REVIEW ARTICLE

Increasing land and water use efficiencies by intercropping summer legumes with corn in Egypt

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The per capita acre age of cultivated summer legumes is decreasing in Egypt. Improving the efficiency of agricultural resources utilization is needed to increase the output per unit area in marginal and sandy lands. Excessive applied irrigation water and nitrogen (N) mineral fertilization are common agricultural practices that often negatively influence soil and environmental quality in crop production systems in Egypt. By intercropping, it should help to raise total agricultural production under limited agricultural resources. These have been a surge of interest in this work on intercropping summer legumes with corn to explore their effects and improve their productivities to increase farmer's income. Intercropping provides practical solutions for increasing crop and livestock production, as well as, soil productivity for rural and Bedouin farmers in Egypt and Arab communities without any additional agricultural resources. Soybean and peanut are considered one of the most important oil crops in the world, and their proteins are an important source for feeding poultry and fish. Cowpea and fresh fodder of corn plants are an important source of protein for feeding dairy animals. These legumes are produced through intercropping in wide areas in many countries. Intercropping should technically increase oil and protein production to compensate oil and protein shortages in Egypt and the Arab world. Results of 40 years (1979-2019) of scientific research on intercropping enabled development of technological packages for intercropping summer legumes with corn to realize high yield of both crops under different environments in Egypt to increase crop and livestock production, as well as farmer's income. Legume roots facilitate N to absorb by intercropped corn roots and in turn increase the ability of corn plants to tolerate water shortage. Meanwhile, corn plants protect legume plants from high temperature which increase the ability of summer legume plants to tolerate water shortage. Ministry of Egyptian Agriculture, in cooperation with Cairo University and Agricultural Research Center, intercropped soybean with corn in 20377 hectares of rural farms from 1983 to 1989. They realize 4.7 ton/hectare of corn grains equivalent to the national average yield of solid corn in these Governorates, in addition to a bonus of about two tons of soybean seeds per hectare and land equivalent ratio (LER) of this system recorded 1.65 under different environments. In another study, field trials were conducted by growing soybean with corn under sandy soil with an application of 5273 m^3/hectare of irrigation water. They realize 2.12 and 3.65 ton/ hectare of soybean seeds and corn grains, respectively, and LER reached 1.54. Also, field trials were conducted by growing corn in peanut fields with an application of 4818 m^3/hectare of irrigation water. They realize 2.78 ton/hectare of peanut pods, in addition to five tons of corn grains per hectare where LER recorded 1.8 with 276 USD/hectare. To increase fresh fodder production for livestock feeding, a field trial was conducted under sandy soil conditions with an application of 5034 m^3/hectare of irrigation water by harvesting of corn plants as fresh fodder at 85 days from corn planting. They realize 17.70 ton/hectare of corn fresh fodder + 1.62 ton/hectare of peanut pods under intercropping culture where LER recorded 1.57 with 783 USD/hectare. Also, a field trial was conducted under high temperature with an application of 8948 m^3/hectare of irrigation water by harvesting of cowpea plants as fresh fodder at 75 days from cowpea planting. They realize 17.83 ton/hectare of cowpea fresh fodder + 7.60 ton/hectare of corn grains where LER recorded 1.45 with 823 USD/hectare. Soybean plants gave intercropped corn plants an amount of N estimated at 20% of the recommended N fertilizer rate of corn; meanwhile this amount reached 12.5% by intercropping cowpea with corn under limited N conditions. To enhance soil fertility for the successive winter crop, total soil N was enhanced after harvesting of intercrops (corn + peanut) by 3.78% as compared with that after harvesting of solid peanut. Meanwhile, total soil phosphor (P) was enhanced after harvesting of intercrops (corn + peanut) by 8.62% as compared with that after harvesting of solid peanut for the successive crop. These are examples for the potential contribution of intensive cropping systems to enhance efficiency of available agricultural resources.

Key Words: Intercropping, Summer legumes, Corn, LER, Water use efficiency, Farmer's income

INTRODUCTION

This review article will focus attention on earlier works for intercropping legumes with corn from 1979 to 2019 for demonstrate successful intercropping cowpea (*Vigna unguiculata* L), peanut (*Arachis hypogaea* L) or soybean (*Glycine max* L, Merr) with corn (*Zea mays* L) under extreme conditions in Egypt. Egypt is the land of history; it is the most populous country in the Arab world and the second-most populous on the African Continent. Egypt is in the northeastern corner of Africa between latitudes 21 and 31 North and longitudes 25 and 35 East with a total area of 1,001, 450 km^2; the country stretches about 1,105 km from North to South and up to 1,129 km from East to West. It is bordered in the North by the Mediterranean Sea; in the East by the Gaza Strip and the Red Sea; in the South by Sudan; and in the West by Libya (Figure 1). Egypt has continued its plan to bring about real agricultural development in marginal and poor areas, and to raise the capacities of the Egyptian rural and Bedouin people and improve their incomes, in a way that basically guarantees food security. Most of the Egyptian farming communities is living below poverty line. The obvious reason is that most land holdings are so fragmented to extent that the average holding is less than half hectare. This situation can be attributed to two main reasons; the first reason is the agrarian reform adopted by the 23 July Revolution which split the land owned by big landlords and distributed it to landless farmers. Meanwhile, the other season is the heritage system in which land is usually divided between sons and daughters when the father or the mother dies. Likewise, small farmers in some Arab countries are seriously constrained by limited land resources (water and soil fertility). Hence, Egypt that is one of the Arab world is facing unprecedented crises in water, energy and arable land. Egypt has a large percentage of its lands, up to 90% of desert lands, which are classified as marginal lands, which are characterized by different degrees of salinity, scarcity of fresh water and the presence of salty groundwater. An interview conducted in Al-Falah Today newspaper on June 29, 2019, Dr. Fadl Hashem, Executive Director of the Climate Change Information

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Center of the Agricultural Research Center, reported that it is difficult to limit the losses of climate change to the Egyptian agricultural sector in every season, noting that there are many problems facing the agricultural sector, perhaps the most important of which is not good farm operations carried out by the farmer. He added that delaying or early planting, lack of irrigation water, and choosing irrigation schedules that contravene technical recommendations, inefficiency of agricultural land, types of fertilizers, pesticides, and methods of controlling diseases and pests, all of them. The causes affect together with climate change and inevitably lead to a lack of crop and livestock production. He added that there are some recommendations in order to prevent damaging climatic fluctuations like intercropping.

Figure 1) Map of Egypt.

Unfortunately, in developing countries as in Egypt, the agricultural development is facing by several constraints concerned with limitation of soil, water and inputs, associated with continuous growth population, resulting in reduced production per capita. Particularly, the Egyptian farmers are frequently followed easy and old practices such as the relay sowing of crops, exhausting more land area, water and inputs. Moreover, this practice is commonly used for the principle crops which occupied most of the available old land area in Nile Valley, while other crops, of secondary importance, such as cowpea, peanut and soybean are restricted in small areas. Egypt is facing acute shortage of edible oil and protein where vegetable oil is imported in large quantities to satisfy the domestic needs of the country. The gap between production and consumption reaches more than 90%. In Egypt, soybean was commercially cultivated in 1970 on about 1260 hectares with an average seed yield of about 126 kg per hectare. The acreage has increased rapidly, reaching 65000 hectares in 1983, with an average seed yield of about 400 kg per hectare. Unfortunately, due to factors beyond the control of the Egyptian state, soybeans planted area began to decline continuously till it reached 13000 hectares in 2018 with an average seed yield of about 500 kg per hectare. This decline in acreage might be attributed to the competition with other strategic summer crops like corn, as well as high production costs and lower economic return as compared with other summer crops. In the summer, corn is the major strategic crop in Egypt. Fortunately, legumes ranked the second after cereals in terms of food production, which accounted for 27% of the world's primary crop production and contributed 33% of protein needs [1]. Consequently, the idea of intercropping legumes with corn in Egypt was born in the early sixties of the last century.

Intercropping is the practice of producing multiple crops in a given time and space. This system is used in many parts of the world especially in regions where the small farmer intensively utilizes a limited land area [2] and is recommended to increase total agriculture products in Egypt [3]. The system soybean+corn was adopted, and research compared different intercropping patterns, selection of tolerant genotypes for each partner crop and effects of population densities of plants and their distribution in the unit area. Yields of intercropping as high as 90% for corn and 60% for soybean of respective solid culture of crops were scored.

Ministry of Egyptian Agriculture has given the first author (Prof. Dr. Abd El-Alim A. Metwally) a national project in 1983 to grow soybeans with corn under intercropping culture in 14 Egyptian Governorates (26000 hectare). Eight Governorates (20377 hectare) were selected for this study, three Governorates in East of Egypt (Sinai borders), one Governorate in North of Egypt (The Mediterranean Sea Borders) and three Governorates in South of Egypt for six years (Table 1). This national project was implemented in demonstration fields through Ministry of Egyptian Agriculture. In East of Egypt, Sharkia Governorate had higher yield of intercrops (1.84 and 5.80 ton/hectare of soybean seeds and corn grains, respectively) than the others. In North of Egypt, Kafr El-Sheikh Governorate recorded 1.98 ton/hectare of soybean+4.80 ton/hectare of corn grains. In South of Egypt, El-Minia Governorate had higher yield of intercrops (2.17 and 4.40 ton/hectare of soybean seeds and corn grains, respectively) than the others. It seems that corn plants protected soybean plants from high temperature in South of Egypt, which explained the relative high in soybean seed yield as compared with the others.

Table 1) Acreage, average yield and LER in major field applications in intercropping soybean with corn through different Governorates (1983-1989).

Governorate	Acreage (hectare)	Average yields (ton/hectare)		LER
		Soybean	Corn	
East of Egypt (Sinai borders)				
Sharkia	4750	1.84	5.8	1.9
Dakahlia	3830	2.26	4.8	1.86
Domyat	122	1.48	4.83	1.56
North of Egypt (The Mediterranean Sea borders)				
Kafr El-Sheikh	1891	1.98	4.8	1.75
South of Egypt				
El-Minia	8270	2.17	4.4	1.74
Assiut	1114	2.03	3.3	1.45
Sohag	318	1.3	5.16	1.56
Kena	82	1.28	4.23	1.37
Solid culture				
Corn	840000	---	4.8	1
Soybeans	41000	2.62	---	1

This data shows that growing summer legumes with corn has two contradictory effects that cannot be separated on legume crop, the first effect is the protection of summer legumes from high temperature, and the second effect is the negative impact on efficiency of photosynthesis of summer legumes due to shade.

Land equivalent ratio (LER) for intercrops were greater than 1.00 indicating less land requirements of intercropping system than solid plantings of both species. The values of LER were estimated by using data of solid plantings of both species. LER of more than 1.00 indicates yield advantage, equal to 1.00 indicates no gain or no loss and less than 1.00 indicates yield loss [4]. It can be used for replacement and additives series of intercropping. The results obtained were strongly coincided with the definition of LER. Figure (2) shows LER of intercropping soybeans with corn through different Governorates from 1983 to 1989 according to Egyptian national project of intercropping soybeans with corn in 1983. All values of LER exceeded 1.00 indicating intercropping soybeans with corn is successful practice under Egyptian conditions.

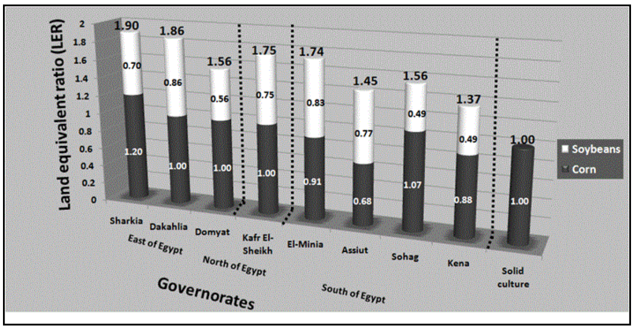

Figure 2) Land equivalent ratio (LER) of intercropping soybeans with corn through different Governorates (1983-1989).

LER values ranged from 1.90 by intercropping soybean with corn in Sharkia Governorate to 1.37 by intercropping soybean with corn in Kena Governorate. The results indicate that intercropping soybeans with corn had high advantage for increasing total yield per unit area for six consecutive years. Accordingly, maximizing agricultural resources through intensification of agricultural systems are very important to reflect greater production and income per unit area/year. These results show that rural and Bedouin farmers are easily able to accept modern ideas and apply these advanced systems to meet their food and feed needs by increasing crop and livestock production.

On the other hand, peanut cultivated area declined to reach about 100 thousand hectare in 2018 with an average yields of 3.00 tons/hectare. Meanwhile, cowpea is an important summer forage crop in Egypt. Teosinte +cowpea mixture was superior to sole cropping with an increase in forage and protein yields [5]. However, Zeidan et al. stated that fodder corn sole planting gave higher fresh and dry forage yields than either cowpea or guar whereas, planting cowpea in pure stand gave higher protein yield per unit area when compared with fodder corn and guar [6]. Consequently, cowpea, peanut and soybean have a great importance as a summer legume crops cultivated in Egypt and all over the world for oil and protein production. These legumes are the most important sources of vegetable oil and protein because it has the highest oil and protein contents among the leguminous crops.

This technique could be build the resilience of food security systems in Sinai, North and South of Egypt especially in raising capacities to face the effects of shortage in available basic growth resources on areas related to agriculture, to take all necessary measures to deal with these conditions and changes. The promising plans aims to provide a set of specific and simple mechanisms that will increase agricultural and livestock production. Livestock production in Egypt is unique in that it is confined almost exclusively to irrigated cropping areas. The rest of Egypt is largely uninhabited desert, without sufficient grass or other natural forage to support grazing by more than a few tens of thousands of camels, sheep and goats. Livestock production complements irrigated crop production in many ways, but it is also highly competitive with crop production in others. Since crop production is still not highly mechanized, livestock are required for work, and in many cases farmers choose to keep dual purpose animals which can produce milk and meat as well as work-native cattle, in particular but also the water buffalo, are prozed for this dual purpose characteristic. However, water is one of the major factors in arid and semiarid regions. Agriculture in Egypt is depending on surface irrigation with water from the River Nile. The existence of groundwater aquifer in Sinai is mostly deep and non renewable [7]. A water resource in Egypt (arid region) is scarce due to rare rainfall and high values of evapotranspiration. Additionally, food security, water scarcity and rapid population, as well as climate change scenarios required effective strategies for efficient management [8]. It is important to note that intercropping summer legumes with corn can contribute effectively in feeding livestock in the marginal areas and sandy lands [9]. The current price structure in Egypt makes livestock production one of the most profitable enterprises for the small farmers who can utilizing from silage efficiently in summer season. These promising plans work to organize farmers in formal social entities and train them to enable them to reach practical models to increase land usage with net return.

Intercropping reduces applied irrigation water

The traditional rotational irrigation system in Egypt was investigated by El-Kholy, El-Alfy and Gergis [10-12]. This system has some disadvantages such as; severe shortage of water at the tail reaches; low conveyance efficiency; high operational cost; and excessive water losses to drains. The cropped area in Egypt does not exceed 3.3% (3.5 hectare) of the total area of planting and is confined to the narrow strip along the River Nile, in addition to the Nile Delta which is located between the Damietta east tributory and Rosetta tributary on the west. So, understanding of the relationships between deficit irrigation and soil with every stages of crop growth, application of modern methods of irrigation, and improving irrigation efficiency would be helpful in this regard. The intercropping is one of the agricultural strategies for increasing water productivity to make maximum use of soil moisture. In this concern, Metwally suggested that growing the legumes with cereal could increase relative atmospheric humidity by about 3.50 to 5.00%, air temperature by about 1.50 to 2.50^{o}C and soil temperature by about 2 to 3^{o}C than sole plantings of the legumes [9]. Accordingly, Abdel-Galil et al. grew soybeans with corn in the poor lands (sandy lands) under limited irrigation water (sprinkler irrigation); and thereby intercropping soybeans with corn contributed largely in water use efficiency of economic yield by 16.94% as compared to traditional solid plantings of corn in clay soils [13,14].

Table 2 shows available and potential water resources in Egypt. These results show The Nile contributed 55.5 billion m^3 (75%) of total water requirements, meanwhile groundwater came in the second rank by 15%. Rainfall came in the last rank by 1% only which indicating Egyptian lands are located in semi arid conditions. Consequently, Egypt is one of the countries facing great challenges due to its limited water resources represented mainly by its fixed share of the Nile water and its aridity as a general characteristic. The agriculture requirements exceed 80 percent of the total demand for water [15]. The per capita share of water has dropped dramatically to less than 1000 m^3, which is classified as "Water poverty limit". It is projected that the value decreases to 500 m^3 per capita in the year 2025 [16]. Thus, water is a primary limiting factor in Egyptian agriculture especially after building the Ethiopian Renaissance Dam which could affected negatively Nile water of downstream countries, *i.e.* South Sudan, Sudan and Egypt and thus a significant deficiency in the amount of water allocated for irrigation and agriculture. Some Egyptian experts said that the Ethiopian dam could cause great harm to Egypt, as it may lead to a lack of Nile water, dry agricultural land and increase soil salinity in the Delta region. It is important to address our efforts to this fundamental issue by increasing crop production per unit area with reducing their water consumption especially on the reclaimed sandy soils. Maximizing the other water resources especially ground water and rainfall have become an urgent necessity for rural and Bedouin farmers in marginal and poor fertile lands. Accordingly, this can be achieved through an effective use of modern cropping and irrigation techniques. Use of intercropping culture under drip and sprinkler irrigation could be playing an important role for maximizing land equivalent ratio under low fertility of marginal and sandy lands.

Table 2) Available and potential water resources (in billion m^3) annually.

Water resource	Potential amount	%	Amount in use	%
The Nile	55.5	75	51.7	83
Ground water	11.3	15	5.2	8
Reuse of agricultural drainage water	5	7	3.7	6
Treated sewage water	1.5	2	1.5	2
Rainfall	0.5	1	0.5	1
Total	73.8	100	62.6	100

Table 3 show results of intercropping summer legumes with corn in all marginal and new lands of Egypt under limited irrigation water. Several field experiments in sandy soil conditions showed advantages of growing summer legumes with corn under limited irrigation water in East of Egypt (Sinai borders). In this concern, Monib et al. reported that growing soybean with corn in sandy soils with an application of 3900 m^3/hectare of irrigation water gave high yield of intercrops (2.24 and 2.45 ton/hectare of soybean seeds and corn grains, respectively) [17]. Also, Metwally et al. found that growing corn with peanut under sandy soil with an application of 4818 m^3/hectare of irrigation water had high yield of intercrops (5.16 and 2.78 ton/hectare of corn grains and peanut pods, respectively) [18]. Land equivalent ratio (LER) of this system reached 1.80. This system achieved 276 USD/hectare. Moreover, Abdel-Galil et al. indicated that growing soybean with corn under sandy soil with an application of 5273 m^3/hectare of irrigation water produced high yield of intercrops (2.12 and 3.65 ton/ hectare of soybean seeds and corn grains, respectively) [13]. Land equivalent ratio (LER) of this system reached 1.54.

Moreover, Metwally et al. demonstrated that growing corn with peanut under sandy soil conditions with an application of 5034 m^3/hectare of irrigation water had high yield of intercrops (3.42 and 1.76 ton/hectare of corn grains and peanut pods, respectively) [19]. Land equivalent ratio (LER) of this system reached 1.29. This system achieved 873 USD/hectare. In the same experiment, growing corn with peanut under sandy soil conditions with an application of 5034 m^3/hectare of irrigation water had high yield of intercrops (17.70 and 1.62 ton/hectare of corn fresh fodder and peanut pods, respectively). Land equivalent ratio (LER) of this system reached 1.57. This system achieved 783 USD/hectare. Finally, Metwally and Hefny found that growing corn with peanut under sandy soil conditions with an application of 5034 m^3/hectare of irrigation water had high yield of intercrops (3.18 and 1.72 ton/hectare of corn grains and peanut pods, respectively). Land equivalent ratio (LER) of this system reached 1.35 [19]. This system achieved 560 USD/hectare.

A field experiment in clay-salt soil conditions showed advantages of growing summer legumes with corn under limited irrigation water in North of Egypt (The Mediterranean Sea borders). In this concern, El-Shamy et al. reported that growing soybean with corn in clay-salt soils with an application of 8568 m^3/hectare of irrigation water gave high yield of intercrops (1.88 and 7.11 ton/hectare of soybean seeds and corn grains, respectively) [20]. Land equivalent ratio (LER) of this system reached 1.65. This system achieved 1523 USD/hectare. Meanwhile, two field experiments in clay soil conditions showed advantages of growing summer legumes with corn under limited irrigation water and high temperature in South of Egypt. In this concern, Abdel-Wahab and Abdel-Rahman reported that growing soybean with corn in clay soils with an application of 8948 m^3/hectare of irrigation water gave high yield of intercrops (1.54 and 4.61 ton/hectare of soybean seeds and corn grains, respectively) [21]. Land equivalent ratio (LER) of this system reached 1.12. This system achieved 830 USD/hectare.

Also, Abdel-Wahab et al. reported that growing cowpea with corn in clay soils with an application of 8948 m^3/hectare of irrigation water gave high yield of intercrops (17.83 and 7.60 ton/hectare of cowpea forage and corn grains, respectively) [21]. Land equivalent ratio (LER) of this system reached 1.45. This system achieved 823 USD/hectare. Under limited irrigation water, a field experiment was carried out in Middle of Egypt by Metwally et al. and they reported that growing soybean with corn in clay soils with an application of 6069 m^3/hectare of irrigation water gave high yield of intercrops (1.34 and 6.66 tons/hectare of soybean seeds and corn grains, respectively) [14]. Land equivalent ratio (LER) of this system reached 1.29. This system achieved 350 USD/hectare. It seems that legume roots facilitated N to absorb by corn roots and in turn increased leaf area duration of corn by enhancing indol-3-acetic acid (IAA) that increased the ability of corn plants to tolerate water shortage under limited water conditions.

Intercropping reduces mineral N fertilization

Rural and Bedouin farmers should aim to match the supply of nitrogen (N) for crop production systems. Excessive mineral N fertilization can cause serious environmental problems, such as greenhouse gas emission, soil degradation, freshwater contamination, and natural resource consumption. Although intercropping legumes with cereals is a common practice because of the advantages in N use but Good and Beatty reported that excessive mineral N is often used to reach high yields for most crops, especially in developing countries. Generally, it is known that any plant obtain mineral nutrients through root uptake from the soil solution [22,23]. Hence, it is expected that the interaction between the two species will integrate with mineral N fertilizer through activity of soil microorganisms where soil bacterial community composition is altered in response to N addition [24].

So, advantage of intercropping summer legumes with corn in marginal and new lands in Egypt is decreasing N inputs of corn crop which decreased amounts of mineral N to underground water and preserving the environment from the pollution. The Egyptian researches proved that growing summer legumes with corn can facilitate N uptake of corn by biological N fixation (BNF) that reflected positively on N use efficiency of corn. In this concern, Monib et al. reported that inocula of rhizobia and associative N_2-fixers contributed to the corn-soybean system in sandy soils with an estimated average of 41.6 and 131 kg N per hectare, respectively [17]. They added that growing legume root system may provide N for neighboring cereal plants and for rhizosphere microflora. Moreover, Metwally et al. reported that diazotroph inoculation of corn increased significantly each of LAI, biological and productivity of corn compared with uninoculated plants [25]. Legumes contribute to a diversification of cropping systems and as N_2-fixing plant in sandy soil; it can improve the exchanges of nutrients and water in a sandy soil where plant roots thrive. This is because summer legumes have the ability of enriching the N content of these soils by fixing N from the air that improved productivity of sandy soils in Egypt [26]. The positive effects of bacterial inoculation are mainly attributed to the production of phytohermones that improve root development beside N_2-fixation. Consequently, soybean or cowpea facilitates N uptake of corn by BNF that reflected positively on N use efficiency of corn [13,7]. Moreover, shading of the cereals can contribute largely in increase the capacity of the Calvin cycle and the thylakoid reactions to regenerate ribulose bisphosphate (RuBP) that consumed by RUBISCO in leaves of intercropped legumes under hot summer season where temperature reaches 40-45°C [27]. They added that intercropping legumes with cereals could increase the capacity of starch and sucrose synthesis of cereals to consume triose phosphates and regenerate inorganic phosphate for photo-phosphorylation which reflected positively on corn grain yield per hectare.

Figure 3 show results of intercropping summer legumes with corn in all marginal and new lands of Egypt under limited mineral N fertilizer. One field experiment in sandy soil conditions showed advantages of growing summer legumes with corn under limited mineral N fertilizer in East of Egypt (Sinai borders). In this concern, Monib et al. reported that nodulated soybean roots gave 47.6 kg N per ha to intercropped corn plants [17].

One field experiment in clay-salt soil conditions showed advantages of growing summer legumes with corn under limited mineral N fertilizer in North of Egypt (The Mediterranean Sea borders). In this concern, El-Shamy et al. found that nodulated soybean roots gave 47.6 kg N per ha for intercropped corn plants [20]. They added that mixed system played an important role to improve edaphic environmental conditions in rhizosphere of intercropped corn roots, which reflected positively on ear leaf N and IAA contents that maximized carbon assimilation and crop productivity compared to solid culture. One field experiment in clay soil conditions showed advantages of growing summer legumes with corn under limited mineral N fertilizer and high temperature in South of Egypt. In this concern, Abdel-Wahab et al. found that nodulated cowpea roots gave 35.7 kg N per ha to intercropped corn plants [21].

Table 3) The irrigation system, soil structure, applied irrigation water, intercropping system, average yield of intercrops, LER and farmer' benefit for intercropping summer legumes with corn.

Source	The irrigation system	Soil structure	Applied irrigation water (m^3/hectare)	Intercropped crops	Intercropping system	Average yields (ton/hectare)		LER	Farmer's benefit (USD/hectare)
						Main crop	Intercrop		
Mounib et al. (1998)	Drip irrigation (Sinai borders)	Sandy	3900	corn (main crop) +soybean (intercrop)	2 corn ridges:2 soybean ridges	2.45 ton of corn grains	2.24 ton of soybean seeds	---	---
Metwally et al. (2005)	Sprinkler irrigation (Sinai borders)	Sandy	4818	peanut (main crop)+corn (intercrop)	Mixed system	2.78 ton of peanut pods	5.16 ton of corn grains	1.8	276
Abdel-Galil et al. (2014)	Sprinkler irrigation (Sinai borders)	Sandy	5273	corn (main crop) +soybean (intercrop)	2 corn ridges:4 soybean ridges	3.65 ton of corn grains	2.12 ton of soybean seeds	1.54	---
El-Shamy et al. (2014)	Furrow irrigation (The Mediterranean Sea borders)	Clay-salt	8568	corn (main crop) +soybean (intercrop)	Mixed system	7.11 ton of corn grains	1.88 ton of soybean seeds	1.65	1523
Abdel-Wahab and Abdel-Rahman (2016)	Furrow irrigation (South of Egypt)	Clay	8948	corn (main crop) +soybean (intercrop)	2 corn ridges:2 soybean ridges	4.61 ton of corn grains	1.54 ton of soybean seeds	1.12	830
Abdel-Wahab et al. (2016)	Furrow irrigation (South of Egypt)	Clay	8948	corn (main crop) +cowpea (intercrop)	Mixed system	7.60 ton of corn grains	17.83 ton of cowpea forage	1.45	823
Metwally et al. (2017)	Drip irrigation (Middle of Egypt)	Clay	6069	corn (main crop) +soybean (intercrop)	Mixed system	6.66 ton of corn grains	1.34 ton of soybean seeds	1.29	350
Metwally et al. (2018)	Sprinkler irrigation (Sinai borders)	Sandy	5034	peanut (main crop)+corn (intercrop)	Mixed system	1.76 ton of peanut pods	3.42 ton of corn grains	1.29	873
		Sandy	5034	peanut (main crop)+corn (intercrop)	Mixed system	1.62 ton of peanut pods	17.70 ton of corn fresh fodder	1.57	783
Metwally and Hefny (2018)	Sprinkler irrigation (Sinai borders)	Sandy	5034	peanut (main crop)+corn (intercrop)	Mixed system	1.72 ton of peanut pods	3.18 ton of corn grains	1.35	560

Intercropping enhances soil productivity

Intercropping played a major role in enhancing soil productivity in marginal and new lands as shown in Table 4 and Figure 4. It has been observed that the canopies and roots of intercrops freely intermingle resulting in complementary interactions between the two species under alternating ridges 2:2, such as complementary use of different nutrients.

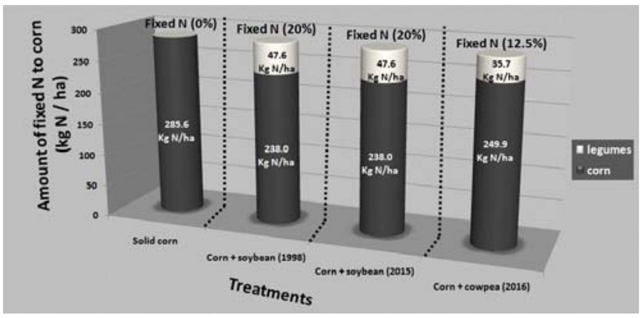

Figure 3) Amount of fixed N from intercropped legumes to corn crop.

Table 4) Complementary effects between corn and legume under alternating ridges 2:2.

Complementary effects	Intercropping culture (2 corn ridges:2 legume ridges)	
	Corn	Legume
CO_2–fixation	C4-crop	C3-crop
Light saturation	1	0.33
CO_2–fertilization	Benefited	Release (photorespiration)
Cation exchange capacity (roots)	Release K+	Release P-, N+, Mg++ and Ca++

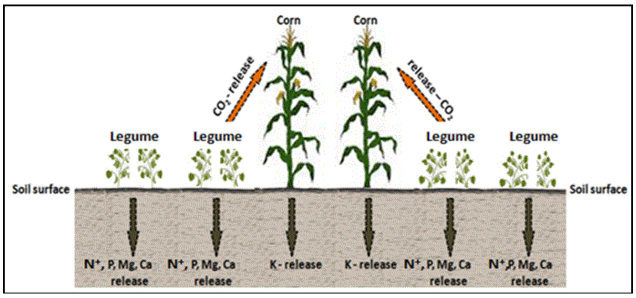

Figure 4) Advantage of intercropping summer legumes with corn on soil productivity under limited agricultural resources.

The results show that legume as C3-crop has 33% of light saturation that loses large amounts of carbon dioxide and consequently enhances total soil phosphor (P^-), nitrogen (N^+), magnesium (Mg^{++}) and calcium (Ca^{++}). Corn as C4-crop has 100% of light saturation that benefited largely from legume photorespiration in photosynthesis process and consequently enhances total soil potassium (K^+). These results confirmed that intercropping legumes with corn enhanced soil productivity especially under marginal and new lands.

In this concern, cereal+legume can achieve higher P uptake on such soils than the corresponding monocultures in either pot or field conditions [28]. Underlying mechanisms include increased P mobilization via chelation of Ca^2+ by citrate exuded from the roots of one of the intercropped species [29]. According to Metwally and Hefny, roots variation of the intercrops (corn+peanut) changed three dimensions of the experiential soil (from the top to the bottom of the soil profile, from North to South and from East to West); and it is apt to suggest that soil structure and porosity was improved than the roots of solid crops [30]. Accordingly, variation between root system morphology and its distribution of the intercrops was biological tool in determining the magnitude of belowground biological soil interactions than roots of solid corn or peanut. So, it is expected that intercropping corn with peanut altered the dynamics of organic matter turnover and the rate of nutrient cycling in sandy soil conditions.

Table 5 shows chemical properties of sandy soil (Sinai borders) after harvest the summer intercrops as compared to those of solid plantings of both species. These results indicate that intercropping reduced soil $CaCO_3$ and pH, meanwhile it enhanced soil organic matter, available N, P and K as compared with those of solid planting.

Table 5) Chemical properties of sandy soil (Sinai borders) after harvested the summer crops.

Complementary effects	Cropping systems of the summer crops		
	Peanut+corn	Solid corn	Solid peanut
$CaCO_3$ (%)	1.26	1.7	1.7
Organic matter (%)	1.09	0.85	0.92
pH	7.65	7.94	7.26
Available N (mg/100 g soil)	3.02	2.16	2.91
Available P (mg/100 g soil)	1.89	1.45	1.74
Available K (mg/100 g soil)	14.02	12.1	14

In other words, intercropping corn with peanut enhanced total soil N by 39.81 and 3.78% as compared with solid plantings of corn and peanut, respectively. Also, intercropping corn with peanut enhanced total soil P by 30.34 and 8.62% as compared with solid plantings of corn and peanut, respectively. Moreover, intercropping corn with peanut enhanced soil K by 15.86% as compared with solid planting of peanut. These results indicated the intercropping enhanced soil productivity for the following winter crop (wheat plants under clay soil or barley plants under sandy soil) which will reflect positively on wheat or barley grains quality. This will lead to an increase in livestock production (camels, cow, buffalo, sheep and goats). These results are agreement with Zhi-Gang et al. who reported that both yields and nutrient acquisition were significantly greater in all four intercropping systems (corn+faba bean, corn+soybean, corn+chickpea and corn+turnip) than corresponding solid cropping over two years [31].

Worldwide source of high-quality food and feed, legumes contribute to reduce the emission of greenhouse gases, as they release 5-7 times less greenhouse gases per unit area as compared with other crops; allow the sequestration of carbon in soils with values estimated from 7.21 g per kg dry matter, 23.6 versus 21.8 g C per kg year; and induce a saving of fossil energy inputs in the system thanks to N fertilizer reduction, corresponding to 277 kg per ha of CO_2 per year. Legumes could also be competitive crops and, due to their environmental and socioeconomic benefits, could be introduced in modern cropping systems to increase crop diversity and reduce use of external inputs. They also perform well in conservation systems, intercropping systems, which are very important in developing countries as well as in low-input and low-yield farming systems [32-35].

CONCLUSION

It can be concluded that intercropping summer legumes with corn increased yields of cowpea, peanut and soybean in marginal and new lands in Egypt without any additional agricultural resources. Intercropping practice can maintain photosynthetic integrity during corn growth and development under limited growth resources. Intercropping summer legumes with corn improved fertility of marginal and sandy lands than solid plantings of both crops. Intercropping summer legumes with corn increased LER and water use efficiency under limited agricultural resources.

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