobium melitota* before seeding it and Arabic gum was used as a sticking agent. Calcium super phosphate (15.5% P_2O_5) was applied at rate of 476 kg ha^{-1} during soil preparation in the two winter seasons. Mineral N fertilizer was applied at rate of 35.7 kg N ha^{-1} for Egyptian clover, 17.8 and 35.7 kg N ha^{-1} for faba bean, 191.3 and 285.6 kg N ha^{-1} for onion and 119.5 and 178.5 kg N ha^{-1} for wheat under intercropping and sole cultures, respectively. Also, mineral N fertilizer for cotton plants was applied at rate of 142.8 kg N ha^{-1} in two equal doses at 45 and 60 days from cotton sowing, meanwhile mineral N fertilizer for cowpea plants was applied at rate of 17.8 and 35.7 kg N ha^{-1} under intercropping and sole cultures, respectively, in one equal dose at 25 days from cowpea sowing. Mineral N fertilizer for sesame plants was applied at rate of 35.7 and 71.4 kg N ha^{-1} under intercropping and sole cultures, respectively, in two equal doses at 25 and 40 days from sesame sowing. Mineral K fertilizer was applied for all the tested crops as recommended for each crop. Table 2 shows sowing and harvest dates of winter and summer field crops in the two growing seasons.

Crop	Season			
	First Season		Second Season	
	Sowing Date	Harvest Date	Sowing Date	Harvest Date
Egyptian clover	21st October	11th March	18th October	7th March
Faba bean	21st October	29th April	18th October	26th April
Onion	21st October	14th April	18th October	12th April
Wheat	21st October	8th May	18th October	5th May
Cotton	22nd March	16th September	18th March	13th September
Cowpea	14th May	27th July	11th May	24th July
Sesame	14th May	30th August	11th May	28th August

Table 2: Sowing and harvest dates of all the studied field crops in the two seasons.

The experiment included twelve cropping systems as follows:

- Egyptian clover seeds were broadcasted at the rate of 47.6 kg ha^{-1}. After the third cutting of Egyptian clover, cotton seeds were grown in two sides of the bed, two plants together distanced at 25 cm. This cropping system was expressed as Egyptian clover/cotton in the winter season and sole cotton in the summer season (conventional cropping system).
- Egyptian clover seeds were broadcasted at the rate of 47.6 kg ha^{-1}. After the third cutting of Egyptian clover, cotton seeds were grown in two sides of the bed, two plants together distanced at 25 cm. Two rows of cowpea seeds were grown in middle of cotton beds, two plants together distanced at 20 cm. This cropping system was expressed as Egyptian clover/cotton in the winter season and cotton+cowpea in the summer season.
- Egyptian clover seeds were broadcasted at the rate of 47.6 kg ha^{-1}. After the third cutting of Egyptian clover, cotton seeds were grown in two sides of the bed, two plants together distanced at 25 cm. One row of sesame seeds were grown in middle of cotton beds, two plants together distanced at 20 cm. This cropping system was expressed as Egyptian clover/cotton in the winter season and cotton+sesame in the summer season.
- Two rows of faba bean seeds were grown in middle of the bed, two plants together distanced at 15 cm. Cotton seeds were grown in two sides of faba bean beds, two plants together distanced at 25 cm. This cropping system was expressed as faba bean+cotton in the winter season. After faba bean harvest, cotton continued alone in the summer season (sole cotton).
- Two rows of faba bean seeds were grown in middle of the bed, two plants together distanced at 15 cm. Cotton seeds were grown in two sides of faba bean beds, two plants together distanced at 25 cm. Two rows of cowpea seeds were grown in middle of cotton beds, two plants together distanced at 20 cm. This cropping system was expressed as faba bean+cotton in the winter season and cotton +cowpea in the summer season.
- Two rows of faba bean seeds were grown in middle of the bed, two plants together distanced at 15 cm. Cotton seeds were grown in two sides of faba bean beds, two plants together distanced at 25 cm. One row of sesame seeds were grown in middle of cotton beds, two plants together distanced at 20 cm. This cropping system was expressed as faba bean+cotton in the winter season and cotton +sesame in the summer season.
- Four rows of onion transplants were grown in middle of the bed, one plant distanced at 10 cm. Cotton seeds were grown in two sides of onion beds, two plants together distanced at 25 cm. This cropping system was expressed as onion+cotton in the winter season. After onion harvest, cotton continued alone in the summer season (sole cotton).
- Four rows of onion transplants were grown in middle of the bed, one plant distanced at 10 cm. Cotton seeds were grown in two sides of onion beds, two plants together distanced at 25 cm. Two rows of cowpea seeds were grown in middle of cotton beds, two plants together distanced at 20 cm. This cropping system was expressed as onion+cotton in the winter season and cotton +cowpea in the summer season.
- Four rows of onion transplants were grown in middle of the bed, one plant distanced at 10 cm. Cotton seeds were grown in two sides of onion beds, two plants together distanced at 25 cm. One row of sesame seeds were grown in middle of cotton beds, two plants together distanced at 20 cm. This cropping system was expressed as onion+cotton in the winter season and cotton+sesame in the summer season.
- Four rows of wheat grains were drilled at the rate of 119.0 kg ha^{-1} in middle of the bed. Cotton seeds were grown in two sides of wheat beds, two plants together distanced at 25 cm. This cropping system was expressed as wheat+cotton in the winter season. After wheat harvest, cotton continued alone in the summer season (sole cotton).
- Four rows of wheat grains were drilled at the rate of 119.0 kg ha^{-1} in middle of the bed. Cotton seeds were grown in two sides of wheat beds, two plants together distanced at 25 cm. Two rows of cowpea seeds were grown in middle of cotton beds, two plants together distanced at 20 cm. This cropping system was expressed as wheat+cotton in the winter season and cotton+cowpea in the summer season.
- Four rows of wheat grains were drilled at the rate of 119.0 kg ha^{-1} in middle of the bed. Cotton seeds were grown in two sides of wheat beds, two plants together distanced at 25 cm. One row of sesame seeds were grown in middle of cotton beds, two plants together distanced at 20 cm. This cropping system was expressed as

wheat+cotton in the winter season and cotton+sesame in the summer season.

In addition to:

- Sole Egyptian clover or wheat by broadcasting Egyptian clover seeds or drilling wheat grains at the rate of 47.6 or 119.0 kg ha^{-1}, respectively. With respect to Egyptian clover 5 cuts, the fifth cutting was done at first week of May in the two seasons.
- Sole onion or faba bean by growing three or two rows in ridges, one or two plants together distanced at 10 or 25 cm, respectively.
- Sole cowpea or sesame by growing two rows in ridges, two plants together distanced at 20 cm.

The treatments were the combinations between four winter cropping systems and three summer cropping systems. The twelve cropping systems were compared in a split plot design with three replications. Four winter cropping systems were randomly assigned to the main plots, while three summer cropping systems were allocated in subplots. Sub-plot area was 21.6 m^2. With regarding to intercropping systems and sole cultures of wheat and Egyptian clover, each plot contained six beds, each bed was 3.0 m in length and 1.2 m in width. In case of sole cultures of faba bean, onion, cowpea and sesame, each plot contained twelve ridges, each ridge was 3.0 m in length and 0.6 m in width.

The studied characters

Soil samples were taken from rhizosphere of cotton roots: The following chemical analyses were recorded after 45 days from cotton sowing; N, P and K (ppm), ferulic acid (μg g^{-1}) and total count of *Bacillus* sp. (CFU g^{-1}). These analyses were done in General Organization for Agricultural Equalization Fund, ARC, Giza, Egypt and the Regional Center for Food & Feed, ARC, Giza, Egypt. Soil samples were collected for chemical analysis before adding mineral N fertilizer for cotton plants.

Seed cotton yield and its attributes: The following traits were measured on ten guarded plants from each sub-plot at harvest; intercepted light intensity (lux) at the middle of the plant by Lux-meter apparatus at 12 h and expressed as percentage from light intensity measured above the plant, plant height (cm), nodal position of the first sympodium (cm), numbers of monopodia and sympodia $plant^{-1}$, number of open bolls $plant^{-1}$, seed cotton yield $plant^{-1}$ (g), boll weight (g) and 100-seed weight (g). Lint (%) was calculated as the relative amount of lint in a seed cotton sample, expressed in percentage. Seed cotton yield ha^{-1} (t) was recorded on the basis of sub-plot area by harvesting all plants of each sub-plot and converted to yield ha^{-1}. Lint cotton yield ha^{-1} (t) was calculated by multiplying seed cotton yield ha^{-1} (t) in lint (%).

Cotton fiber quality: The fiber properties were measured using High Volume Instrument (HVI) methods according to A.S.T.M. [31] by the Cotton Technology Res. Division, Cotton Res. Inst., ARC, Egypt.

Fiber length: Upper half mean (mm); upper half mean is the mean length by the number of fibers in the largest half by weight of fibers in a cotton sample. UHM length is normally equivalent to the staple length.

Uniformity index (%): Uniformity index is the ratio between mean length and upper half quartile length, express as a percentage. Uniformity index is an indicator of how fibers will perform in the spinning of yarn.

Fiber bundle tensile: Strength (g/tex); strength reports the force, in grams, required to break a bundle of fibers one tex unit in size. A tex unit is the weight in grams of 1,000 meters of fiber.

Elongation (%): Elongation at break is the amount of stretch a fiber can take before it breaks.

Fineness: Micronaire reading; micronaire is a measure of the air permeability of compressed cotton fibers. It is often used as an indication of fiber fineness and maturity.

Color: Reflectance 'RD' (%).

Yields of the other crops: Forage yields of Egyptian clover and cowpea ha^{-1} (t) were estimated as fresh weight of three and two cuttings, respectively, taken from sub-plot. Seed yields of faba bean and sesame ha^{-1} (t) were recorded on the basis of plot area by harvesting all plants of each sub-plot. Bulb yield ha^{-1} (t) was estimated as fresh weight of bulbs taken from sub-plot. Grain yield of wheat ha^{-1} (t) was recorded on the basis of sub-plot area by harvesting all plants of each sub-plot. All the yields were converted to yield ha^{-1}.

Competitive relationships

Land equivalent ratio (LER): LER is the ratio of area needed under sole cropping to one of intercropping at the same management level to produce an equivalent yield [32]. LER is calculated as follows: $LER=(Y_a/Y_{aa})+(Y_b/Y_{bb})+(Y_c/Y_{cc})$, where Y_{aa}=Pure stand yield of crop a (cotton), Y_{bb}=Pure stand yield of crop b (Egyptian clover, faba bean, onion or wheat), Y_{cc}=Pure stand yield of crop c (cowpea or sesame), Y_a=Intercrop yield of crop a (cotton), Y_b=Intercrop yield of crop b (Egyptian clover, faba bean, onion or wheat) and Y_c=Intercrop yield of crop c (cowpea or sesame).

Area Time Equivalent Ratio (ATER): ATER provides more realistic comparison of the yield advantage of intercropping over monocropping in terms of time taken by component crops in the intercropping systems. ATER was calculated by formula: $ATER=LER \times D_c/D_t$ [33], Where LER is land equivalent ratio of crop, D_c is time taken by crop, D_t is time taken by whole system.

Financial evaluation

Farmer's benefit was calculated by determining each of total return, costs and net returns of intercropping cultures, as well as, sole cultures.

1) Total return ha^{-1} $year^{-1}$ (US$)=yield a × price a+yield b × price b +yield c × price c. The prices were presented by Bulletin of Statistical Cost Production and Net Return [10], as well as, market prices where a=cotton, b=winter crop and c=summer crop.

2) Net return ha^{-1} $year^{-1}$ (US$)=total return-variable costs for the crops in sole and intercropping cultures. The costs were presented by Bulletin of Statistical Cost Production and Net Return [34], as well as, market prices.

Statistical analysis

Analysis of variance of the obtained results of each season was performed. The measured variables were analyzed by ANOVA using MSTATC statistical package [35]. Mean comparisons were performed using the least significant differences (L.S.D) test with a significance level of 5% [36].

Results and Discussion

Winter crop interference effects on seed cotton yield and yield attributes

According to San Emeterio et al. [24], these results could be divided to interference effects of the tested crops on Egyptian cotton characters that include above and under-ground conditions.

Above-ground conditions: Data in Table 3 show that the winter cropping systems had significant effects on intercepted light intensity within cotton plants, seed cotton yield plant^{-1}, boll weight, 100-seed weight, lint percentage, seed cotton and lint yields ha^{-1} in the two growing seasons, meanwhile plant height, nodal position of the first sympodium, numbers of monopodia and sympodia plant^{-1}, and number of open bolls plant^{-1} were not affected. Egyptian clover/cotton sequential double cropping system was superior to all relay intercropping patterns for seed cotton yield plant^{-1}, boll weight, 100-seed weight, lint percentage, seed cotton and lint yields ha^{-1} followed by relay intercropping patterns; faba bean+cotton and onion+cotton. Egyptian clover/cotton increased seed cotton yield plant^{-1} by 11.79 and 22.38%, boll weight by 18.18 and 14.09%, 100-seed weight by 3.27 and 6.33%, seed cotton yield ha^{-1} by 32.46 and 24.32%, in the first and second seasons, respectively, compared with wheat+cotton (Table 3).

Also, onion+cotton increased seed cotton yield plant^{-1} by 2.07 and 6.77%, boll weight by 3.18 and 4.54%, 100-seed weight by 0.36 and 1.53%, seed cotton yield ha^{-1} by 15.21 and 3.27%, in the first and second seasons, respectively, compared with wheat+cotton (Table 3). The positive effect of Egyptian clover/cotton or onion+cotton pattern on seed cotton yield and its attributes could be due to there was no-overlapping between the Egyptian clover and cotton for basic growth resources and these conditions were relatively similar with those of onion+cotton pattern. Leaf canopy of onion formed whole space that is available for cotton plants during the seedling, growth and development stages.

Winter Cropping Systems	Characters											
	Intercepted Light Intensity at Middle of the Plant (%)	Plant Height (cm)	Nodal Position of the First Sympodium	Monopodia Plant^{-1} (no.)	Sympodia Plant-^{1} (no.)	Open Bolls Plant^{-1} (no.)	Seed Cotton Yield Plant^{-1} (g)	Boll Weight (g)	100-Seed Weight (g)	Lint (%)	Seed Cotton Yield ha^{-1} (t)	Lint Cotton Yield ha^{-1} (t)
First season												
Egyptian Clover	12.79	129.75	9.93	1.66	16.52	14.17	35.54	2.60	8.52	42.53	3.06	1.29
Faba Bean	11.52	130.17	9.86	1.70	16.44	14.45	33.73	2.40	8.36	42.16	2.88	1.20
Onion	12.92	125.81	10.04	1.62	16.66	14.26	32.45	2.27	8.28	40.89	2.61	1.06
Wheat	10.53	124.20	9.94	1.67	16.44	14.06	31.79	2.20	8.25	40.25	2.31	0.92
L.S.D. 0.05	**1.20**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**1.53**	**0.06**	**0.25**	**0.26**	**0.38**	**0.15**
Second season												
Egyptian Clover	14.61	126.40	10.30	1.02	14.56	14.10	34.12	2.51	9.73	42.73	3.68	1.55
Faba Bean	12.51	125.21	10.17	0.95	14.61	13.92	30.18	2.36	9.33	42.17	3.17	1.30
Onion	14.79	125.06	10.33	0.88	14.77	13.92	29.77	2.30	9.29	42.03	3.05	1.26
Wheat	11.05	125.21	10.23	1.02	14.77	13.75	27.88	2.2	9.15	41.98	2.96	1.22
L.S.D. 0.05	**1.06**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**1.06**	**0.11**	**0.14**	**0.18**	**0.12**	**0.05**

Table 3: Effect of winter crop interference on seed cotton yield and yield attributes in the first and second seasons.

Consequently, cotton plant has the longest period of vegetative growth during available normal climatic conditions from seedling to reproductive stage with high light intensity; 12.79 and 14.61% of full sunlight for Egyptian clover/cotton in the first and second seasons, respectively, and 12.92 and 14.79 % of full sunlight for onion+cotton pattern in the first and second seasons, respectively. Additionally, it is likely that cotton seedlings were benefitted greatly from low day temperatures that play a major role in carbon dioxide assimilation rates and more photosynthates during the spring season. It is known that seed cotton yield and its components decreased with delaying planting date [37,38].

These results reveal that Egyptian clover/cotton or onion+cotton pattern furnished better above-ground conditions for cotton growth and development which could be reflected on high seed germination, the timely appearance of seedling and the optimum development of the root system compared with the other patterns. Similar results were observed by Kamel et al. [4] who found that the preceding winter crops

(Egyptian clover, faba bean and wheat) had significant effects on number of open bolls plant^{-1} and seed cotton yield unit area^{-1}. On the other hand, El-Naggar et al. [39] and Babu [40] reported that onion enhanced the seed cotton yield. In another study, Metwally et al. [41] showed that Egyptian clover/cotton recorded the highest seed cotton yield compared with those of relay intercropping patterns. Furthermore, Jayakumar and Surendran [42] proved that cotton +onion resulted in the maximum cotton equivalent yield.

With respect to relay intercropping cotton with faba bean, faba bean +cotton increased seed cotton yield plant^{-1} by 6.10 and 8.24%, boll weight by 9.09 and 7.27%, 100-seed weight by 1.33 and 1.96%, seed cotton yield ha^{-1} by 24.67 and 7.09 %, in the first and second seasons, respectively, compared with wheat+cotton (Table 3). These results could be due to faba bean+cotton decreased inter-specific competition between the two species for basic growth resources such as solar radiation, air temperature and wind compared with relay intercropping cotton with wheat. It is known that the climate of Egypt in the winter season (December-February) is cold, moist and rainy, in addition to the main feature in the early spring season is the desert or Khamasine winds [43]. Accordingly, it is expected that the genetic make-up of Giza 843 cultivar interacted positively with its plant density (67% of the recommended plant density unit area^{-1}) to make the surrounding environment with cotton more-lighter than those of wheat+cotton pattern especially from the late winter season to early spring season.

Additionally, the whole space is available for cotton plants that are still in the seedling stage after faba bean harvest, and the gaps that appear after 45 days from cotton planting have to be bridged by the expanding leaf canopy of cotton. Consequently, it is likely that this positive effect will enhance sink capacity of cotton to intercept more solar radiation where resource use efficiency is not likely to be much affected in intercropping systems with component crops that differ in growing period, since competition between component crops is weak [44]. These results reveal that faba bean+cotton pattern furnished better above-ground conditions especially light intensity for increasing cotton above ground biomass accumulation from seedling to development stage than those of wheat+cotton pattern. These results are in accordance with those observed by Hussein and Haikal [45] who revealed that the faba bean+cotton pattern produced the highest seed yields plant^{-1} and unit area-^{1} compared with the others. Also, Metwally et al. [41] reported that growing cotton with faba bean by relay intercropping system at 20th March gave significant increases in seed cotton yield as compared to the corresponding cropping system of wheat.

With regard to wheat+cotton pattern, light intensity was decreased within intercropped cotton canopy with wheat compared with that of Egyptian clover/cotton, faba bean+cotton and onion+cotton pattern (Table 3). In other words, growing cotton with wheat increased inter-specific competition between the intercrops for basic growth resources especially light penetration between them. It is known that shade diminished cotton sink capacity [46] and the fewer cotton bolls plant^{-1} of this pattern were produced. According to Du et al. [47], wheat +cotton showed a pronounced delay in early development due to the initial shading from wheat on cotton seedlings. These results are in similar with those observed by Metwally et al. [41] who indicated that Egyptian clover/cotton recorded higher seed cotton yield than those of wheat+cotton.

Under-ground conditions: Egyptian clover, faba bean, onion and wheat were differed significantly for major soil elements, content of ferulic acid and population density of *Bacillus* sp. in the cotton rhizosphere after 45 days from cotton sowing in the two growing seasons (Table 4). Soil N content of the cotton rhizosphere varied from 14.0 to 32.0 ppm and from 20.0 to 40.0 ppm in the first and second seasons, respectively without significant differences either among Egyptian clover, faba bean and onion or between onion and wheat. Also, P content of the cotton rhizosphere varied from 30.0 to 44.0 ppm and from 36.0 to 48.0 ppm in the first and second seasons, respectively without significant differences between Egyptian clover and faba bean. Moreover, K content of the cotton rhizosphere varied from 262.0 to 330.0 ppm and from 292.0 to 366.0 ppm in the first and second seasons, respectively. On the other hand, ferulic acid content of the cotton rhizosphere varied from 3.0 to 15.1 μg g^{-1} and from 2.6 to 19.5 μg g^{-1} in the first and second seasons, respectively without significant differences either among Egyptian clover, faba bean and onion or between onion and wheat. Also, *Bacillus* sp. content of the cotton rhizosphere varied from 4.7 × 105 to 4.9 × 106 CFU g^{-1} and from 5.5 × 105 to 5.7 × 106 CFU g^{-1} in the first and second seasons, respectively without significant differences between Egyptian clover and faba bean. It is known that N and P are among the most limiting nutrients for plant growth. P is generally deficient in most of the soils due to its ready fixation [48].

In general, soil N, P and K availabilities in the cotton rhizosphere were increased by cutting of Egyptian clover or harvesting of faba bean in the experimental soil as compared with wheat+cotton pattern in the two growing seasons (Table 4).

It is likely that deep-growing roots of the legumes could be changed three dimensions in the experimental soil (from the top to the bottom of the soil profile, from North to South and East to West) and thereby accelerated the weathering of the experimental soil by aggregate stability and soil porosity. Accordingly, the fixed N by the legume is released; making it available to other plants and this helps to fertilize the soil [49] and soil bacteria specifically interact with plant roots in the rhizosphere, where bacterial number is generally higher than in the free soil [50]. It is known that PGPR (*Rhizobium* and *Bacillus* sp.) require N to decompose crop residues and can get this either from the residue or soil solution. Therefore, it is expected that complementary interactions between the root system of the legume and PGPR such as N transfer or complementary use of different soil nutrients were occurred; leading to an increase in cation exchange capacity (CEC) through PGPR activity that converted organic N to NH_4^+ in the soil solution or exchangeable pool [51].

Winter Crops	N (ppm)		P (ppm)		K (ppm)	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Egyptian clover	32.0	40.0	40.0	44.0	316.0	328.0
Faba bean	30.0	32.0	38.0	42.0	285.0	299.0

Onion	26.0	30.0	44.0	48.0	330.0	366.0
Wheat	14.0	20.0	30.0	36.0	262.0	292.0
L.S.D. 0.05	**14.08**	**11.66**	**3.83**	**3.41**	**22.65**	**27.11**
Winter Crops	**Ferulic Acid Content (μg g^{-1} soil)**		***Bacillus* sp. (CFU g^{-1} soil)**			
	1st Season	**2nd Season**	**1st Season**		**2nd Season**	
			Original Data	**Transformed Data**	**Original Data**	**Transformed Data**
Egyptian clover	3	2.6	1.5 x 10^6	6.17	1.9 x 10^6	6.27
Faba bean	6	5.8	1.0 x 10^6	5.97	1.2 x 10^6	6.05
Onion	10	12	4.9 x 10^6	6.68	5.7 x 10^6	6.75
Wheat	15.1	19.5	4.7 x 10^5	5.67	5.5 x 10^5	5.73
L.S.D. 0.05	**4.81**	**3.22**	**-**	**0.33**	**-**	**0.24**

Table 4: Chemical and biological analyses in rhizosphere of cotton roots after 45 days from cotton sowing.

On the other hand, P may react strongly with calcium (Ca) in alkaline soils and its solubility was restricted as a result of increasing soil pH above normal range in the two growing seasons (Table 1). Cotton plant takes up only negatively charged primary and secondary orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-}) as nutrient. Thus, it may be possible that PGPR secreted some low molecular mass organic acids such as indole acetic acid (IAA) to chelate mineral ions for bring P into soil solution. Consequently, it is likely that the acidification of PGPR cells and their surrounding leads to the release of P-ions by H^+ substitution for Ca^{2+} [52], and thereby Egyptian clover or faba bean residues contained more P and have lower C/P ratios due to its greater capacity to utilize soil P. So, it is expected that N (released from N_2 fixation) and P were available because of soil pH was reduced due to proton released from roots of the legumes. Consequently, organic P mineralization contributed to the available P pool that mineralized by PGPR, especially there was association between PGPR and plant roots in P nutrition [53]. It is known that legume crop increased the mobilization of P from sparingly soil P compounds [54].

The soil solution must be replenished with K from other sources in the soil and that replenishment may come primarily from readily available, "exchangeable" K. It seems that faba bean as seed crop may be exhausted soil K more than Egyptian clover as forage crop especially dry plant residues of faba bean shoot had concentration of K more than Egyptian clover shoot as mentioned by Tang and Yu [55]. It is known that clay and organic matter act as a buffer, absorbing and releasing mineral ions. Egyptian clover or faba bean residues and living PGPR biomass may be formed organic matter that is important to K fertility with regarded to soil pH that affected the rate of residues decomposition. According to Beegle and Durst [56], organic matter provides many negative charged sites for holding exchangeable soil K. This biological situation facilitated released K into the soil solution in rhizosphere of cotton roots, especially Askegaard and Eriksen [57] reported that there was a residual benefit of the legumes on the growth of the subsequent crop through reducing K leaching.

With respect to ferulic acid, its content was decreased in rhizosphere of cotton roots by cutting of Egyptian clover or harvesting of faba bean compared with wheat+cotton pattern in the two growing seasons (Table 4). It seems that low concentration of ferulic acid in rhizosphere of cotton roots played a major role in under-ground interactions to maintain efficiency of photosynthetic process of cotton plant which reflected positively on the yield attributes. It is known that clover had 2 to 10 times lower concentrations of ferulic acid than various grasses [58] and the lowest content of this acid was found in faba bean among sixteen beans [59]. These results reveal that the legume component Egyptian clover or faba bean improved soil nutrient cycling to the subsequent or intercropped cotton plants, respectively, which reflected positively on boll development.

With respect to onion+cotton pattern, onion is a high-value crop with a shallow root system that is irrigated frequently and fertilized with high N rates to maximize yield. Also, the shallow root system of onion is an important consideration for efficient management of mobile nutrients such as nitrate-N and sulfate-S. Bulbs may be secreted some sulfur (S) compounds in the experimental soil which oxidized by soil *Bacillus* sp. to sulfate (SO_4^{2-}) that reduced soil pH and thereby increased soil N availability. Soil N has its greatest solubility between soil pH 4 and soil pH 8. Above or below that range, its solubility is seriously restricted [60].

According to Shanmugham [61], growing cotton with onion absorbed more P and produced more dry matter and seed cotton yield than that of sole cotton. P is taken up as H_2PO_4 ion by the crop from the soil solution. Therefore, onion could be secreted some S compounds in the rhizosphere of intercropped cotton which enhanced growth of *Bacillus* sp. that produced phytohormones such as IAA [62] and resulted in an increase in P uptake by cotton. In this concern, Narula et al. [63] indicated that *Bacillus* sp. increased cotton yield. So, it is likely that onion+cotton pattern increased cotton root growth for efficient uptake of the other soil nutrients compared with those of wheat+cotton pattern in the two growing seasons.

Also, soil K availability was increased in rhizosphere of intercropped cotton during the early growth stage of cotton compared with the other winter copping systems. Obviously, onion had positive effects on soil K availability that could be maintained moderate relationship between sources and sink capacity of cotton plant. K plays a vital role where promotes photosynthetic process and consequently more dry matter accumulation in the plant [64] and thereby K deficiency restricted fruit production to a greater extent than vegetative growth [65].

Although content of ferulic acid was found in rhizosphere of intercropped cotton with onion came in the second rank after that of intercropped cotton with wheat but might have restricted root growth and development of cotton with an unclear effect. However, *Bacillus* sp. may be reduced relatively ferulic acid effects of onion on cotton growth by utilized this acid as sole carbon (C) source [66]. Accordingly, this negative effect seems to be depending on concentration of ferulic acid in the rhizosphere of cotton roots and *Bacillus* sp. activity that play an important role in plant protection and growth promotion [67] by induced chemical changes in plants [68]. The highest onion yield was observed by *Bacillus* sp. activity [69]. Accordingly, it is expected that cotton growth and development will be improved by absorbing more soil nutrients which affected positively cotton yield attributes.

With regard to wheat+cotton pattern, growing cotton with wheat during reproductive stage of the cereal component for two months increased approximately inter-specific competition between the two species for absorbing soil N during this period. After wheat harvest, it is expected that wheat residues decomposition probably had higher C to N ratio and immobilized more soil N for the intercropped cotton. Optimal amount of P and K in the soil cannot be utilized efficiently if N is deficient in plant where N mediates the utilization of P, K and other elements in plants [70]. Also, the highest concentration of ferulic acid in rhizosphere of intercropped cotton roots with wheat may be inhibited enzymatic oxidation of indole acetic acid (IAA) which affected negatively cell elongation and division, and thereby subsequent plant growth and development [71]. Thus, once integrated into the soil, phenolics can control nutrient cycling [72] that inhibited significantly the growth and root activity of cotton seedlings [73]. Accordingly, it is likely that intercropped cotton plants with wheat suffered from soil nutrient deficiency especially in the early growth stage which reflected negatively on some physiological functions. These findings imply that wheat+cotton pattern had growth inhibiting on rhizosphere of cotton which reflected negatively on seed cotton yield attributes.

Summer crop interference effects on seed cotton yield and yield attributes

Data in Table 5 show that the summer cropping systems had significant effects on intercepted light intensity within cotton plants, plant height, nodal position of the first sympodium, numbers of monopodia and sympodia plant^{-1}, number of open bolls plant^{-1}, seed cotton yield plant^{-1}, boll weight, 100-seed weight, seed cotton and lint yields ha^{-1} in the two growing seasons meanwhile lint percentage was not affected. Sole cotton and cotton+cowpea pattern recorded higher intercepted light intensity within cotton plants, number of sympodia plant^{-1}, number of open bolls plant^{-1}, seed cotton yield plant^{-1}, boll weight, seed index, seed cotton and lint yields ha^{-1} than those of cotton +sesame pattern in the two growing seasons without any significant differences between them.

Cotton+sesame pattern recorded the highest values of plant height, nodal position of the first sympodium, number of monopodia plant^{-1} in the two seasons compared with the others. Cotton+cowpea pattern achieved higher intercepted light intensity within cotton plants, number of sympodia plant^{-1}, number of open bolls plant^{-1}, seed cotton yield plant^{-1}, boll weight, 100-seed weight, seed cotton and lint yields ha^{-1} than those of cotton+sesame pattern in the two growing seasons (Table 5).

Conversely, cotton+sesame pattern decreased significantly intercepted light intensity within cotton plants, number of sympodia plant^{-1}, number of open bolls plant^{-1}, seed cotton yield plant^{-1}, boll weight, 100-seed weight, seed cotton and lint yields ha^{-1} than those of cotton+cowpea pattern in the two growing seasons (Table 5). These results could be attributed to cropping interference effects of above and under-ground conditions. These results confirmed by Vaiyapuri et al. [74] who indicated that cowpea did not affect the seed cotton yield, but intercropping sesame with cotton resulted in significant reduction in seed cotton yield.

Above-ground conditions: The positive competitive effect of cotton +cowpea pattern could be due to this cropping system decreased inter-specific competition between the intercrops for above-ground conditions especially light intensity (Table 5). Cotton+cowpea pattern increased light intensity by 45.23 % in the first season and 34.57 % in the second season within cotton canopy compared with those of cotton +sesame pattern. Cutting cowpea plants at 45 and 75 days from cowpea sowing led to increase in light penetration within cotton canopy which reflected positively on cotton above ground biomass during boll formation and maturation. These results indicate that there was less inter-specific competition between the two species, especially cotton plants were able to use adequate light and had less competition for growth factors [75].

From the other point, cotton+sesame pattern decreased light intensity by 32.11 % in the first season and 26.30 % in the second season within cotton plants compared with those of sole cotton. These results could be due to shading effect of sesame plants increased inter-specific competition between the intercrops for above-ground conditions especially light intensity which reflected negatively on number of open bolls plant^{-1} and boll weight. The results are in the same context with Attia and Seif El-Nasr [76] and Khan et al. [77] who found that drastic reduction of cotton plants in cotton+sesame pattern was due to fast growth of sesame at earlier growth stage, which suppressed the growth of companion cotton crop.

Under-ground conditions: The positive allelopathic effect of cotton +cowpea pattern may be attributed to increased inter-specific competition between them for soil N that reflected positively on better nodulation of cowpea and thereby more soil N available for cotton roots. No doubt that cowpea plants absorbing less soil N than cotton plants [78].

These results are in accordance with Rusinamhodzi [79] who found that biological N fixation in cowpea is positively affected by the companion cotton crop in intercropping; some of the N fixed in the intercrop may be transferred from cowpea to cotton crop during the season. On the other hand, deep roots of sesame may be included some allelochemicals that had a negative effect on competitive ability between the two species for soil nutrients.

It is known that sesame is deep rooted which lead to scavenge for fertility below most crops roots zones [80]. The inhibitory effect of cotton+sesame pattern might be due to the higher competitive ability or allelopathic potential of sesame plants [81].

Summer Cropping Systems	Characters											
	Intercepted Light Intensity at Middle of the Plant (%)	Plant Height (cm)	Nodal Position of the First Sympodium	Monopodia Plant^{-1} (no.)	Sympodia Plant^{-1} (no.)	Open Bolls Plant^{-1} (no.)	Seed Cotton Yield Plant^{-1} (g)	Boll Weight (g)	100-Seed Weight (g)	Lint (%)	Seed Cotton Yield ha^{-1} (t)	Lint Cotton Yield ha^{-1} (t)
First Season												
Sole cotton	13.45	122.55	7.83	1.60	17.00	14.40	33.53	2.41	8.43	41.53	2.87	1.19
Cotton+cowpea	13.26	124.03	7.90	1.62	16.68	14.57	34.02	2.43	8.37	41.33	2.74	1.13
Cotton+sesame	9.13	135.86	8.10	1.77	15.87	13.75	32.59	2.26	8.24	41.51	2.53	1.05
L.S.D. 0.05	**0.65**	**2.84**	**0.19**	**0.08**	**0.79**	**0.48**	**0.94**	**0.10**	**0.06**	**N.S.**	**0.22**	**0.09**
Second Season												
Sole cotton	14.56	120.60	8.10	0.92	14.92	14.11	31.25	2.43	9.49	42.28	3.32	1.40
Cotton + cowpea	14.44	120.81	8.09	0.95	14.88	13.99	30.63	2.39	9.41	42.27	3.21	1.35
Cotton + sesame	10.73	135.00	8.59	1.04	14.24	13.66	29.59	2.2	9.22	42.14	3.00	1.26
L.S.D. 0.05	**0.61**	**3.17**	**0.27**	**0.07**	**0.36**	**0.3**	**0.93**	**0.05**	**0.14**	**N.S.**	**0.11**	**0.05**

Table 5: Effect of summer crop interference on seed cotton yield and yield attributes in the first and second seasons.

The interaction between winter and summer crop interference on seed cotton yield and yield attributes

Data in Table 6 show that the interaction between winter and summer cropping systems had significant effects on seed cotton yield plant^{-1} and lint percentage in the first season, boll weight and 100-seed weight in the second season, mean while the other studied traits were not affected in the two growing seasons. Cotton+cowpea pattern that preceded by Egyptian clover recorded higher seed cotton yield plant^{-1}, boll weight, seed index and lint percentage than those of the other cropping systems. On the other hand, the cropping system (wheat +cotton/cotton+sesame) gave the lowest values of seed cotton yield plant^{-1}, boll weight, 100-seed weight and lint percentage. These results could be attributed to Egyptian clover/cotton interacted positively with intercropping cowpea with cotton to give higher seed cotton yield plant^{-1}, boll weight, 100-seed weight and lint percentage. In other words, cowpea furnished wet environment to maintain K uptake continuous within different tissues of cotton plants that resultant from residues of Egyptian clover where uptake of K in cotton plant slow down beyond 120 days due to moisture stress in the soil [82]. They added that K resulted in significantly higher seed cotton yield. The inadequate biomass production was a major factor limiting yield formation of intercropped cotton [46]. These data reveal that there was effect of winter cropping system × summer cropping system on seed cotton yield plant^{-1} and lint percentage in the first season, as well as, boll weight and seed index in the second one.

Interaction	Characters	First Season		Second Season	
		Seed Cotton Yield Plant^{-1} (g)	Lint (%)	Boll Weight (g)	100-Seed Weight (g)
Egyptian clover	**Sole cotton**	34.13	42.26	2.66	9.86
	Cotton + cowpea	37.52	43.14	2.59	9.74
	Cotton + sesame	34.98	42.21	2.29	9.58
Faba bean	**Sole cotton**	34.52	42.01	2.45	9.43
	Cotton + cowpea	34.10	41.8	2.44	9.40
	Cotton + sesame	32.57	42.67	2.18	9.17
Onion	**Sole cotton**	33.50	41.44	2.39	9.40
	Cotton + cowpea	32.56	40.3	2.33	9.35
	Cotton + sesame	31.30	40.93	2.19	9.13

Wheat	**Sole cotton**	31.96	40.43	2.24	9.28
	Cotton + cowpea	31.92	40.09	2.21	9.17
	Cotton + sesame	31.50	40.24	2.15	9.00
L.S.D. 0.05		**2.06**	**0.44**	**0.13**	**0.28**

Table 6: Effect of the interaction between winter and summer crop interference on seed cotton yield and yield attributes in the two growing seasons.

Winter crop interference effects on cotton fiber quality

In Egypt, expanding the area planted with short and medium staple cotton and reducing the area planted with extra-long staple cotton is a demand that the spinning and textile industry has made for years, the industry relies on short and medium staple cotton to produce the type of yarn required for producing some of the more popular fabrics [83].

Upper half mean, uniformity index, fiber strength, fiber elongation, micronaire reading and color-reflectance were affected significantly by winter cropping systems (Table 7). Egyptian clover/cotton was superior to all relay intercropping patterns for upper half mean, uniformity index and fiber elongation meanwhile the highest fiber strength and color-reflectance, as well as, the lowest micronaire were obtained by wheat+cotton pattern in the two-growing season. These results indicate that Egyptian clover/cotton pattern had good fiber quality compared with the other cropping systems. It is known that fiber length is directly related to yarn fineness, strength, and spinning efficiency [84]. Accordingly, it may be possible that cotton with a low uniformity index is likely to have a high percentage of short fibers. Such cotton may be difficult to process and is likely to produce low-quality yarn. Onion+cotton pattern produced high fiber quality (fiber strength and color-reflectance) compared with the other cropping systems. Fine cottons tend to have greater tensile strength than the short and coarse cottons. With respect to relay intercropping cotton with faba bean or wheat, cotton fiber quality was decreased by residues of faba bean or wheat and produced short cotton fibers. It is known that the importance of short-fiber content in determining fiber-processing success, yarn properties and fabric performance led to reduce the cost of textile processing and to increase the value of the raw fiber [85].

Above-ground conditions: The positive effect of Egyptian clover/cotton pattern on cotton fiber quality could be due to this cropping system furnished better above-ground conditions especially light intensity and daytime temperatures before boll formation compared with wheat+cotton pattern. Although different fiber quality properties may be established at earlier stages of fiber development in all the cropping systems, but cotton plant response to nutrient availability might be depended on the availability of other required resources during flowering and boll formation stage.

Winter Cropping Systems	Characters					
	Fiber Length Parameters		Fiber Strength (g/tex)	Fiber Elongation (%)	Micronaire Reading	Color-Reflectance RD %
	Upper Half Mean	Uniformity Index (%)				
First Season						
Egyptian clover	32.4	87.31	42.57	9.65	3.86	75.12
Faba bean	30.98	86.46	42.07	9.44	3.91	74.88
Onion	31.57	86.9	43.02	9.57	3.79	75.35
Wheat	30.63	85.8	41.7	9.31	3.95	74.68
L.S.D. 0.05	**0.2**	**0.15**	**0.08**	**0.04**	**0.08**	**0.14**
Second Season						
Egyptian clover	34.24	88.55	43.61	10.02	3.96	74.94
Faba bean	33.44	87.36	43.06	9.77	4.00	74.74
Onion	33.96	88.08	44.2	9.89	3.91	75.16
Wheat	32.98	86.98	42.52	9.63	4.03	74.56
L.S.D. 0.05	**0.27**	**0.15**	**0.14**	**0.04**	**0.08**	**0.15**

Table 7: Effect of winter crop interference on cotton fiber quality in the first and second seasons.

Therefore, the advantage of Egyptian clover/cotton pattern could be attributed to the last date of Egyptian clover cutting furnished available normal climatic resources for cotton fiber growth compared with the relay intercropping cotton with faba bean or wheat. The light environment surrounding plants affected seedling growth [86]. Moreover, the minimum, optimum, and maximum temperatures for cotton vary depending on growth and developmental processes [87]. These results reveal that Egyptian clover/cotton pattern produced good fiber quality for high upper half mean, uniformity index and fiber elongation compared with the other cropping systems.

Clearly, growing cotton after Egyptian clover received relatively lower solar radiation than those of onion+cotton pattern which reflected on dry matter accumulation of cotton during fiber growth and development. It is expected that canopy structure of cotton plant after Egyptian clover was relatively greater than that of onion+cotton pattern as a result of Egyptian clover residues. In other words, growing cotton plants after Egyptian clover may be received relatively lower solar radiation and higher warmer temperature than those of onion +cotton pattern. In this concern, Pettigrew et al. [88] showed that reduced photosynthetic rates and the modulation of other metabolic factors, in association with lower light intensities, may result in lower micronaire and fiber strength which explained lower fineness and strength for cotton fibers that followed Egyptian clover.

Conversely, higher cotton fiber length (upper half mean, uniformity index and fiber elongation) after Egyptian clover cutting may be due to this copping system furnished relatively warmer night temperature environment that accelerated fiber growth and development compared with onion+cotton pattern. Fiber length (upper-half mean length) was correlated negatively with the difference between maximum and minimum temperature [89]. Fibers grown at 15°C took 3 to 5 d longer to reach 2 mm in length than did control fibers grown at 24°C [90].

Under-ground conditions: Upper half mean, uniformity index and fiber elongation were enhanced as a result of soil N, P and K availabilities after Egyptian clover cutting, faba bean harvest or onion uprooting compared with those after wheat harvest in the two growing seasons (Table 4). The results could be attributed to soil N availability was sufficient to maintain good fiber quality. Soil N availability may be promoted some proteins synthesis such as IAA before boll maturing. According to Gialvalis and Seagull [91], external application of IAA promoted fiber initiation. On the other hand, cotton fiber primary wall contains semi-crystalline cellulose fibrils, which are surrounded by a matrix composed mainly of other polysaccharides including xyloglucan and pectin [92]. The elongating fiber wall must compromise strength and flexibility. Thus, IAA also accelerated entry into the transition phase and the onset of high-rate cellulose synthesis [93]. Moreover, soil N availability maintained good deposition of cellulose layers. Furthermore, N promoted fiber maturity [94]. Accordingly, it is expected that there was an increase in amount of assimilated proteins to carbohydrate available for mature bolls which affected positively fiber initiation, primary and secondary elongation, as well as, maturity.

However, the advantage of onion+cotton pattern probably due to some S compounds, it is expected that bulbs secreted some S compounds which increased soil N and Ca availabilities [60] to enhance some proteins such as Ca dependent protein kinases (GhCDPK1 protein) that is responsible for cotton fiber elongation [95]. It is important to mention that GhCDPK1 protein is localized in the plasma membrane of onion epidermal cells during transient transformation assays [96]. Therefore, it is essential to keep the two companion nutrients (N and S) in balance with each other and to meet adequately balanced supply of both nutrients to plant [97].

With regard to soil P content, residues of the legume crop (Egyptian clover or faba bean) and onion increased availability of soil P (Table 4). These results probably due to soil P availability promoted fiber length [98] through cell division and energy transfer which resulted in early boll development and thereby reflected positively on hastening of maturity [99]. Similar results were observed by Sawan et al. [100] who indicated that P response and availability leading to initiation and development of greater number of fibers per seed.

With respect to soil K content, upper half mean, uniformity index, fiber strength, fiber elongation and color-reflectance were increased as a result of soil K availability of Egyptian clover/cotton, wheat+cotton or onion+cotton pattern compared with those of wheat+cotton pattern in the two growing seasons but the reverse was true for micronaire reading (Table 4). These results could be attributed to soil K availability increased fiber elongation and micronaire by maintaining sufficient water pressure within the boll [99] and cell osmotic pressure to delay fiber cellulose accumulation and carbohydrate acquisition.

With regard to ferulic acid content, upper half mean, uniformity index, fiber length and fiber elongation were increased as a result of decreasing ferulic acid after Egyptian clover cutting, faba bean harvest or onion uprooting compared with those after wheat harvest, but the reverse was true for micronaire reading in the two growing seasons (Table 4). It is known that low content of ferulic acid in rhizosphere of cotton roots did not inhibit major nutrient cycling which reflected positively on enzymatic oxidation of IAA and thereby acceptable rate cellulose synthesis in mature bolls. The phenolic compounds and lignin content are believed to play an important role in cotton fiber development and quality [101] where ferulic acid is part of lignin and flavonoid biosynthetic pathways [102].

With respect to population density of *Bacillus* sp., it is known that exogenous IAA increased the proportion of epidermal cells that differentiated as fibers [90] where *Bacillus* sp. improved production of substances with IAA [22]. IAA is required for primary elongation in cotton fiber development [103]. Consequently, these results suggest that Egyptian clover, faba bean and onion residues improved cotton fiber quality compared with residues of wheat crop.

Consequently, it is likely that wheat+cotton pattern led to imbalance in shoot to root growth of cotton during growth and development stages. Accordingly, it is expected that wheat+cotton pattern produced more carbohydrates than necessary to support cotton development and thereby increase in the amount of carbohydrate available to mature bolls. High content of ferulic acid in rhizosphere of cotton roots could be defected in complementary use of major soil nutrients and *Bacillus* sp which reflected negatively on fiber development and quality. It is known that ferulic acid inhibited enzymatic oxidation of IAA that reflected negatively on cell elongation and division [104] where it is involved in cell wall elongation arrest [105]. These results could be attributed to ferulic acid accelerated cell elongation and division and thereby subsequent the primary and secondary cell wall in a shorter time than the normal growth.

On the other hand, reflectance degree was lowest with the most severe N treatment; this means fibers produced by the most N-deficient plants appeared less bright than fibers produced by N-sufficient plants [106]. N and K stress during this phase of fiber development was shown to have detrimental effects on cotton fiber quality [107]. Also, Guo et al. [108] indicated that soil P deficiency inhibited completely fiber elongation.

Summer crop interference effects on cotton fiber quality

Upper half mean, uniformity index, fiber strength, fiber elongation, micronaire reading and color-reflectance were affected significantly by summer cropping systems (Table 8). Cotton+cowpea pattern had the highest values of upper half mean, uniformity index, fiber strength, fiber elongation and color-reflectance compared with the other treatments in the two growing seasons. On contrary, the lowest micronaire was observed in cotton+cowpea pattern compared with the others in the two growing seasons.

Summer Cropping Systems	Characters					
	Fiber Length Parameters		Fiber Strength (g/tex)	Fiber Elongation (%)	Micronaire Reading	Color-Reflectance RD%
	Upper Half Mean	Uniformity Index (%)				
First season						
Sole cotton	31.60	86.81	42.49	9.51	3.88	75.07
Cotton+cowpea	31.77	87.00	42.64	9.55	3.80	75.25
Cotton+sesame	30.82	86.03	41.90	9.41	3.96	74.71
L.S.D. 0.05	0.13	0.13	0.11	0.02	0.07	0.16
Second season						
Sole cotton	33.85	87.93	43.5	9.84	3.96	74.85
Cotton+cowpea	34.05	88.02	43.67	9.88	3.90	75.05
Cotton+sesame	33.07	87.29	42.87	9.76	4.07	74.65
L.S.D. 0.05	0.19	0.08	0.08	0.02	0.05	0.11

Table 8: Effect of summer crop interference on cotton fiber quality in the first and second seasons.

Above-ground conditions: Cotton+cowpea pattern caused significant increments in cotton fiber quality compared with those of sole cotton (Table 8). The positive competitive effect of cotton+cowpea pattern on cotton fiber quality could be attributed to increase in light penetration within cotton plants during boll formation especially low irradiance decreased fiber strength [109]. Moreover, cutting cowpea plants at 45 and 75 days from cowpea sowing led to increase in solar radiation penetration between intercropped cotton plants than sole cotton. Consequently, it is expected that this biological situation did not reduce leaf area of cotton plant which permitted more transpiration and photosynthesis rate of intercropped cotton. Accordingly, starch content will be increased in the leaves and transferred to the fiber during boll growth and development.

The negative competitive effect of cotton+sesame pattern on cotton fiber quality could be due to this pattern decreased light penetration within cotton canopy which reflected negatively on the studied traits. It seems that plant density of sesame (50% of the recommended plant density unit area^{-1}) had adverse effects of shading on cotton plant and affected negatively dry matter accumulation in cotton fiber during boll formation. It is known that long-term shading decreased the strength of cotton fiber [110] and the fiber length of cotton [111] as a result of decreasing sucrose and starch contents of subtending leaves [112].

Cotton+sesame pattern affected negatively light penetration within cotton canopy which may be enhanced endogenous ABA of cotton; fiber elongation was negatively correlated with increasing ABA concentration [113]. It is known that increase in ABA content is positively signal for the beginning of fiber wall thickening [96]. These results are in accordance with those observed by Einhorn and Arrington [114] who revealed that ABA indirectly reduced carbon assimilation via stomatal closure, but may also induce abscission directly through hormone action.

Under-ground conditions: The positive allelopathic effect of cotton +cowpea pattern had on cotton fiber quality could be due cowpea secreted some allelochemicals in rhizosphere of cotton roots where ethylene concentration in different tissues of cotton plant. According to Burg [115], ethylene is produced by roots and it is an endogenous plant hormone that may act as a modulator of the action of other hormones in growth and development [116]. Consequently, ethylene promoted fiber length [96] as a result of enhancing ethylene concentration through plant growth regulators, salicylic acid, gibberellic acid and ethylene, are considered to be allelochemicals [117]. Cotton+cowpea pattern may be affected negatively light penetration within cowpea canopy that inhibited elongation of cowpea epicotyls by endogenous ethylene [118]. The increase in ethylene may be absorbed by intercropped cotton roots and translocated to different tissues of cotton plant through adjacent cowpea plants by making the surrounding environment with cotton moister. Planting cowpea between cotton plants improved soil cover and ultimately reduced moisture loss from the soil [81]. Consequently, these results reveal that cowpea plants furnished better under-ground conditions for soil nutrients availability which reflected positively on enlargement, filling and maturation of boll development. The negative allelopathic effect of cotton+sesame pattern on cotton fiber quality may be due to deep roots of sesame secreted some allelochemicals in the rhizosphere of cotton plants which diminished source and sink capacity and thereby delay in reproductive growth of cotton. Fiber quality is mainly associated with nutritional and environmental conditions during the boll development [112].

The interaction between winter and summer cropping systems

The interaction between winter and summer cropping systems had no significant effects on upper half mean, uniformity index, fiber strength, fiber elongation, micronaire reading and color-reflectance in the two growing seasons. These data show that each of these two factors act independently on cotton fiber quality meaning that winter cropping systems responded similarly to summer cropping systems for these traits.

Competitive relationships

To assess the benefits of growing two or more crops together, or intercropping, is to measure productivity using the LER and ATER. LER compares the yields from growing two or more crops together with yields from growing the same crops in sole culture. ATER provides more realistic comparison of the yield advantage of intercropping over sole cropping in terms of variation in time taken by the component crops of different intercropping systems. Generally, the cropping system Egyptian clover/cotton+cowpea achieved the highest LER and ATER followed by the cropping system onion+cotton/cotton +cowpea compared with the other cropping systems in both seasons (Table 9). Advantage of the cropping system (Egyptian clover/cotton +cowpea) could be due to relative yield of cotton was high as a result of no-overlapping between the Egyptian clover and cotton for basic growth resources, then this advantage was continued by intercropping cowpea with cotton in the summer season. Also, onion+cotton pattern played a major role in increasing seed cotton yield plant^{-1} through positive competitive and allelopathic effects of onion and these effects were improved by intercropping cowpea with cotton in the summer season. With respect to the cropping system (wheat+cotton/cotton +sesame), the inhibitory effect of this system could be due to integration between negative interference effects of wheat and sesame on seed cotton yield plant^{-1} for above and under-ground conditions during the year. These results are similar to those obtained by Khan et al. [77] who revealed that intercropping cowpea with cotton achieved higher LER than intercropping sesame with cotton, especially negative allelopathic effects of intercropping sesame with cotton were observed by Shah et al. [81].

Winter Cropping System	Summer Cropping System	Yield ha^{-1} (t)			Relative Yield			LER	ATER
		Winter Crops	Cotton	Summer Crops	Winter Crops	Cotton	Summer Crops		
First Season									
Egyptian clover	**Cotton+cowpea**	27.93	3.03	28.84	0.63	0.94	0.57	2.14	0.75
	Cotton+sesame	27.93	2.93	0.658	0.63	0.90	0.56	2.09	0.72
Mean		**27.93**	**2.98**	**---**	**0.63**	**0.92**	**0.56**	**2.11**	**0.73**
Faba bean	**Cotton+cowpea**	1.90	2.91	27.88	0.57	0.90	0.55	2.02	0.69
	Cotton+sesame	1.90	2.80	0.642	0.57	0.86	0.53	1.96	0.66
Mean		**1.90**	**2.85**	**---**	**0.57**	**0.88**	**0.55**	**1.99**	**0.67**
Onion	**Cotton+cowpea**	31.68	2.69	26.97	0.73	0.83	0.53	2.09	0.73
	Cotton+sesame	31.68	2.26	0.608	0.73	0.70	0.52	1.95	0.66
Mean		**31.68**	**2.47**	**---**	**0.73**	**0.76**	**0.52**	**2.02**	**0.69**
Wheat	**Cotton+cowpea**	5.74	2.34	26.38	0.70	0.72	0.52	1.94	0.67
	Cotton+sesame	5.74	2.15	0.604	0.70	0.66	0.52	1.88	0.64
Mean		**5.74**	**2.24**	**---**	**0.70**	**0.69**	**0.52**	**1.91**	**0.65**
Second season									
Egyptian clover	**Cotton+cowpea**	31.52	3.70	27.86	0.66	0.97	0.56	2.19	0.78
	Cotton+sesame	31.52	3.47	0.623	0.66	0.91	0.55	2.12	0.73
Mean		**31.52**	**3.58**	**---**	**0.66**	**0.94**	**0.55**	**2.15**	**0.75**
Faba bean	**Cotton+cowpea**	2.05	3.18	27.09	0.60	0.84	0.54	1.98	0.68
	Cotton+sesame	2.05	2.96	0.614	0.60	0.78	0.54	1.92	0.65
Mean		**2.05**	**3.07**	**---**	**0.60**	**0.81**	**0.54**	**1.95**	**0.66**

Onion	**Cotton+cowpea**	34.46	3.06	26.52	0.73	0.80	0.53	2.06	0.72
	Cotton+sesame	34.46	2.80	0.599	0.73	0.74	0.53	2.00	0.68
Mean		**34.46**	**2.93**	**---**	**0.73**	**0.77**	**0.53**	**2.03**	**0.70**
Wheat	**Cotton+cowpea**	5.65	2.92	26.08	0.67	0.77	0.52	1.96	0.68
	Cotton+sesame	5.65	2.78	0.593	0.67	0.73	0.52	1.92	0.65
Mean		**5.65**	**2.85**	**---**	**0.67**	**0.75**	**0.52**	**1.94**	**0.66**

Table 9: Competitive relationships of winter and summer cropping systems, as well as, their interaction in the two growing seasons.

Egyptian clover 5 cuts: 44.35 and 47.21 t ha^{-1}, sole faba bean: 3.32 and 3.39 t ha^{-1}, sole onion: 43.15 and 46.95 t ha^{-1}, sole wheat: 8.20 and 8.33 t ha^{-1}, sole cotton: 3.22 and 3.78 t ha^{-1}, sole cowpea: 50.4 and 49.69 t ha^{-1}, sole sesame: 1.15 and 1.12 t ha^{-1} in the first and second seasons, respectively.

Financial evaluation

The financial return of cotton under different cropping systems compared with sequential double cropping system (Egyptian clover/cotton) is shown in Table 10. Total return of cotton varied between treatments from US$ 1654 to 2979 ha^{-1} as compared with sequential double cropping system (US$ 1780 ha^{-1}) in the first season. Also, total return of cotton varied between treatments from US$ 1820 to 3265 ha^{-1} compared with sequential double cropping system (US$ 2001 ha^{-1}) in the second one. Net return of cotton varied between treatments from US$ 486 to 1910 ha^{-1} as compared with sequential double cropping system (US$ 689 ha^{-1}) in the first season. Also, net return of cotton varied between treatments from US$ 652 to 2196 ha^{-1} compared with sequential double cropping system (US$ 910 ha^{-1}) in the second one. Net return of the cropping system (onion+cotton/cotton+cowpea) recorded the highest net return in comparison with the other cropping systems in the two growing seasons. These results reveal that the cropping system (onion+cotton/cotton+cowpea) is more profitable to Egyptian farmers than conventional double cropping system (Egyptian clover/cotton). These results may be due to onion had higher yielding ability compared to the other crops in the cropping systems. These findings are parallel with those obtained by Basu [119] who showed that intercropping cotton with legumes or non-legumes have been found to be profitable in the cotton zones. Also, Metwally et al. [41] indicated that net returns from cropping systems depend on the total production of crop components of cotton, faba bean, wheat and Egyptian clover, as well as, variable and fixed costs.

Winter Cropping Systems	Summer Cropping Systems	Financial Return (US$ ha^{-1})				
		Winter Crops (US $ ha^{-1})	Cotton (US$ ha^{-1})	Summer Crops (US $ ha^{-1})	Total Return (US$ ha^{-1} year^{-1})	Net Return (US$ ha^{-1} year^{-1})
First Season						
Egyptian clover	**Sole cotton**	508	1272	---	1780	689
	Cotton+cowpea	508	1197	288	1993	862
	Cotton+sesame	508	1157	405	2070	866
Mean		**508**	**1208**	**346**	**1947**	**805**
Faba bean	**Sole cotton**	493	1161	---	1654	486
	Cotton+cowpea	493	1150	278	1921	713
	Cotton+sesame	493	1106	395	1994	713
Mean		**493**	**1139**	**336**	**1856**	**637**
Onion	**Sole cotton**	1647	1138	---	2785	1756
	Cotton+cowpea	1647	1063	269	2979	1910
	Cotton+sesame	1647	893	374	2914	1772
Mean		**1647**	**1031**	**321**	**2892**	**1812**
Wheat	**Sole cotton**	789	964	---	1753	585

	Cotton+cowpea	789	924	263	1976	778
	Cotton+sesame	789	850	372	2011	740
Mean		**789**	**912**	**317**	**1913**	**701**
Second Season						
Egyptian clover	**Sole cotton**	508	1493	---	2001	910
	Cotton+cowpea	508	1462	278	2248	1117
	Cotton+sesame	508	1371	383	2262	1058
Mean		**508**	**1442**	**330**	**2170**	**1028**
Faba bean	**Sole cotton**	532	1288	---	1820	652
	Cotton+cowpea	532	1256	270	2058	850
	Cotton+sesame	532	1169	378	2079	798
Mean		**532**	**1237**	**324**	**1985**	**766**
Onion	**Sole cotton**	1791	1264	---	3055	2026
	Cotton+cowpea	1791	1209	265	3265	2196
	Cotton+sesame	1791	1106	368	3265	2124
Mean		**1791**	**1193**	**316**	**3195**	**2115**
Wheat	**Sole cotton**	777	1213	---	1990	822
	Cotton+cowpea	777	1153	260	2190	992
	Cotton+sesame	777	1098	365	2240	969
Mean		**777**	**1154**	**317**	**2143**	**927**

Table 10: Financial advantages of cotton under different cropping systems in the first and second seasons.

Prices of main products are that of 2016: US$ 395.2 ha^{-1} for ton of seed cotton, US$ 615.8 ha^{-1} for ton of sesame seeds, US$ 259.6 ha^{-1} for ton of faba bean seeds, US$ 169.3 ha^{-1} for one cut of Egyptian clover, US$ 137.6 ha^{-1} for ton of wheat grains, US$ 52.0 ha^{-1} for ton of onion and US$ 10.0 ha^{-1} for one ton of cowpea.

Conclusion

Our results reveal that onion had positive crop interference effects on cotton and this effect was improved by intercropping cowpea with cotton in the summer season and can be helpful to understand performance of cotton fiber (quantity and quality). Egyptian farmers achieved an increase in their income when growing cowpea with cotton plants that intercropped with onion. Although the cropping system (Egyptian clover/cotton+cowpea) recorded high lint cotton yield and longer fibers, but economically efficient cropping system (onion+cotton/cotton+cowpea) that produced stronger and finer fiber for the manufacture of higher quality textiles could be recommended.

References

1. FAO (1997) Plant Nematode Problems and their Control in the Near East Region. Part II: Country reports, Food and Agriculture Organization of the United Nations, Rome.
2. El-Ramady HR, El-Marsafawy SM, Lewis LN (2013) Sustainable agriculture and climate changes in Egypt. InSustainable agriculture reviews, pp: 41-95.
3. El Fawal MA, El Okkia AF, Abdel-Bary AA and El-Khishen AA (1975) Effects of Planting Date and Seeding Rate on Egyptian Cotton (Gossypium barbadense). Exp Agric 11: 215-220.
4. Kamel AS, El-Habbak KE, El-Masry MA, El-Mihi MM, Gaber EA (1991) Effect of preceding crops and planting methods on growth yield and yield components of cotton. Ann Agric Sci 29: 689-698.
5. Seif El Nasr FM, Attia Zahira M, Khalil HE, Shams SA, Kamel AS (1996) Growing long duration winter crop in cotton rotation. Ann Agric Sci 34: 501-512.
6. Abuldahab AA, Sohair ADE and Ali E (2000) Cotton growth parameters and production of Giza 75, cotton variety as affected by sowing date and nitrogen levels. J Agric Sci Mansoura Univ 25: 7367-7379.
7. Hussein SM (2005) Planting, date, pattern and fertilizers levels for cotton grown in relay intercropping with wheat. Zagazig Journal of Agricultural Research 32: 1403-1425.
8. Al-Ghazi Y, Bourot S, Arioli, T, Dennis ES, Llewellyn DJ (2009) Transcript profiling during fiber development identifies pathways in secondary metabolism and cell wall structure that may contribute to cotton fiber quality. Plant and Cell Physiology 50: 1364-1381.
9. Long RL, Bange MP, Gordon SG, Van der Sluijs MH, Naylor GR, et al. (2010) Fiber quality and textile performance of some Australian cotton genotypes. Crop Science 50: 1509-1518.

10. Bulletin of Statistical Cost Production and Net Return (2017) Winter field crops and vegetables and fruit. Agriculture Statistics and Economic Sector, Ministry of Egyptian Agriculture and Land Reclamation, Part (1); Egypt.
11. Roberts DW (1987) A dynamical systems perspective on vegetation theory. Vegetatio 69: 27-33.
12. Hobbie SE (1992) Effects of plant species on nutrient cycling. Trends in Ecology & Evolution 7: 336-339.
13. Basra AS (1999) Growth regulation of cotton fibers. Cotton Fibers: Developmental Biology, Quality Improvement and Textile Processing, pp: 47-63.
14. Wells R (2002) Stem and root carbohydrate dynamics of two cotton cultivars bred fifty years apart. Agronomy Journal 94: 876-882.
15. Cetin O, Basbag S (2010) Effects of climatic factors on cotton production in semi-arid regions—a review. Res Crop 11: 785-791.
16. Morrow MR, Krieg DR (1990) Cotton management strategies for a short growing season environment: Water-nitrogen considerations. Agronomy Journal 82: 52-56.
17. Graf E (1992) Antioxidant potential of ferulic acid. Free Radical Biology and Medicine 13: 435-448.
18. Singh BK, Millard P, Whiteley AS, Murrell JC (2004) Unravelling rhizosphere–microbial interactions: opportunities and limitations. Trends in Microbiology 12: 386-393.
19. Gui-Ying J, Jian-Guo L, Yan-Bin L (2015) Allelochemicals from cotton (Gossypium hirsutum) rhizosphere soil: Inhibitory effects on cotton seedlings. Allelopathy Journal 35: 153-162.
20. Rice EL (1992) Allelopathic effects on nitrogen cycling. In Allelopathy, pp: 31-58.
21. Reva ON, Dixelius C, Meijer J, Priest FG (2004) Taxonomic characterization and plant colonizing abilities of some bacteria related to Bacillus amyloliquefaciens and Bacillus subtilis. FEMS Microbiology Ecology 48: 249-259.
22. Idris EE, Bochow H, Ross H, Borriss R (2004) Use of Bacillus subtilis as biocontrol agent. VI. Phytohormonelike action of culture filtrates prepared from plant growth-promoting Bacillus amyloliquefaciens FZB24, FZB42, FZB45 and Bacillus subtilis FZB37. Journal of Plant Diseases and Protection, pp: 583-597.
23. Wan P, Huang Y, Tabashnik BE, Huang M, Wu K (2012) The halo effect: suppression of pink bollworm on non-Bt cotton by Bt cotton in China. PLoS ONE 7: e42004.
24. San Emeterio L, Damgaard C, Canals RM (2007) Modelling the combined effect of chemical interference and resource competition on the individual growth of two herbaceous populations. Plant and Soil 292: 95-103.
25. Toaima SE, Gadallah RA, Mohamadin ESA (2007) Effect of relay intercropping systems on yield and its components of wheat and cotton. Annals of Agricultural Science (Cairo) 52: 317-326.
26. Sherif SA, Ibrahim ST (2011) Relay Intercropping of Cotton with Wheat in Reclaimed Land. Egypt J Agron 33: 51-65.
27. Abdel-Galil AGM (2015) Maximizing nitrogen uses in cotton–wheat relay intercropping system in response to two wheat plant densities. Advances in Environmental Biology 9: 502-511.
28. Lamlom MM, Abdel-Wahab SI, Abdel-Wahab TI, Gendy EK (2015) Chemical and Biological Influences of some Preceded Winter Field Crops on Productivity of Intercropped three Maize Cultivars with Soybean.
29. Jackson ML (1958) Soil Chemical Analysis. Prentice Hall, Englwood Cliffis, New Jersy.
30. Chapman HD, Pratt PE (1961) Methods of Analysis for Soil, Plant and Water. Division Agric Sci, California Univ, U.S.A.
31. ASTM (2003) (American Society for Testing and Materials). ASTM D1348: Standard Test Methods for Moisture in Cellouse. ASTM, West Conshohocken, PA.
32. Mead R, Willey RW (1980) The concept of a "land equivalent ratio" and advantages in yields from intercropping. Exp Agric 16: 217-228.
33. Hiebsch CK (1980) Principles of Intercropping. "Effect of N fertilization and crop duration on equivalency ratios in intercrops versus monoculture comparisons". PhD Thesis. North Carolina State University, Raleigh, NC, USA.
34. Bulletin of Statistical Cost Production and Net Return (2017) Summer and Nili Field Crops and Vegetables and Fruit, Agriculture Statistics and Economic Sector, Ministry of Egyptian Agriculture and Land Reclamation, Part (2), Egypt.
35. Freed RD (1991) MSTATC Microcomputer Statistical Program. Michigan State Univ. East Lansing, Michigan, USA.
36. Gomez KA, Gomez AA (1984) Statistical Procedures for Agricultural Research. John Willey and Sons, New York.
37. Kamel AS, El-Said IO, Salem MS, El-Hawarry NA, El-Masry MA (1992) Relay intercropping of cotton with some long duration winter crops. Proc 5th Conf Agron Zagazig 2: 588-596.
38. Elayan SED, Abdalla AMA, Abdel-Gawad NSD, Faramawy WAE (2015) Effect of delaying planting date on yield, fiber and yarn quality properties in some cultivars and promising crosses of Egyptian cotton. American-Eurasian J Agric Environ Sci 15: 754-763.
39. El-Naggar HMM, El-Habbak KE, Shams SAA (1996) Effect of intercropping onion with cotton and chemical weed control on growth, yield and associated weeds in both crops. Ann Agr Sci 34: 839-857.
40. Babu R (1998) Cotton (Gossypium hirsutum) based cropping system in Ghatprabha command area of Karnataka. Indian J Agron 43: 261-263.
41. Metwally AA, Abuldahab AA, Shereif MN, Awad MM (2016) Productivity and land equivalent ratio of intercropping cotton with some winter crops in Egypt. American J Exp Agric 14: 1-15.
42. Jayakumar M, Surendran U (2017) Intercropping and balanced nutrient management for sustainable cotton production. J Plant Nut 40: 632-644.
43. Hasanean HM (2004) Precipitation variability over Mediterranean and its Linkage with El Nino Southern Oscillation (ENSO). J Meteorology 29: 289.
44. Fukai S, Trenbath BR (1993) Processes determining intercrop productivity and yields of component crops. Field Crops Res 34: 247-271.
45. Hussein A, Samira M, Haikel MA (2000) Possibility of cotton cultivation under the desert conditions in North Sinai. Egypt J Appl Sci 15: 139-150.
46. Dusserre J, Crozat Y, Warembourg FR, Dingkuhn M (2002) Effects of shading on sink capacity and yield components of cotton in controlled environments. Agronomie 22: 307-320.
47. Du X, Chen B, Meng Y, Zhao W, Zhang Y, et al. (2016) Effect of cropping system on cotton biomass accumulation and yield formation in double–cropped wheat–cotton. Int J Plant Prod 10: 29-44.
48. Collavino MM, Sansberro PA, Mroginski LA, Aguilar OM (2010) Comparison of in vitro solubilization activity of diverse phosphate-solubilizing bacteria native to acid soil and their ability to promote Phaseolus vulgaris growth. Biol Fertil Soils 46: 727-738.
49. Postgate J (1998) Nitrogen Fixation. 3rd ed. Cambridge University Press: Cambridge UK.
50. Sylvia DM, Fuhrmann JJ, Hartel PG, Zuberer DA (1999) Principles and Applications of Soil Microbiology, p: 550.
51. Jones C, Jacobsen J (2001) Nitrogen cycling, testing and fertilizer recommendations. Nutrient management module 3. Montana State Univ.
52. Mullen MD (2005) Phosphorus in soils: biological interactions. Hillel D (ed.). Encyclopedia of soils in the environment. Elsevier, Oxford, pp: 210-215.
53. Jorquera MA, Hernández MT, Rengel Z, Marschner P, Mora ML (2008) Isolation of culturable phosphobacteria with both phytate mineralization and phosphate-solubilization activity from the rhizosphere of plants grown in a volcanic soil. Biol Fertil Soils 44: 1025-1034.
54. Alamgir M, Mc Neill A, Tang CX, Marschner P (2012) Changes in soil P pools during legume residue decomposition. Soil Biol Biochem 49: 70-77.
55. Tang C, Yu O (1999) Impact of chemical composition of legume residues and initial soil pH on pH change of a soil after residue incorporation. Plant and Soil 215: 29-38.

56. Beegle DB, Durst PT (2001) Managing Potassium for Crop Production. Penn State College of Agric Sci, Pennsylvania State Univ, Univ Park, PA.
57. Askegaard M, Eriksen J (2008) Residual effect and leaching of N and K in cropping systems with clover and ryegrass catch crops on a coarse sand. Agric Ecosystems Environ 123: 99-108.
58. Eraso F, Hartley RD (1990) Monomeric and dimeric phenolic consituents of plant cell walls —possible factors influencing wall biodegradability. J Sci Food Agric 51: 163-170.
59. Yao Y, Cheng X, Wang L, Wang S, Ren G (2011) Biological potential of sixteen legumes in China. Int J Mol Sci 12: 7048-7058.
60. Vossen P (2006) Changing pH in Soil. University of California Cooperative Extension.
61. Shanmugham K (1988) Effect of onion and greengram intercrops on phosphorus release and is uptake by cotton. Current Sci 57: 1128-1130.
62. Arshad M, Frankenberger WT (1998) Plant growth regulating substances in the rhizosphere. Microbial production and functions. Adv Agron 62: 46-151.
63. Narula N, Saharan B, Kumar V, Bhatia R, Bishnoi L, et al. (2005) Impact of the use of biofertilizers on cotton (Gossypium hirsutum) crop under irrigated agro-ecosystem. Arch Agron Soil Sci 51: 69-77.
64. Marschner H (1995) Mineral Nutrition of Higher Plants. Academic Press: London.
65. Pettigrew WT, Meredith WR (1997) Dry matter production, nutrient uptake and growth of cotton as affected by potassium fertilization. J Plant Nutrition 20: 531-548.
66. Gurujeyalakshmi G, Mahadevan A (1987) Dissimilation of ferulic acid by Bacillus subtilis. Current Microbiology, 16: 69-73.
67. Berg G (2009) Plant-microbe interactions promoting plant growth and health: perspectives for controlled use of microorganisms in agriculture. Appl Microbiol Biotechnol 84: 11-18.
68. Gange AC, Eschen R, Schroeder V (2012) The soil microbial community and plant foliar defences against insects. Jason GR, Dicke M, Hartley SE (eds.). The Ecology of Plant Secondary Metabolites: From Genes to Global Processes. Cambridge Univ Press, UK, pp: 170-188.
69. Colo J, Hajnal-Jafari TI, Durić S, Stamenov D, Hamidović S (2014) Plant growth promotion rhizobacteria in onion production. Pol J Microbiol 63: 83-88.
70. Brady NC (1984) The Nature and Properties of Soil. Macmillan Publishing Co, USA.
71. Arnaldos TL, Munoz R, Ferrer MA, Calderon AA (2001) Changes in phenol content during strawberry (Fragaria x ananasa, cv. Chandler) callus culture. Physiologia Plantarum 113: 315-322.
72. Kraus TEC, Dahlgren RA, Zasoski RJ (2003) Tannins in nutrient dynamics of forest ecosystems - a review. Plant and Soil 256: 41-66.
73. Jiang GY, Liu JG, Li YB (2015) Allelochemicals from cotton (Gossypium hirsutum) rhizosphere soil: Inhibitory effects on cotton seedlings. Allelopathy J 35: 153-162.
74. Vaiyapuri K, Rajendran P, Amanullah MM, Somasundaram E (2008) Green manure intercropping in cotton-A review. Agric Rev 29: 157-166.
75. Hadejia IB (2011) Performance of cowpea (Vigna unguiculata L. Walp) varieties intercropped into maize (Zea mays) under different planting patterns. Ahmadu Bello Univ, Zaria.
76. Attia ZM, Seif El-Nasr FM (1993) Effect of intercropping sesame with cotton and sesame density on yield and yield components of both crops. Ann Agric Sci, Moshtohor 31: 1931-1940.
77. Khan MB, Akhtar M, Abdel-Khaliq A (2001) Effect of planting patterns and different intercropping systems on the productivity of cotton (Gossypium hirsutum L.) under irrigated conditions of Faisalabad. Int J Agri Biol 3: 432-435.
78. Peoples MB, Lilley DM, Brett VF, Ridley AM, Garden DL (1995) Effects of surface applications of lime and superphosphate to acid soils on the growth and N2 fixation by subterranean clover in mixed pasture swards. Soil Biol Biochem 27: 663-671.
79. Rusinamhodzi L (2006) Effects of cotton–cowpea intercropping on crop yields and soil nutrient status under Zimbabwean rain-fed conditions. Thesis of MSc degree, Depart Soil Sci Agric Engin, Fac Agric, Zimbabwe Univ.
80. Langham R, Riney J, Smith G, Wiemers T (2008) Sesame Grower Guide. Sesaco Corporation.
81. Shah AN, Iqbal J, Fahad S, Tanveer M, Yang G, et al. (2016) Allelopathic influence of sesame and green gram intercrops on cotton in a replacement series. Clean-Soil, Air, Water 45: 1-10.
82. Aladakatti YR, Hallikeri SS, Nandagavi RA, Naveen NE, Hugar AY, et al. (2011) Yield and fiber qualities of hybrid cotton (Gossypium hirsutum) as influenced by soil and foliar application of potassium. Karnataka J Agric Sci 24: 133-136.
83. Cotton Gain Annual March (2016) Egypt: Cotton and Products Annual 2016. Grain Report, USDA Foreign Agricultural Service, Global Agricultural information Network.
84. Moore JF (1996) Cotton Classification and Quality. Glade EH Jr, Meyer LA, Stults H (eds.). The cotton industry in the United States. USDA-ERS Agric Econ Rep, US Gov Print Office, Washington DC, pp: 51–57.
85. Wakelyn PJ, Adair PK, Bertoniere NR, Bragg CK, Poole HB (1998) Focus on cotton textile research: results report. Natl Cotton Counc, TN, USA.
86. Schopfer P, Plachy C (1984) Control of seed germination by abscisic acid. Plant Physiol 6: 155-160.
87. Reddy AR, Reddy KR, Hodges HF (1997) Dynamics of canopy photosynthesis in Pima cotton as influenced by growth temperatures. Indian J Exp Biol 35: 1002-1006.
88. Pettigrew WT, Heitholt JJ, Meredith WR Jr (1996) Genotypic interactions with potassium and nitrogen in cotton of varied maturity. Agron J 88: 89-93.
89. Hanson RG, Ewing EC, Ewing EC Jr (1956) Effect of environmental factors on fiber properties and yield of Deltapine cottons. Agron J 48: 546-581.
90. Thaker VS, Saroop S, Vaishnav PP, Singh YE (1989) Genotypic variations and influence of diurnal temperature on cotton fiber development. Field Crops Res 22: 1-13.
91. Gialvalis S, Seagull RW (2001) Plant hormones alter fiber initiation in unfertilized, cultured ovules of Gossypium hirsutum. J Cotton Sci 5: 252–258.
92. Singh, B, Avci U, Inwood SEE, Grimson MJ, Landgraf J, et al. (2009) A specialized outer layer of the primary cell wall joins elongating cotton fibers into tissue-like bundles. Plant Physiol 150: 684-699.
93. Singh B, Cheek HD, Haigler CH (2009) A synthetic auxin (NAA) suppresses secondary wall cellulose synthesis and enhances elongation in cultured cotton fiber. Plant Cell Rep 28: 1023-1032.
94. Zhao W, Wang Y, Zhou Z, Meng Y, et al. (2012) Effect of nitrogen rates and flowering dates on fiber quality of cotton (Gossypium hirsutum L.). Am J Exp Agric 2: 133-159.
95. Huang QS, Wang HY, Gao P, Wang GY, Xia GX (2008) Cloning and characterization of a calcium dependent protein kinase gene associated with cotton fiber development. Plant Cell Rep 27: 1869-1875.
96. Stiff MR, Haigler CH (2013) Recent Advances in Cotton Fiber development. North Carolina State University, Raleigh, NC 27695, USA, pp: 163-192.
97. Gormus O, EL-Sabagh A (2016) Effect of nitrogen and sulfur on the quality of the cotton fiber under Mediterranean conditions. J Exp Biology Agric Sci 4: 662-669.
98. Vieira DJ, Beltrao NE, Ribeiro VG (1998) Effect of nitrogen and phosphorus fertilizers on yield of herbaceous cotton in southwestern Bahia: Iyapora, BA, 1995/96. Research in Progress-Algoda-o National Research Center 77: 3.
99. Stewart WM (2005) Nutrition affects cotton yield and quality. Agri-Briefs, Agronomic News Items, no. 6, Norcross, Georgia, USA.
100. Sawan ZM, Mahmoud MH, El-Guibali AH (2008) Influence of potassium fertilization and foliar application of zinc and phosphorus on growth, yield components, yield and fiber properties of Egyptian cotton (Gossypium hirsutum L.). J Plant Ecology 1: 259-270.

101. Han LB, Li YB, Wang HY, Wu XM, Li CL, et al. (2013) The dual functions of WLIM1a in cell elongation and secondary wall formation in developing cotton fibers. Plant Cell 25: 4421-4438.
102. Reiss R, Ihssen J, Richter M, Eichhorn E, Schilling B, et al. (2013) Laccase versus laccase-like multi-copper oxidase: a comparative study of similar enzymes with diverse substrate spectra. PLoS ONE 8: e65633.
103. Clement JD (2010) Effects of exogenously applied indole-3-acetic acid (IAA) to Cotton. Doctoral Dissertation, Texas A&M Univ.
104. Volpert R, Osswald W, Elstner EF (1995) Effects of cinnamic acid derivates on indole acetic acid oxidation by peroxidase. Phytochemistry 38: 19-22.
105. Balasubramanian VK, Rai KM, Thu SW, Hii MM, Mendua V (2016) Genome-wide identification of multifunctional laccase gene family in cotton (Gossypium spp.); expression and biochemical analysis during fiber development. Sci Rep 6: 34309.
106. Tewolde H, Fernandez CJ (2003) Fiber quality response of pima cotton to nitrogen and phosphorus deficiency. J Plant Nutrition 26: 223-235.
107. Reddy KR, Koti S, Davidonis GH, Reddy VR (2004) Interactive effects of carbon dioxide and nitrogen nutrition on cotton growth, development, yield and fiber quality. Agron J 96: 1148-1157.
108. Guo K, Tu L, He Y, Deng J, Wang M, et al. (2017) Interaction between calcium and potassium modulates elongation rate in cotton fiber cells. J Exp Botany 68: 5161-5175.
109. Zhao D, Oosterhuis D (1998) Cotton responses to shade at different growth stages: non-structural carbohydrate composition. Crop Sci 38: 1196-1203.
110. Pettigrew TF, Meertens RW (1995) Subtle and blatant prejudice in Western Europe. Eur J Social Psychology 25: 57-75.
111. Wang Q, Sun X, Song X, Guo Y, Li Y, et al. (2006) Effect of shading at different stages of cotton bolls on cotton fibre quality. Acta Agronomica Sinica 32: 671-675.
112. Chen B, Chai Z, Sheng J, Zhang W, Jiang P (2017) Effects of potassium fertilizer on the physiological mechanisms of cotton fiber quality. Pak J Bot 49: 935-943.
113. Dasani SH, Thaker VS (2006) Role of abscisic acid in cotton fiber development. Russ J Plant Physiol 53: 62-67.
114. Einhorn T, Arrington M (2017) ABA and shading induce 'Bartlett' pear abscission and inhibit photosynthesis but are not additive. J Plant Growth Regulation pp: 1-9.
115. Burg SP (1962) The physiology of ethylene formation. Ann Rev Plant Physiol 13: 265-302.
116. Lieberman M (1979) Biosynthesis and action of ethylene. Ann Rev Plant Physiol 30: 533-591.
117. Cheng F, Cheng Z (2015) Research Progress on the use of Plant Allelopathy in Agriculture and the Physiological and Ecological Mechanisms of Allelopathy. Front Plant Sci 6: 1020.
118. Boukar O, Fatokun CA, Huynh BL, Roberts PA, Close TJ (2016) Genomic tools in cowpea breeding programs: status and perspectives. Front Plant Sci 7: 757.
119. Basu AK (1985) Research achievements of all India coordinated cotton improvement project with particular reference to achievements in fertiliser use research. Fertl News 30: 35-42.