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STUDY OF PRODUCTIVITY AND ECONOMIC EVALUATION OF INTERCROPPING COWPEA WITH MAIZE UNDER THREE IRRIGATION WATER LEVELS AND THEIR RESPONSE TO INSECT INFESTATION AND VIRAL INFECTION

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ABSTRACT

The present investigation was carried out at Giza Agricultural Experiments and Research Station, Agricultural Research Center (ARC), Giza, Egypt during the two successive seasons 2016 and 2017. The objective of this investigation was to assess the effect of applied irrigation water, infestation with insects and infection with virus on cowpea and maize productivity, as well as farmer income under intercropping condition. The experiment included nine treatments which were the combinations between three applied irrigation water levels (80, 100 and 120% of the recommended applied irrigation water level of maize) and three cropping systems (intercropping cowpea with maize, sole cowpea and sole maize), in addition to recommended sole maize that grown on ridges 70 cm width and received 100% of applied irrigation water. The experimental design was a strip plot with three replications. Irrigation water treatments were randomly assigned to the vertical strips and cropping systems were allocated in the horizontal strips. Data indicated that the highest applied irrigation water level (120% ETo) had higher water consumptive use than the others. The intercrops had higher water consumptive use than those of sole plantings. With respect to maize crop, increasing applied irrigation water from 80 to 120% ETo significantly increased infestation with aphids, jassids, Hawaiian beet webworm, cotton leafworm and whiteflies on maize leaves, as well as higher grain yield per ha and its attributes. Intercropped maize had higher infestation with aphids, jassids, cotton leafworm and whiteflies, as well as ear leaf area per plant than those of sole maize, meanwhile, the reverse was true for greater sugarcane borer. Intercropped maize plants that received the highest applied irrigation water (120% ETo) had higher infestation with aphids, jassids and cotton leaf worm on maize leaves than the other treatments, meanwhile higher ear leaf area per plant was recorded by application of the recommended applied irrigation water of maize (100% ETo). With respect to cowpea crop, increasing applied irrigation water from 80 to 120% ETo significantly increased infestation with aphids, jassids, leaf miner fly, Hawaiian beet webworm, cotton leafworm and whiteflies, as well as soybean mosaic virus (SMV) infection on cowpea leaves, beside higher plant height, number of branches per plant and forage yield per ha. Intercropped cowpea had lower infestation with aphids, jassids, leaf miner fly and Hawaiian beet webworm, as well as lower SMV infection and number of branches per plant and forage yield per ha than those of sole cowpea. Sole cowpea that received the recommended applied irrigation water of maize (100% ETo) had higher infestation with Hawaiian beet webworm, jassids and leaf miner fly on cowpea leaves than the other treatments, meanwhile, SMV infection was not by the interaction between applied irrigation water levels and cropping systems. Sole cowpea that received the highest applied irrigation water level (120% ETo) had a higher number of branches per plant and forage yield per ha than the other treatments. With respect to competitive and water relationships, as well as economic return, land equivalent ratio (LER) and land equivalent coefficient (LEC) gave higher values over 1.00 and 0.25, respectively, with higher water equivalent ratio (WER) and net return by intercropping cowpea with maize that received 100% ETo in both seasons. These results show that growing two rows of maize on beds 140 cm width (one row/side) with growing two rows of cowpea in middle of maize beds with the application of the recommended applied irrigation water level of maize reduced aphids, jassids and cotton leafworm on maize leaves, and jassids, leaf miner fly and Hawaiian beet webworm on cowpea leaves, as well as increased maize grain and cowpea forage yields per ha, land and water usages, as well as economic return.

Keywords: Irrigation water levels, Intercropping, Cowpea, Maize, Insect infestation, Viral infection, Competitive Relationships, Economic return.

Introduction

Maize (*Zea mays* L.) is a strategic crop and it is used for human consumption, animal and poultry feeding and industrial purposes. Demand for the maize grains in the Egyptian market is intensively increasing where the total cultivated area of maize has reached about 714 thousand ha in 2017 (Bulletin of Statistical Cost Production and Net Return, 2018). The most detailed work on the insect fauna of maize fields was that carried out in Giza by Tawfik *et al.* (1974). Their studies showed that maize fields are inhabited by representatives of 66 families from 14 orders. Moreover, they added that the three maize borers *Sesamia cretica* Led., Chilo *agamemnon Bles*, and *Ostrinia nubilalis* (Hb.), and the aphids are considered the major pests of maize plants in Egypt. Leaf aphid infestation causes direct damage to maize plants by reducing growth and yield (Bing and Guthrie, 1991). Additionally, heavy accumulation of aphid honeydew on maize tassels can block pollen shed and thereby reduce seed set (Carena and Glogoza, 2004). It is worthy to note that glucosinolate accumulation is regulated by the salicylic acid, ethylene and jasmonic acid (JA) signalling pathways as reported by Mewis *et al.* (2005). Particularly, Pieterse and Dicke (2007) showed that many major plant defense mechanisms require the involvement of two signaling molecules, salicylic acid and JA, which are induced in distinct patterns by insect and pathogen damage. Elevated JA levels have been associated with insect resistance in several plant species (Shivaji *et al.*, 2010). It is known that zeatin is a plant growth hormone in the cytokinin family. Plant growth, development and adaptations for different biotic and abiotic stresses are the result of intricate network of many synergistic and antagonistic cooperation between different hormones (O'Brien and Benková, 2013). However, Tzin *et al.* (2015) revealed that piercing/sucking insects such as maize leaf aphid (*Rhopalosiphum maidis*) caused direct damage by acquiring phloem nutrients, as well as indirect damage through the transmission of plant viruses. They added that the most common aphid-induced maize gene expression changes were associated with JA-, salicylic acid-, and auxin-dependent signaling. In this concern, Ahmad *et al.* (2019) indicated that JA have been studied intensively in the past decades for their substantial roles in plant defense comebacks against diverse environmental stresses among model plants. Also, benzoxazinoids contribute to enhanced callose deposition by providing heightened resistance to leaf aphids in maize (Varsani *et al.*, 2019). Consequently, benzyl adenine (BA) is an important index for benzoxazinoids in maize plants to tolerate aphids in maize leaves.

Some leafhopper (jassids) species cause stippling (tiny pale dots) on leaves that may appear as wiggly lines from a distance. This stippling reduces the photosynthetic capacity of affected leaves. The nymphs and adults of the leafhopper suck sap from leaves and characteristic symptoms of hopper burn appear owing to the toxigenic nature of leafhopper (Jayaraj, 1967). The leafhoppers can propagate intensively in North Egypt at warm temperatures and caused a big yield loss as reported by El-Nahal *et al.* (1979). Moreover, females of *Sesamia cretica* lay their eggs under the leaf sheath, and newly hatched larvae enter the plant whorl or stem. In Egypt, population densities of *Sesamia cretica* are high in the Nile delta, especially on early maize crops, sown between late March and mid-May (Mostafa, 1981), in which the borer may cause severe damage (Semeada, 1985 and 1988). In another study, Ezzeldin *et al.* (2006) revealed that the reduction of *Sesamia cretica* population play an important role in increasing the yield of maize and sorghum in Egypt where it attacks those crops less than 4 – 6 week old. On the other hand, Adham *et al.* (2009) showed that the cotton leafworm (*Spodopetra littoralis*) is a well polyphagous herbivore and is regarded as one of the most important agricultural pest in the Middle East. However, the beet webworm (*Spoladea recurvalis* Fab.) mainly inhabits the tropical and sub-tropical areas of the world, where it causes severe damage to crops (Hsu and Srinivasan, 2012). Thus, maize plantations are usually subject to the attacks of a variety of pests most economically important of which are a group of insects, commonly and collectively known as "Maize Borers" in Egypt (Metwally *et al.*, 2015).

On the other hand, cowpea (*Vigna unguiculata* L.) is compatible as an intercrop because of its shade tolerance (Singh and Sharma, 1996). It is grown on about 7–8 million ha^{-1} in warm to hot regions of the world (Mortimore *et al.*, 1997). It is a most diverse cultivated subspecies, the widest distributed, an important food legume and versatile crop (Sanging *et al.*, 2002). All parts of the plant used as food are nutritious providing protein and vitamins, immature pods and peas are used as vegetables while several snacks and main dishes are prepared from the grains (Islam *et al.*, 2006). However, moisture stress markedly retards root hair and nodule growth and nitrogen (N) fixation (Onuh and Donald, 2009). In Egypt, cowpea is promising double purpose forage and seed crop for its green canopy or using it in animal diets as dry seeds, as well as it is a primary source of plant protein for humans and animals in the summer season (HamdAlla *et al.*, 2014). It is the most economically important legume crop in arid regions of sub-Saharan Africa (Ba *et al.*, 2018). However, Singh and Allen (1979) reported that major insect pests of cowpea that cause economic losses are cowpea aphids (*Aphis craccivora* Koch), leafhoppers (*Empoasca* spp.), thrips (*Megalurothrips sjostedti* Trybom), flower-feeding beetles (*Mylabris* spp. and *Coryna* spp.), pod borers (*Maruca vitrata* Fabricius), and cowpea weevil (*Callosobruchus maculatus* Fabricius). However, the key pests of this crop include aphids, leafhoppers, sucking bugs and pod borers which affect 90% plants of total according to the field study (Karungi *et al.*, 2000). The cotton leafworm (*Spodopetra littoralis*) attacks all major crops in Egypt, including cowpea (El-Aswad *et al.*, 2003). Meanwhile, the leafhoppers act negatively on plants by harming the vegetal tissue during feeding and egg laying, a toxic action due to the phytotoxicity of their saliva and an infectious action (Ceotto and Bourgoin, 2008). Consequently, insect pests inflict the most substantial losses as reported by (Murdock *et al.* 2008). Moreover, Reitz *et al.* (2013) indicated that *Liriomyza huidobrensis* (Blanchard), *Liriomyza sativae* Blanchard, and *Liriomyza trifolii* (Burgess) are highly invasive species that have become established in agricultural areas throughout the world, where cowpea productivity is hampered by several biotic stress factors including numerous insect pests that infest and damage the crop at all its development stages in the field (Togola *et al.*, 2017). Cowpea seedlings can be attacked and even killed by aphids if not controlled with insecticides or planting of resistant variety (Boukar *et al.*, 2019). Furthermore, aphids are vectors of SMV on soybean leaves (Abdel-Wahab Sh. *et al.*, 2020).

However, maize production could damaged by insects, so we need to improve tolerance management strategies by determining the optimum level of applied irrigation water under intercropping. Such agricultural development requires the contribution of all related agricultural sciences, especially those of plant protection. No doubt, there are changes in insect pest problems facing the farmers in the old valley due to the no availability of irrigation water in some periods, pesticide misuse and pest resistance, secondary pest outbreaks, climate changes, and the absence or inefficient presence of natural enemies. Modifications that lead to the reduction of population of a pest have been referred to cultural control (Root, 1973). The population of *Empoasca dolichi*, *Sericothrips occipitalis* and *callosobruchus maculates*, as well as lower thrips were reduced in cowpea + maize intercropping (Perfect *et al.*, 1979). It is known that they can complement each other, when grown together, making better use of resources than as monocrops (Willey, 1979). In host-plant, N content is generally considered as an indicator of food quality and a factor affecting host selection by herbivores (Mattson, 1980). Particularly, Hilje *et al.* (2001) showed that cultural practices to manage whitefly can be categorized as avoidance in time or space, behavioral manipulation of the insect, host suitability, and insect removal. On the other hand, cowpea can transfer fixed N to intercropped maize during their joint growing period and this N is an important resource for maize (Abdel-Wahab *et al.*, 2016), especially water management has become very important task to be implemented in Egypt due to the prevailing conditions of water scarcity (Zohry and Ouda, 2016). At surface irrigation, root length density of cowpea reached to soil depth 30-40 cm with lateral distances 5-10 cm and 15-20 cm. Meanwhile, vertical distribution of root length density of maize was increased with soil depth till 20-25 cm, and then it decreased till soil depth 35-40 cm (Mahgoub *et al.*, 2017). Although, Basso and Ritchie (2018) demonstrating that maize (*Zea mays* L.) productivity could be increased with no change in water use rate and result in increased WUE, the root structure of maize plays a major role in lodging, the uptake of nutrients and water and survival under unfavorable soil conditions (Sah *et al.*, 2020).

Thus, intercropping is an essential cultural practice in pest management which is based on the principle of reducing insect pests by increasing the diversity of an ecosystem (Risch, 2005). In addition, there is a modern trend for growing crops on beds (100 – 140 cm width) according to population densities of some field crops to save irrigation water by about 15% compared by traditional practice that included ridges 60-70 cm in width (Ouda *et al.*, 2007). It is known that crop ET is a very important parameter in irrigation management (Payero *et al.*, 2008) for better irrigation scheduling and for efficient use of water resources. Accordingly, intercropping cowpea with maize plays an important role in subsistence food production in both developed and developing countries, especially in situations of limited water resources (Dahmardeh *et al.*, 2010). So, it is expected that intercropping cowpea with maize will furnish specific environmental conditions (e.g. water and temperature regime, nutrient availability, producing a number of plant defensive secondary metabolites in intermediate steps which affect insect growth and development, low inter and intra- competition between plants and interaction with nodulating bacteria). Particularly, Takim (2012) demonstrated that the land equivalent ratio (LER) was higher than one in all intercropping plots of cowpea with maize, indicating optimum exploitation of the environmental resources. Induced resistance is sensed in the undamaged parts of the same plant and the neighboring plants as well (Holopainen and Blande, 2013) probably due to the accumulation of free amino acids that responded to both abiotic and biotic stresses (Florencio-Ortiz *et al.*, 2018). Therefore, the objective of this investigation was to assess the effect of applied irrigation water, infestation with insects and infection with virus on cowpea and maize productivity, as well as farmer income under intercropping condition.

Materials and Methods

A two-year study was carried out at Giza Agricultural Experiments and Research Station, ARC, Giza, Egypt during two successive summer seasons (2016 and 2017). The main factors were three levels of applied irrigation water (80, 100 and 120% of the recommended water irrigation applied level of maize was expressed as 80, 100 and 120% ETo, respectively) and three cropping systems (intercropping cowpea with maize, maize sole planting and cowpea sole planting). The experimental design was strip plot with three replications. Irrigation water treatments were randomly assigned to the vertical strips and cropping systems were allocated in the horizontal strips. Plot area was 25.2 m^2. Each sub plot consisted of 6 raised beds, 3.0 m long and 1.4 m wide. In case of maize sole planting (recommended), each sub plot consisted of 12 ridges, 3.0 m long and 0.7 m wide. Maize was grown in one plant per hill at 25 cm distance under intercropping and sole plantings, meanwhile cowpea was thinned to two plants per hill distanced at 20 cm between hills under intercropping and sole plantings. All normal agricultural practices were performed. Furrow irrigation was the irrigation system in this study. The lowest applied irrigation water (80% ETo) was 6952 and 6682 m^3/ha in the first and second seasons, respectively. The recommended applied irrigation water (100% ETo) was 8334 and 8001 m^3/ha in the first and second seasons, respectively. The highest applied irrigation water (120% ETo) was 9726 and 10224 m^3/ha in the first and second seasons, respectively. Nine treatments were the combinations of the previous factors as follows:

I- Applied irrigation water levels

1- 80% of the recommended applied irrigation water level of maize (80% ETo).

2- 100% of the recommended applied irrigation water level of maize (100% ETo).

3- 120% of the recommended applied irrigation water level of maize (120% ETo).

II- Cropping systems

1- Intercropping planting

Maize plants were grown in both sides of beds 140 cm width by growing one plant/hill distanced 25 cm apart, meanwhile two rows of cowpea were grown in middle of the bed by growing two plants/hill distanced 20 cm apart. Plant density of this system was 50% cowpea + 100% maize.

2- Sole plantings

a- Maize sole planting: maize plants were grown in both sides of beds 140 cm width by growing one plant/hill distanced 25 cm apart.

b- Cowpea sole planting: Four rows of cowpea were grown in middle of the bed (two plants /hill distanced 20 cm apart.

In addition to recommended sole maize: maize plants were grown in one row on ridges 70 cm by growing one plant/hill distanced at 25 cm apart. This treatment received 100% of applied irrigation water. It is important to mention that recommended sole maize and sole cowpea (100%) was used only to eastimate land equivalent ratio (LER and land equivalent coefficient (LEC), as well as economic evaluation.

Furrow irrigation was the irrigation system in the region. Maize Cultivar 'T.W.C. 321' and cowpea cultivar 'Cream 1' were used in this study. Calcium super phosphate (15.5% P_2O_5) at rate of 357 kg per ha was applied during soil preparation in the two summer seasons. Cowpea seeds were inoculated with *Rhizobium melitota* and gum Arabic was used as a sticking agent. Cowpea seeds and maize grains were sown on 16th and 21st May in 2016 and 2017 seasons, respectively. Mineral N fertilizer was added for maize at a rate of 285.6 kg N per ha as ammonium nitrate (33.5% N) in two equal doses; the first and second doses were applied before the first and the second irrigation, respectively, under intercropping and sole plantings. Also, mineral N fertilizer was added for cowpea at a rate of 35.7 kg N per ha as ammonium nitrate (33.5% N) before the first irrigation under intercropping and sole culture. Cowpea plants were cutting on 2nd and 5th August in 2016 and 2017, respectively, meanwhile maize plants were harvested on 22nd and 27th September in 2016 and 2017 seasons, respectively.

The studied traits:

I- Nitrogen, soluble sugar, total amino acids, growth regulators and enzymes in topmost ear leaf of maize: The following variables were recorded in topmost ear leaf of maize at 60 days from maize sowing and analyzed by the General Organization for Agricultural Equalization Fund, Agricultural Research Center, Giza, Egypt and the Regional Center for Food & Feed, A.R.C., Giza, Egypt: N content (mg/g DW), total soluble sugar (mg/g DW), total amino acids (mg/g DW), indole acetic acid 'IAA' (mAU), benzyl adenine 'BA' (mAU), zeatin 'mAU) and jasmonic acid 'JA' (mAU).

II- Water relation measurements: The amounts of applied irrigation water were calculated according to **Vermeiren and Jopling (1984)**. Crop water use was estimated by the method of soil moisture depletion according to **Majumdar (2002)** as follows:

$$\text{Water consumptive use} = \sum_{i=1}^{i-4} \frac{\theta 2 - \theta 1}{100} \times \text{Bdxd}$$

Where: Water consumptive use or actual evapotranspiration, ETa (mm), I = number of soil layer, θ2 = soil moisture content after irrigation, (%, by mass), θ1 = soil moisture contents just before irrigation, (%, by mass), Bd= soil bulk density (g/cm^3), d= depth of soil layer (mm).

III- Maize root length and total account of rhizobia in rhizosphere of maize roots: The following variables were recorded at 60 days from maize sowing. After 24 hours from the irrigation, root length was determined by separating the roots carefully from the soil with minimal root loss. The roots, which were still attached to the shoot, were gently shaken to remove soil adhering to them. After that, plants were cut before the crown base immediately to separate shoots from the roots. The root of each plant was washed then measured. Total count of rhizobia in rhizosphere of maize roots (colony forming unit 'cfu'). The culture medium was yeast extract mannitol agar, counting method was done by dilution plate count, incubation condition was 30 ^{O}C/2 – 3 days. Methods of microbial analysis were described by **Alexander and Clark (1965).** This analysis was done by the General Organization for Agricultural Equalization Fund, Agricultural Research Center, Giza, Egypt.

IV- Insect assemblages

1- **Maize plants:** The infestation of maize plants to aphids, jassids (leafhoppers), Hawaiian beet webworm, whiteflies and greater sugarcane borer was investigated after 60 days from maize planting in both the seasons. Samples were taken at 60 days from maize planting. Three maize plants, representing the sample, were randomly collected from the diagonals of each sub plot and examined to record the population density of five insects: aphids, jassids (leafhoppers), Hawaiian beet webworm, whiteflies and greater sugarcane borer.
2- **Cowpea plants:** The infestation of cowpea plants to aphids, jassids (leafhoppers), leaf miner fly, Hawaiian beet webworm, cotton leafworm and whiteflies was investigated after 60 days from cowpea planting in both the seasons. Samples were taken at 60 days from cowpea planting. Three cowpea plants, representing the sample, were randomly collected from the diagonals of each sub plot and examined to record the population density of five insects: aphids, jassids (leafhoppers), leaf miner fly, Hawaiian beet webworm, cotton leafworm and whiteflies.

V- Survey of viral infected cowpea plants

Samples of cowpea plants naturally displaying symptoms of soybean mosaic diseases were determined at every row in each plot at 60 days from cowpea sowing. The infected plants were labelled. Percentage of infestation was estimated by visual examination for virus symptoms. The percentage of infected cowpea plants was calculated as number of SMV infected / number of plants in plot. Labelled plastic bags containing the collected samples were brought to Virus and Phytoplasma Research Department, Plant Pathology Research Institute, Agricultural Research Center, Giza. Indirect ELISA was used for detection of SMV.

VI- Yield and its attributes

1- **Maize traits:** Ten plants at harvest were taken at random from each sub plot to determine plant height (cm), number of green leaves/plant, topmost ear leaf area/plant (cm^2), number of ears/plant, ear weight (g) and grain yield/plant (g). Grain yield (t/ha) were determined from grain weight of each sub plot and converted to t/ha.
2- **Cowpea traits:** Ten plants at harvest were taken at random from each sub plot to determine plant height (cm) and number of branches/plant. Forage yield (t/ha) was determined from forage weight of each sub plot and converted to t/ha.

VII- Competitive relationships

1- **Water use efficiency (WUE)**: WUE is calculated by dividing plant dry matter yield (kg/ha) to actual evapotranspiration (mm) according to **Howell *et al.* (1992)**.

$$\text{WUE}_{\text{maize}} = \frac{\text{Grain yield (kg /ha)}}{\text{Actual evapotranspiration (mm)}}$$

$$\text{WUE}_{\text{cowpea}} = \frac{\text{Forage yield (kg /ha)}}{\text{Actual evapotranspiration (mm)}}$$

2- **Water Equivalent Ratio (WER):** WER is used to estimate WUE in mixed cropping systems (Bai *et al.*, 2016). It is calculated as follows:

$$\text{WER} = \frac{\text{WUE}_{\text{int}_A}}{\text{WUE}_{\text{mono}_A}} + \frac{\text{WUE}_{\text{int}_B}}{\text{WUE}_{\text{mono}_B}}$$

Where: WUE$_{\text{mono}}$ is the monocropped WUE, and WUE$_{\text{int}}$ is the intercropped WUE of crop A (maize) and B (cowpea), respectively. A WER > 1 would indicate that water use was lower in the mixed stand compared with the sole crop and vice versa.

3- **Land equivalent ratio (LER):** LER defines as the ratio of area needed under sole cropping to one of intercropping at the same management level to produce an equivalent yield (Mead and Willey, 1980). It is calculated as follows: LER = $(Y_{ab} / Y_{aa}) + (Y_{ba} / Y_{bb})$; where Y_{aa} = Pure stand yield of crop a (maize), Y_{bb} = Pure stand yield of crop b (cowpea), Y_{ab} = Intercrop yield of crop a (maize) and Y_{ba} = Intercrop yield of crop b (cowpea).

4- **Land equivalent coefficient (LEC):** LEC is a measure of interaction concerned with the strength of relationship (Adetiloye, 1983). It is calculated as follows: LEC = La × Lb; where: La = relative yield of crop a (maize) and Lb = relative yield of crop b (cowpea).

VIII- Economic evaluation: Farmer's benefit was calculated by determining each of total returns, costs and net returns of intercropping and sole plantings. The prices were presented by market prices (2018) where one ton of maize grains and cowpea cut (forage) are USD 200.00 and USD 33.33, respectively. Financial costs were presented by Bulletin of Statistical Cost Production and Net Return (2018).

1- **Total return/ha (USD):** It is calculated by the following: Total return/ha = maize grain yield × price of maize grains + forage yield × price of cowpea cut (forage).

2- **Net return/ha (USD):** It is calculated by the following: net return/ha = total return – variable costs for the crops in intercropping and sole plantings.

Statistical analysis:

Statistical analysis was carried out according to Freed (1991). Mean comparisons were done using least significant differences (L.S.D) method at 5 percent level of probability to compare differences between the means (Gomez and Gomez, 1984).

Results and Discussion

I. Topmost ear leaf N, total amino acids, zeatin, BA, total soluble sugar and JA contents at 60 days from sowing

To study the physiological responses of maize plant to cropping system under the studied levels of applied irrigation water, some chemical and phytohormones contents of topmost ear leaf, including topmost ear leaf N, total amino acids, zeatin, BA, total soluble sugar and JA, were evaluated at 60 days from sowing (Figure 1) in 2016 summer season. Topmost ear leaf N and total amino acids contents of sole maize plants that received the lowest applied irrigation water level (80% ETo) recorded 24.65 and 22.18 mg/g DW and these contents were increased by 28.11 and 64.74%, respectively, in topmost ear leaf of intercropped maize plants that received the highest applied irrigation water level (120% ETo) at 60 days from sowing. Also, ear leaf zeatin and BA of sole maize plants that received the lowest applied irrigation water level recorded 2106.73 and 997.86 mAU and these contents reached 3938.21 and 709.73 mAU, respectively, by intercropping cowpea with maize that received 120% ETo at 60 days from sowing. Moreover, topmost ear leaf total soluble sugar content ranged from 49.43 mAU by growing maize plants in sole planting that received 80% ETo to 65.25 mAU by intercropping cowpea with maize that received 120% ETo, meanwhile, ear leaf JA content ranged from 95.73 mAU by intercropping cowpea with maize that received 120% ETo to 178.18 mAU by growing maize in sole planting that received 80% ETo at 60 days from sowing. These results show that phytohormones (zeatin, BA and JA) seem to be played a major role in topmost ear leaf growth and developmental regulation through contents of N, total amino acids and soluble sugar to acclimate with intercropping conditions by increasing levels of applied irrigation water up to 120% ETo.

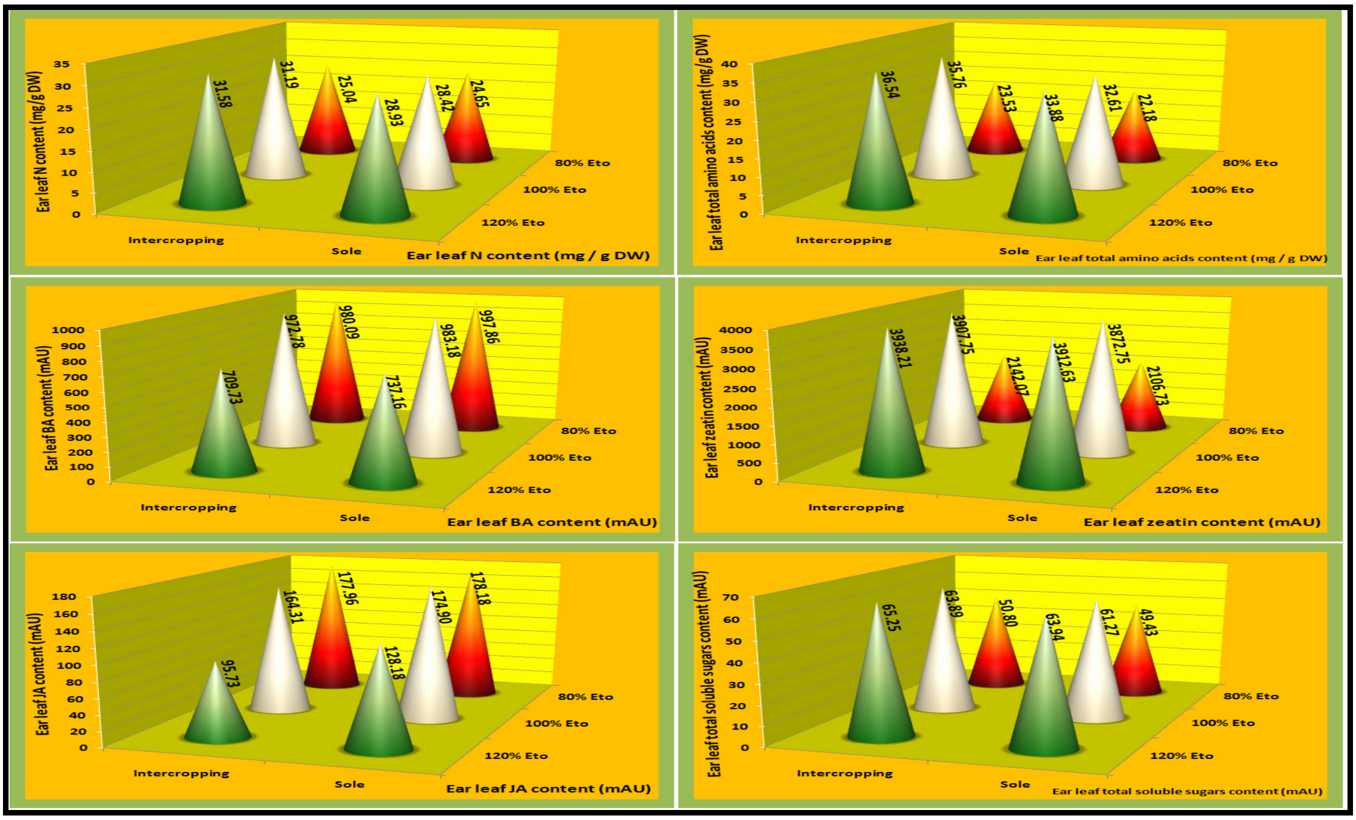

Fig. 1 : Ear leaf N, total amino acids, BA, zeatin, JA and total soluble sugars contents in maize after 75 days from sowing

II- Water consumptive use

a- Applied irrigation water levels

Water consumptive use was significantly affected by applied irrigation water levels in both seasons (Table 1). The lowest applied irrigation water level (6952 and 6682 m^3/ha) gave the lowest water consumptive use (4634 and 4864 m^3/ha) in the first and second seasons, respectively, meanwhile higher water consumptive use (6560 and 6904 m^3/ha) was obtained by the highest applied irrigation water level (9726 and 10224 m^3/ha) in the first and second seasons, respectively. These results may be attributed to the highest applied irrigation water (120% ETo) increased transpiration from plants and thereby high water consumptive use. These results indicate that high water consumptive use required large quantities of irrigation water under irrigated systems. Maize ear leaf of the highest applied irrigation water had the lowest phytohormones (BA and JA contents) than the other levels of applied irrigation water (Figure 1) which positively reflected on water consumptive use. According to Jackson (2017), maize plants had slight and short roots under high JA content, which negatively reflected on water uptake under the lowest applied irrigation water (80% ETo).

b- Cropping systems

Cropping systems significantly affected water consumptive use in both seasons (Table 1). Intercropped maize plants recorded higher water consumptive use than those of sole planting in both seasons. These results could be due to intercropping cowpea with maize increased inter-specific competition between the two species for basic growth resources which positively reflected on ear leaf N, total amino acids and soluble sugar (Figure 1) compared with sole plantings. These results are in harmony with those obtained by Abdel-Wahab *et al.* (2020) who revealed that intercrops had higher water consumptive use than sole plantings.

c- The interaction between applied irrigation water levels and cropping systems

The interaction between applied irrigation water levels and cropping systems had significant effects on water consumptive use in both seasons (Table 1). Intercropping cowpea with maize with application of 120% ETo gave the highest water consumptive use compared with other treatments in both seasons. These results could be due to the highest applied irrigation water (120% ETo) had low ear leaf BA and JA contents (Figure 1) which positively reflected on heavy and length maize roots as a result of increased potassium content (Jackson, 2017). Consequently, it is likely that the roots of intercropped cowpea plants will be able to absorb high quantities of potassium that resultant from maize roots (Metwally *et al.*, 2019). These data revealed that there was effect of applied irrigation water levels × cropping systems on water consumptive use.

III- Maize root length and total account of rhizobia in rhizosphere of maize roots at 60 days from sowing

a- Applied irrigation water levels

The root length of maize and total account of rhizobia in the rhizosphere of maize were affected significantly by the applied irrigation water levels at 60 days from sowing in both seasons (Table 2). Maize plant that received 6952 and 6682 m^3/ha gave higher root length 29.20 and 28.02 cm in the first and second seasons, respectively, meanwhile lower root length (24.89 and 24.22 cm in the first and second seasons, respectively) was obtained by the highest applied irrigation water level. Moreover, the recommended applied irrigation water levels recorded higher total account of rhizobia in rhizosphere of maize than those of the others. At surface irrigation, water moves with soil gravity so that roots penetrated soil profile to deep depths to uptake available soil water. These results may be attributed to increase water irrigation levels up to 120% ETo reduced oxygen that required for root respiration which negatively reflected on soil constituents and processes within the root environment and thereby BA and JA contents of maize ear leaf (Figure 1) and water consumptive use (Table 1). Plant response to high water tables depends on the degree and duration of root system, and possibly on the soil and air temperature and the stage of growth of the plant (Zaidi *et al.*, 2004).

b- Cropping systems

The root length of maize was not significantly affected by cropping systems, meanwhile, the total account of rhizobia in the rhizosphere of maize was affected at 60 days from sowing in both seasons (Table 2). Intercropped maize had a higher total account of rhizobia in the rhizosphere of maize (5.56 and 5.50 cfu) than sole maize (3.24 and 3.14 cfu), in the first and second season, respectively. These results probably due to the spatial arrangement of intercropping cowpea with maize increased inter–specific competition between the two species for basic growth resources especially soil water (Table 1) which increased nodulation of cowpea roots through the formation of more nodules during growth and development of cowpea. Accordingly, it is expected that this biological situation will promote rhizobia growth in the rhizosphere of maize as a result of the non-availability of soil nutrients compared with those in the rhizosphere of sole maize. It is known that many important aspects of plant-soil interactions such as plant nutrient acquisition (Uren and Reisennauer, 1988) and root colonization by rhizosphere microorganisms are mediated by rhizosphere processes (Baker, 1991). These results reveal that the root length of maize is not likely to be much affected in the cropping system than rhizobia in the rhizosphere of maize.

c- The interaction between applied irrigation water levels and cropping systems

The interaction between applied irrigation water levels and cropping systems significantly affected the root length of maize and total account of rhizobia in the rhizosphere of maize at 60 days from sowing in both seasons (Table 2). The lowest applied irrigation water level (80% ETo) had a higher root length of maize than 100 or 120% ETo under cropping systems. However, the recommended applied irrigation water level (100% ETo) gave a higher total account of rhizobia in the rhizosphere of maize than 80 or 120% ETo under cropping systems. Increasing applied irrigation water level from 80 to 120% ETo significantly decreased root length of intercropped and sole maize by 14.21 and 15.29% in the first season, and 13.27 and 13.84% in the second season, respectively. Also, increasing applied irrigation water level from 80 to 120% ETo significantly decreased total account of rhizobia in the rhizosphere of intercropped and sole maize by 3.83 and 2.48% in the first season, and 4.23 and 4.10% in the second season, respectively.

Table 1 : Effect of applied irrigation water levels and cropping systems on water consumptive use in both seasons

Applied irrigation water	Cropping systems	Water consumptive use (m^3/ha)	
		First season	**Second season**
80% ETo	Intercrops	5215	6014
	Sole maize	4495	4545
	Sole cowpea	4194	4035
	Mean	4634	4864
100% ETo	Intercrops	6678	7201
	Sole maize	5094	5130
	Sole cowpea	5036	4856
	Mean	5602	5729
120% ETo	Intercrops	7952	9202
	Sole maize	5837	5868
	Sole cowpea	5891	5644
	Mean	6560	6904
Average of cropping systems	Intercrops	6615	7472
	Sole maize	5142	5181
	Sole cowpea	5040	4845
L.S.D. 0.05 Applied irrigation water		963.36	1183.68
L.S.D. 0.05 Cropping systems		724.64	972.81
L.S.D. 0.05 Interaction		1167.47	1328.75

Table 2 : Effect of applied irrigation water levels and cropping systems on root length and rhizobia total account in rhizosphere of maize at 60 days from sowing in both seasons

Applied irrigation water	Cropping systems	Root length (cm)		Rhizobia total account in rhizosphere of maize roots (cfu)			
		First season	**Second season**	**First season**		**Second season**	
				Original data	**Transformed data**	**Original data**	**Transformed data**
80% ETo	Intercrops	29.05	27.94	3.1 x 10^5	5.48	2.7 x 10^5	5.43
	Sole maize	29.35	28.10	1.7 x 10^3	3.22	1.5 x 10^3	3.17
	Mean	29.20	28.02	---	4.35	---	4.30
100% ETo	Intercrops	27.77	26.68	8.5 x 10^5	5.92	7.8 x 10^5	5.88
	Sole maize	27.63	26.51	2.3 x 10^3	3.35	1.7 x 10^3	3.22
	Mean	27.70	26.59	---	4.64	---	4.55
120% ETo	Intercrops	24.92	24.23	1.9 x 10^5	5.27	1.5 x 10^5	5.20
	Sole maize	24.86	24.21	1.4 x 10^3	3.14	1.1 x 10^3	3.04
	Mean	24.89	24.22	---	4.21	---	4.12
Average of cropping systems	Intercrops	27.24	26.28	---	5.56	---	5.50
	Sole maize	27.28	26.27	---	3.24	---	3.14
L.S.D. 0.05 Applied irrigation water		0.26	0.24		0.12		0.15
F-test 0.05 Cropping systems		N.S.	N.S.		0.05		0.05
L.S.D. 0.05 Interaction		0.26	0.26		0.13		0.17

These results probably attributed to increasing applied irrigation water level from 80 to 120% ETo led to soil nutrients leached away, and formation toxins released by the incomplete breakdown of organic and mineral compounds (Dinnes *et al*., 2002). Generally, it seems that the root length of sole maize was more affected by increasing water irrigation levels up to 120% ETo compared with the root length of intercropped maize. Meanwhile, the total account of rhizobia in the rhizosphere of intercropped maize was more affected by increasing water irrigation levels up to 120% ETo compared with those of intercropped maize. These data indicate that each of these two factors acts dependently on the root length of maize and total account of rhizobia in the rhizosphere of maize at 60 days from sowing.

IV- Insect infestation

1- Maize crop

a- Applied irrigation water levels

At 60 days from sowing, applied irrigation water levels affected significantly infestation with aphids, jassids and whiteflies on maize leaves in both seasons, meanwhile, infestation with Hawaiian beet webworm and cotton leafworm on maize leaves were significantly affected in the first season only (Table 3). Increasing applied irrigation water from 80 to 120% ETo significantly increased infestation with aphids, jassids, Hawaiian beet webworm, cotton leafworm and whiteflies on maize leaves at 60 days from sowing. It is important to mention that there were no significant differences between the lowest applied irrigation water level (80% ETo) and the recommended applied irrigation water level (100% ETo) for infestation with all the studied insects on maize leaves. The highest applied irrigation water level (9726 and 10224 m^3/ha) recorded higher infestation with aphids on maize leaves by 36.94 and 30.00% in the first and second seasons, respectively than the recommended applied irrigation water level (100% ETo). Decreasing aphids assemblages on maize leaves with the application of 80% ETo may be due to the decreased insect protein uptake within the phloem sap, which maintained the plant's defense systems quickly as a result of increasing the induced BA and JA contents in ear leaf (Figure 1), as well as the root length with an acceptable total account of rhizobia in the rhizosphere of maize (Table 2).

Table 3 : Effect of applied irrigation water levels and cropping systems, as well as their interaction on number of insects assemblages in maize leaves at 60 days from sowing (2016 and 2017 seasons)

Applied irrigation water	Cropping systems	Aphids	Jassids	Hawaiian beet webworm	Cotton leafworm	Whitefly	Greater sugarcane borer
		First season					
80% ETo	Intercrop	12.16	13.80	12.30	5.50	11.00	7.00
	Sole maize	12.50	12.80	13.00	7.33	9.80	11.20
	Mean	12.33	13.30	12.65	6.41	10.40	9.10
100% ETo	Intercrop	14.00	13.20	14.00	7.70	12.80	10.30
	Sole maize	12.80	15.70	15.20	7.80	14.00	10.50
	Mean	13.40	14.45	14.60	7.75	13.40	10.40
120% ETo	Intercrop	19.50	21.20	19.20	10.80	16.30	12.70
	Sole maize	17.20	17.00	16.20	8.20	15.50	15.30
	Mean	18.35	19.10	17.70	9.50	15.90	14.00
Average of cropping systems	Intercrop	15.22	16.06	15.16	8.00	13.36	10.00
	Sole maize	14.16	15.16	14.80	7.77	13.10	12.33
L.S.D. 0.05 Applied irrigation water		1.09	1.18	2.78	1.44	3.13	N.S.
F-test 0.05 Cropping systems		*	*	N.S.	N.S.	N.S.	**
L.S.D. 0.05 Interaction		1.20	1.26	N.S.	1.68	N.S.	N.S.
Applied irrigation water	Cropping systems	Second season					
80% ETo	Intercrop	14.30	13.80	13.90	11.50	14.50	13.80
	Sole maize	13.40	14.20	12.70	10.30	14.50	14.20
	Mean	13.85	14.00	13.30	10.90	14.50	14.00
100% ETo	Intercrop	16.50	14.40	14.80	11.90	16.00	14.00
	Sole maize	14.50	14.40	13.70	11.08	13.90	12.70
	Mean	15.50	14.40	14.25	11.49	14.95	13.35
120% ETo	Intercrop	20.90	20.10	16.60	12.70	18.50	14.60
	Sole maize	19.40	14.20	13.30	11.00	17.08	14.90
	Mean	20.15	17.15	14.95	11.85	17.79	14.75
Average of cropping systems	Intercrop	17.23	16.10	15.10	12.03	16.33	14.13
	Sole maize	15.76	14.26	13.23	10.79	15.16	13.93
L.S.D. 0.05 Applied irrigation water		1.27	2.23	N.S.	N.S.	2.02	N.S.
F-test 0.05 Cropping systems		*	*	N.S.	*	*	N.S.
L.S.D. 0.05 Interaction		1.46	N.S.	N.S.	1.20	N.S.	N.S.

It is known that maize N uptake is dependent on physiological mechanisms occurring in the roots (Henry and Raper, 1991), as well as on environmental conditions such as humidity, temperature, and water availability (Scholberg *et al.*, 2002). So, it is expected that low water consumptive use enhanced ear leaf of maize glucosinolates accumulation that has a negative impact on aphid growth (De Vos *et al.*, 2007). Meanwhile, the increased BA could be arrested aphids herbivore growth by increasing benzoxazinoids accumulation that correlated with the increased accumulation of callose as a defense against aphids feeding (Ahmad *et al.*, 2011). Moreover, aphids secreted a variety of proteins into the phloem as they are feeding (Elzinga and Jander, 2013), and some of these are known to suppress plant defense responses (Elzinga *et al.*, 2014). These results are in the same context as those obtained by Varsani *et al.* (2019) who indicated that leaf aphids population was significantly higher on benzoxazinoids-deficient maize plants. Also, Xie *et al.* (2020) reported that there were lower net reproductive rates of aphids, intrinsic rates of increase and finite rates of increase under drought stress compared with aphids reared on plants in the absence of stress.

The highest applied irrigation water (120% ETo) had higher ear leaf total amino acids and N contents than those of the other levels of applied irrigation water (Figure 1), which positively reflected on aphids growth and development under high water consumptive use (Table 1). Lower N concentration implies lower levels of leaf protein and amino acids and, as a result, reduced nutritive value for herbivores (Lincoln *et al.*, 1986). It is known that aphids are considered to rely primarily on free amino acids for their nutritional requirements (Rahbe *et al.*, 1995). These results indicate that aphids benefited from maize leaves that had elevated levels of total amino acids and N in phloem sap under high water consumptive use compared with the other levels of applied irrigation water (Figure 1). These results are in harmony with Faria *et al.* (2007) who showed that Bt maize had higher amino acids levels than the other maize lines which might partially explain the observed increased aphid performance. Also, aphid populations were increased with increasing foliar N in maize leaves (Van Emden and Harrington, 2007). Moreover, the highest applied irrigation water (120% ETo) had higher ear leaf total soluble sugars and zeatin contents than those of the other irrigation water levels which positively reflected on aphids growth and development. These results may be due to aphids didn’t prefer soluble sugars or zeatin with high concentrations. The results reveal that ear leaf total soluble sugars and zeatin contents act as powerful feeding stimulants for aphids with increasing applied irrigation water levels up to 120% ETo. The host plant, which contained the lowest level of total soluble sugars, does not become infected with aphids (Kamel and El-Gengaihi, 2009). Additionally, herbivore pressure of the plants is associated with the abundance of zeatin under well-watering conditions (Schäfer *et al*., 2015).

With respect to jassids, the highest applied irrigation water level (120% ETo) recorded higher infestation of this insect on maize leaves by 32.17 and 19.09% in the first and second seasons, respectively, than the recommended applied irrigation water level (100% ETo). Low populations of jassids on maize leaves with the application of 80% ETo may be due to the high temperature surrounding the plants as a result of water shortage (Table 1) which translated into low leaf water potential and cell turgor pressure where leafhopper populations appear to build up with the rains (Bosque-Pérez and Buddenhagen, 1999). The population of leafhoppers increases as temperature decreases (Patel *et al*., 2015).

On the other hand, the highest applied irrigation water (120% ETo) recorded higher ear leaf N and total amino acids contents than those of the other irrigation water levels which positively reflected on jassids infestation on maize leaves. Leafhoppers perform better on plants that are high in soluble N (Prestidge, 1982). Also, Prestidge and McNeill (1983) showed that jassids preference may depend on the presence or absence of individual amino acids. Conversely, the highest applied irrigation water (120% ETo) had lower ear leaf BA and JA contents than those of the other levels of applied irrigation water which positively reflected on jassids growth and development. In this concern, Lang *et al.* (1999) found that spider mites in a maize crop depressed populations of leafhoppers where Lepidopteran larvae, beetles, spider mites and vertebrate grazers are natural enemies for the insect pests (Balkema-Boomstra *et al.* 2003). It is known that high cucurbitacin B (1.126%) was obtained in the presence of benzyl adenine and naphtalene acetic acid (Toker *et al*., 2003) where cucurbitacin attracted the natural enemies, spider mites, to the plant (Heil, 2008). In another study, Pieterse *et al.* (2012) demonstrated that JA mediated signaling pathways against phloem-feeding insects which explained lower jassids assemblages in maize plants that received the lowest (80% ETo) or the recommended (100% ETo) applied irrigation water. In contrast, the highest applied irrigation water (120% ETo) gave higher ear leaf total soluble sugars and zeatin contents than those of the other irrigation water levels which positively reflected on jassids growth and development. These results could be attributed to 120% ETo reduced soil air, which negatively affected the nutritional status of the leaves through an imbalance in the distribution of zeatin and their tendency to hydrolyze the carbohydrates into soluble sugars that benefited the growth of jassids. Despite the presence of zeatin hormone with a high concentration in maize leaves, the deficiency of oxygen availability to the root of maize led to an imbalance in the hormonal state of the plant.

With respect to Hawaiian beet webworm, the highest applied irrigation water level (120% ETo) recorded higher infestation of this insect on maize leaves by 21.23% in the first season than the recommended applied irrigation water level (100% ETo). Decreasing Hawaiian beet webworm density on maize leaves with the application of 80% ETo may be due to lower phenylacetaldehyde compound in leaves of maize plants. The moth attractant phenylacetaldehyde is effective in capturing *S. recurvalis* (Othim *et al.*, 2017). The highest applied irrigation water (120% ETo) had lower ear leaf JA and BA contents than those of the other levels of applied irrigation water which positively reflected on Hawaiian beet webworm growth and development probably through furnishing suitable environment which allowed the insects to feed, reproduce and produce new generations.

Also, this biological situation could enhance the availability of soil potassium in the rhizosphere of maize which reflected on the vegetative growth of maize. Spraying with BA increased the total number of microhairs per maize leaf (Ramadan and Flowers, 2004). In Africa, the Hawaiian beet webworm/amaranth leaf-webber, *Spoladea recurvalis*, has often been reported to be a major pest in amaranth fields, with a potential of causing complete defoliation of foliage under severe outbreaks (Aderolu *et al*., 2013). Amaranth foliage has high nutritive and medicinal value as it is rich in vitamins and potassium (Niveyro *et al*., 2013). Moreover, potassium shortage activates of signaling cascades including reactive oxygen species and phytohormones; *i.e.* JA (Hafsi *et al*., 2014) especially C4-crop has 100% of light saturation enhanced total soil potassium (Metwally *et al*., 2019).

Meanwhile, the highest applied irrigation water (120% ETo) had higher ear leaf N and amino acid contents than those of the other levels of applied irrigation water which positively reflected on Hawaiian beet webworm infestation on maize leaves. Consequently, it seem that the highest applied irrigation water (120% ETo) increased ear leaf N and amino acids contents that enhanced leaf protein content compared with the other levels of applied irrigation water. It is known that Hawaiian beet webworm attracted to the leaves that contain high vegetable proteins (Niveyro *et al*., 2013). Moreover, the highest applied irrigation water (120% ETo) recorded higher ear leaf total soluble sugars and zeatin contents than those of the other levels of applied irrigation water which reflected positively on Hawaiian beet webworm growth and development. Herbivore pressure of the plants is associated with the abundance of zeatin under well-watering conditions (Schäfer *et al*., 2015).

With respect to cotton leafworm, the highest applied irrigation water level (120% ETo) recorded higher infestation of this insect on maize leaves by 22.58% in the first season than the recommended applied irrigation water level (100% ETo). Decreasing cotton leafworm assemblages on maize leaves with the application of 80% ETo may be due to the inverse relationship between N supply and the biosynthesis of more phenolics which negatively reflected on insect assemblages. With regard to ear leaf N and amino acid contents, the highest applied irrigation water (120% ETo) gave higher ear leaf N and amino acids contents than those of the other levels of applied irrigation water which positively reflected on cotton leafworm infestation on maize leaves. According to Adham *et al.* (2009), cotton leafworm required total protein and N to survive grow and reproduce. Also, the highest applied irrigation water (120% ETo) had lower ear leaf JA and BA contents than those of the other levels of applied irrigation water which positively reflected on cotton leafworm growth and development. It is known that JA induces the production of benzoxazinoids, a class of metabolites that can provide protection against insect herbivores, pathogens, and competing plants (Frey *et al*., 2009). Feeding by chewing herbivores brings benzoxazinoid glucosides into contact with β-glucosidases, leading to the formation of toxic breakdown products (Niemeyer, 2009).

On the other hand, the highest applied irrigation water (120% ETo) recorded higher ear leaf total soluble sugar and zeatin contents than those of the other levels of applied irrigation water which positively reflected on cotton leaf worm growth and development. Cotton leaf worm density was increased by high levels of carbohydrates (Adham *et al.*, 2009). Moreover, herbivore pressure of the plants is associated with the abundance of zeatin under well watering conditions (Schäfer *et al.*, 2015).

With respect to whiteflies, the highest applied irrigation water level (120% ETo) recorded higher infestation of this insect on maize leaves by 18.65 and 18.99% in the first and second seasons, respectively, than the recommended applied irrigation water level (100% ETo). Decreasing whiteflies density on maize leaves with the application of 80% ETo may be due to whitefly prefer moist leaves (high water consumption) that increase their feeding and assemblages (Abdel-Wahab T. *et al.*, 2020).

The highest applied irrigation water (120% ETo) recorded lower ear leaf JA and BA contents than those of the other levels of applied irrigation water which positively reflected on whiteflies' growth and development. It is likely that increasing applied irrigation water from 80 to 120% ETo increased N supply in leaves of maize and reduced the biosynthesis of phenolics that plays an important role in defense mechanism against insect attack (Marchner, 1995). Also, the highest applied irrigation water (120% ETo) had higher ear leaf N and amino acids contents than those of the other levels of applied irrigation water which positively reflected on whiteflies on maize leaves. It is known that Bemisia populations increased linearly with the increase of plant N content as reported by Lu *et al.* (2007). Moreover, the highest applied irrigation water (120% ETo) gave higher ear leaf total soluble sugar and zeatin contents than those of the other levels of applied irrigation water which positively reflected on whiteflies growth and development because of sugars is attracted more whiteflies for feeding (Athar *et al.* 2011).

b- Cropping systems

Cropping systems affected significantly infestation with aphids and jassids on maize leaves in both seasons, meanwhile, infestation with greater sugarcane borer on maize leaves was affected significantly in the first season and infestation with cotton leaf worm and whitefly were affected significantly in the second one (Table 3). The results indicate that intercropping cowpea with maize had higher infestation with aphids, jassids, cotton leaf worm and whiteflies than those of sole maize. Meanwhile, the reverse was true for greater sugarcane borer. It has been observed that excessive supply of N caused plant tissue to soften and offer little resistance to chewing or sucking insects/pests (Athar *et al.*, 2011). It is known that a symbiotic relationship was found between summer legumes and corn under intercropping which reduced N mineral fertilization of the two species. This relationship due to cowpea plants that fixed the atmospheric N by rhizobia to facilitate N for intercropped maize roots (El-Shamy *et al.*, 2015; Abdel-Wahab *et al.*, 2016; Abdel-Wahab *et al.*, 2019; Metwally *et al.*, 2019 and Abdel-Wahab and Abdel-Wahab, 2020).

Higher aphids assemblages were recorded in intercropped maize leaves than sole maize in both seasons. These results show that intercropped maize plants were susceptible to infestation with aphids than sole maize probably due to higher N, total amino acids and soluble sugars contents in intercropped maize plants (Figure 1). Aphids feed on carbohydrates and amino acids from the leaf tissue with alternating between sexual and asexual generations, which allows them to proliferate rapidly (Guerrieri and Digilio, 2008).

Higher jassids assemblages within maize leaves were recorded in intercropped maize than sole maize in both seasons. These results show that intercropped maize were susceptible to infestation with jassids than sole maize. It was observed that leafhopper population density shows a sharp peak in grasses surrounding maize fields (Asanzi *et al.*, 1994). Consequently, cowpea appears to be a natural refuge for hoppers where feeding and reproduction become available. Maize plants had low leafhopper populations when there is an abundance of grass hosts for oviposition and development (Bosque-Pérez and Buddenhagen, 1999). Higher cotton leafworm assemblages within maize leaves were recorded in intercropped maize than sole maize in both seasons. These results show that intercropped maize were susceptible to infestation with cotton leafworm than sole planting. Cowpea plants are clearly a safe haven for cotton leafworm that transferred to maize plants through the biological coexistence particularly Abd-Allah *et al.* (2018) reported that the most insects attacking cowpea plants are *Spodoptera littoralis*. They added that the effect of temperature was significant and positive while the relative humidity effect was negative on the population density of egg-masses of *S. littoralis*. Also, higher whiteflies assemblages within maize leaves were recorded in intercropped maize than sole maize in both seasons. These results show that intercropped maize plants were susceptible to infestation with whiteflies than sole planting probably due to cowpea furnished wet environment surrounding maize plants. Whiteflies were increased as maize plant density increased in the intercropping system meaning whiteflies prefer moist environment (Abdel-Wahab T. *et al.*, 2020).

Meanwhile, sole maize had higher infestation with greater sugarcane borer than intercropped maize probably due to higher temperature surrounding maize plants under sole planting than intercropped ones. It is known that maize plants are more susceptible to be attacked by greater sugarcane borer under dry conditions, where hot and dry weather can favor attacks (Del Rio and Simpson, 2014).

c- The interaction between applied irrigation water levels and cropping systems

The interaction between applied irrigation water levels and cropping systems significantly affected infestation with aphids and cotton leafworm in both seasons, as well as jassids in the first season (Table 3). Intercropping cowpea with maize had higher infestation with aphids on maize leaves than the other treatments under 120% ETo. These results could be due to applied irrigation water levels differentially interacted with cropping systems to affect aphids around the leaves of maize plants. Sole or intercropped maize plants that received the lowest applied irrigation water (80% ETo) had lower infestation with aphids than the other treatments. This biological situation probably due to 80% ETo did not satisfy maize water requirements which translated into low BA and JA contents of ear leaf (Figure 1) and water consumptive use (Table 1) that reflected on increased root length of maize plant (Table 2). On the other hand, sole maize plants recorded lower infestation with aphids than intercropped ones under the recommended applied irrigation water (100% ETo). It seems that growing cowpea with maize in the same bed increased aphids assemblages around maize plants than sole maize under 100% ETo probably due to cowpea that enhanced rhizobia in the rhizosphere of maize more than those of rhizosphere of intercropped maize (Table 2), which positively reflected on total N, amino acids and soluble sugars contents of ear leaf (Figure 1). Meanwhile, maize roots suffered from increased irrigation water over the recommended that negatively affected BA and JA contents of ear leaf (Figure 1) as a result of deficiency of availability of oxygen to the root of maize. This biological situation was improved by the continuous supply of the fixed N through cowpea that attracted aphids under high water consumptive use. Thus, the cropping systems appeared to have a greater significant effect on aphids spreading around the leaves of maize plants than the effect of applied irrigation water under 100 and 120% ETo and this effect disappears under low water consumptive use.

With respect to jassids, intercropping cowpea with maize with the highest applied irrigation water (120% ETo) recorded a higher infestation of this insect on maize leaves than the other treatments. These results may be attributed to increased the maize tissue softness as a result of increasing applied irrigation water up to 120% ETo and this thinness was enhanced by the continuous supply of the fixed N by cowpea (Metwally *et al.*, 2019), indicating a suitable environment to attract jassids. It appears that jassids spreading on the leaves of maize plants are influenced greatly by applied irrigation water than the cropping systems.

Intercropping cowpea with maize plants with application of the highest irrigation water (120% ETo) had higher infestation with cotton leafworm on maize leaves than the other treatments. These results may be due to the highest applied irrigation water (120% ETo) reduced relative humidity and this biological situation was enhanced by growing cowpea with maize that attracts cotton leafworm. It appears that applied irrigation water and intercropping planting had the same impact on the spread of cotton leafworm on the leaves of maize plants. These data reveal that cropping systems differently responded to applied irrigation water levels at 60 days from sowing for aphids and cotton leafworm in both seasons, and for jassids in the first season.

2- Cowpea crop

a- Applied irrigation water levels

At 60 days from sowing, applied irrigation water levels significantly affected infestation with aphids, jassids, leaf miner fly, Hawaiian beet webworm and whiteflies on cowpea leaves in both seasons, meanwhile cotton leafworm was affected in the first season only (Table 4). Increasing applied irrigation water from 80 to 120% ETo significantly increased infestation with aphids, jassids, leaf miner fly, Hawaiian beet webworm, cotton leafworm and whiteflies on cowpea leaves at 60 days from sowing.

It is important to mention that there were no significant differences between 80 and 100% ETo for infestation with all the studied insects on cowpea leaves except cotton leafworm. The highest applied irrigation water level (9726 and 10224 m^3/ha) recorded higher infestation with aphids on cowpea leaves by 29.81 and 28.57% in the first and second seasons, respectively than the recommended applied irrigation water level (100% ETo). Decreasing aphids assemblages on cowpea leaves with the application of 80% ETo may be due to low water consumptive use (Table 1) translated into plant cell turgor pressure, where successful feeding and nutrient uptake by aphids require adequate plant cell turgor pressure (Holtzer *et al.*, 1988). Lower net reproductive rates of aphids, intrinsic rates of increase, and finite rates of increase were observed under drought stress compared with aphids reared on plants in the absence of stress (Xie *et al.*, 2020).

With respect to, the highest applied irrigation water level (9726 and 10224 m^3/ha) recorded higher infestation of jassids, leaf miner fly Hawaiian beet webworm on cowpea leaves by 22.80 and 43.87%, 23.20 and 32.39% and 32.79 and 18.56% in the first and second seasons, respectively than the recommended applied irrigation water level (100% ETo). Decreasing jassids assemblages on cowpea leaves with the application of 80% ETo may be due to the leaf tissue was relatively dry and did not have enough moisture to be a suitable refuge for the insect to lay eggs, particularly Murtaza *et al.* (2019) showed that humidity is favorable for jassid growth and development. Meanwhile, decreasing leaf miner fly assemblages on cowpea leaves with the application of 80% ETo may be attributed to the insect's inability to tolerate the leaves dryness and consequently an incomplete life cycle of this insect within the plant tissue. The selection of the host plant by *Liriomyza* is positively correlated with the water content of the leaves (Wei *et al.*, 2000). On the other hand, decreasing Hawaiian beet webworm assemblages on cowpea leaves with the application of 80% ETo could be due to low potassium content in the tissue of cowpea leaves which furnished unsuitable environment for Hawaiian beet webworm growth and development.

The highest applied irrigation water level (9726 and 10224 m^3/ha) recorded higher infestation with cotton leafworm and whiteflies on cowpea leaves by 18.34 and 6.09% and30.59 and 20.00% in the first and second seasons, respectively, than the recommended applied irrigation water level (100% ETo). Decreasing cotton leafworm and whiteflies assemblages on cowpea leaves with the application of 80% ETo probably due to due to the leaf tissue was relatively dry and did not have enough moisture to be a suitable refuge for these insects to lay eggs. According to Montagnini and Jordan (1983), whitefly attack was increased with increasing soil water through rainfall rate.

b- Cropping systems

At 60 days from sowing, cropping systems significantly affected infestation with Hawaiian beet webworm on cowpea leaves in both seasons, meanwhile infestation with aphids, jassids and leaf miner fly on cowpea leaves was significantly affected in the second season (Table 4). Intercropped cowpea had lower infestation with aphids, jassids, leaf miner fly and Hawaiian beet webworm than those of sole cowpea at 60 days from sowing. These results may be attributed to maize plants acted as a biological barrier to insect attacks on cowpea plants. Conversely, sole cowpea probably suffered from higher warmer temperatures than intercropped ones which positively reflected on insect growth and development. Warming has a direct positive effect on insect herbivore performance by increasing fecundity (Meisner *et al.*, 2014) and reducing their development time (Van De Velde *et al.*, 2016). Moreover, the adults of Hawaiian beet webworm are attracted to the light as reported by Jackson (2017). Certainly, temperatures tend to enhance insect survival because it accelerated metabolism which may lead to higher consumption, growth, and development rate (Kamel *et al.*, 2018).

c- The interaction between applied irrigation water levels and cropping systems

The interaction between applied irrigation water levels and cropping systems significantly affected infestation with Hawaiian beet webworm in both seasons, as well as jassids and leaf miner fly at 60 days from sowing in the second season (Table 4). Sole cowpea with application of the highest applied irrigation water (120% ETo) had higher infestation with Hawaiian beet webworm on cowpea leaves than the others. Sole cowpea had high temperature and solar radiation that attracts Hawaiian beet webworm (Figueroa, 2003 and Jackson, 2017). The infestation with Hawaiian beet webworm may be increased with increasing leaf potassium content under 120% ETo as a result of increasing photosynthesis process and potassium uptake in tissues of sole cowpea.

With respect to jassids, sole cowpea with application of the highest applied irrigation water (120% ETo) had higher infestation with jassids on cowpea leaves than the others. These results could be due to jassids attack increases with increasing humidity (120% ETo) and increasing light transmission (sole cowpea) which reflected positively on jassids assemblages (Jackai, 1995). With respect to leaf miner fly, sole cowpea with application of the highest applied irrigation water (120% ETo) had higher infestation with leaf miner fly on cowpea leaves than the others. High temperatures are harmful for the parasitoids of leaf miner fly (Costa-Lima *et al.*, 2014) which increased leaf miner fly assemblages on sole cowpea. The infestation with leaf miner fly was increased with increasing leaf moisture content (120% ETo) which reflected positively on insect growth rate. These data show that cropping systems differently responded to applied irrigation water levels at 60 days from sowing for Hawaiian beet webworm in both seasons, and for jassids and leaf miner fly in the second season

Table 4 : Effect of applied irrigation water levels and cropping systems, as well as their interaction on number of insects assemblages in cowpea leaves at 60 days from sowing (2016 and 2017 seasons)

Applied irrigation water	**Cropping systems**	**Aphids**	**Jassids**	**Leaf miner fly**	**Hawaiian beet webworm**	**Cotton leafworm**	**Whitefly**
		First season					
80% ETo	Intercrop	12.16	13.00	13.70	12.30	5.50	11.00
	Sole cowpea	11.30	11.30	12.80	15.20	6.00	11.80
	Mean	11.73	12.15	13.25	13.75	5.75	11.40
100% ETo	Intercrop	14.00	13.20	15.50	14.00	7.70	12.80
	Sole cowpea	13.50	15.30	13.80	16.80	9.20	14.00
	Mean	13.75	14.25	14.65	15.40	8.45	13.40
120% ETo	Intercrop	19.50	21.20	18.80	19.20	10.80	16.30
	Sole cowpea	16.20	13.80	17.30	21.70	9.20	18.70
	Mean	17.85	17.50	18.05	20.45	10.00	17.50
Average of cropping systems	Intercrop	15.22	15.80	16.00	15.16	8.00	13.36
	Sole cowpea	13.66	13.46	14.63	17.90	8.13	14.83
L.S.D. 0.05 Applied irrigation water		3.58	3.23	3.45	1.77	2.32	3.64
F-test 0.05 Cropping systems		N.S.	N.S.	N.S.	*	N.S.	N.S.
L.S.D. 0.05 Interaction		N.S.	N.S.	N.S.	1.84	N.S.	N.S.
Applied irrigation water	Cropping systems	Second season					
80% ETo	Intercrop	14.30	13.80	14.50	13.90	11.50	14.50
	Sole cowpea	15.10	15.60	16.40	14.60	13.00	15.30
	Mean	14.70	14.70	15.45	14.25	12.25	14.90
100% ETo	Intercrop	16.50	14.40	15.60	14.80	11.90	16.00
	Sole cowpea	16.40	15.00	14.90	18.60	12.70	16.00
	Mean	16.45	14.70	15.25	16.70	12.30	16.00
120% ETo	Intercrop	19.50	20.10	20.08	16.60	12.70	18.50
	Sole cowpea	22.80	22.20	20.30	23.00	13.40	19.90
	Mean	21.15	21.15	20.19	19.80	13.05	19.20
Average of cropping systems	Intercrop	16.76	16.10	16.72	15.10	12.03	16.33
	Sole cowpea	18.10	17.60	17.20	18.73	13.03	17.06
L.S.D. 0.05 Applied irrigation water		1.67	1.26	0.54	2.36	N.S.	3.33
F-test 0.05 Cropping systems		*	*	*	**	N.S.	N.S.
L.S.D. 0.05 Interaction		N.S.	1.37	0.66	2.93	N.S.	N.S.

V- Soybean mosaic virus (SMV)

Figure (2) indicates the infection severity within intercropped and sole cowpea leaves under the studied applied irrigation water levels at 60 days from sowing. Applied irrigation water from 80 to 120% ETo led to an increase in the extent of the virus's effect in the cowpea leaf tissue, and these negative changes were enhanced under sole cowpea.

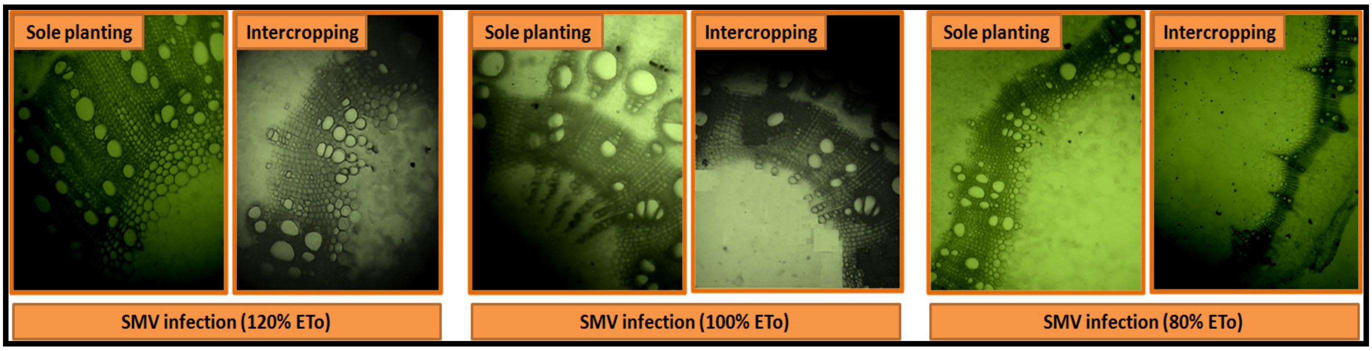

Fig. 2 : The infection severity within intercropped and sole cowpea leaves under the studied applied irrigation water levels at 60 days from sowing

a- Applied irrigation water levels

Applied irrigation water levels significantly affected infection with SMV on cowpea leaves at 60 days from sowing in both seasons (Table 5). Increasing applied irrigation water from 80 to 120% ETo significantly increased infection with SMV on cowpea leaves at 60 days from sowing. It is worthy to note that there were no significant differences between 120 and 100% ETo for infection with SMV in both seasons. The highest applied irrigation water level (9726 and 10224 m^3/ha) recorded higher infection with SMV by 18.45 and 18.17% in the first and second seasons, respectively than the lowest applied irrigation water level (80% ETo). Decreasing infection with SMV on cowpea leaves that received the lowest applied irrigation water level (80% ETo) could be attributed to aphids assemblages on cowpea leaves were lower than those of the other levels of applied irrigation water (Table 4).

Table 5 : Effect of applied irrigation water levels and cropping systems, as well as their interaction on infection with SMV in cowpea leaves at 60 days from sowing (2016 and 2017 seasons)

Treatments		Infection with SMV/plant (%)	
		First season	**Second season**
80% ETo	Intercrop	29.26	32.73
	Sole cowpea	30.67	33.41
	mean	29.96	33.07
100% ETo	Intercrop	33.75	36.56
	Sole cowpea	35.22	37.95
	mean	34.48	37.25
120% ETo	Intercrop	35.20	37.23
	Sole cowpea	35.78	40.93
	mean	35.49	39.08
Average of cropping systems	Intercrop	32.73	35.50
	Sole cowpea	33.89	37.43
L.S.D. 0.05 Applied irrigation water		2.29	3.05
F-test 0.05 Cropping systems		1.13	1.72
L.S.D. 0.05 Interaction		N.S.	N.S.

b- Cropping systems

Cropping systems significantly affected infection with SMV at 60 days from sowing in both seasons (Table 5). The results indicate that leaves of intercropped cowpea had a lower infection with SMV than those of sole cowpea. These results could be due to intercropping furnished more humid environment for cowpea plants than sole planting (Table 1) which positively reflected on SMV infection, besides maize plants acted as a biological barrier to aphids attacks on cowpea plants at 60 days from sowing under intercropping conditions.

c- The interaction between applied irrigation water levels and cropping systems

The interaction between applied irrigation water levels and cropping systems did not significantly affect infection with SMV on cowpea leaves at 60 days from sowing in both seasons (Table 5). These data indicate that each of these two factors acts independently on infection with SMV in cowpea leaves at 60 days from sowing.

VI- Economic yield and its attributes

1- Maize crop

a- Applied irrigation water levels

Plant height, number of green leaves/plant, topmost ear leaf area/plant, number of ears/plant, ear weight, grain yield/plant, 100-grain weight and grain yield/ha were significantly affected by applied irrigation water levels in both seasons (Table 6).

Table 6 : Effect of applied irrigation water levels and cropping systems, as well as their interaction on maize grain yield and its attributes (2016 and 2017 seasons)

Irrigation water treatments	Cropping systems	Plant height (cm)	Number of green leaves / plant	Topmost ear leaf area/plant (cm^2)	No. of ears / plant	Ear weight (g)	Grain yield (g/plant)	100–grain weight (g)	Grain yield (t/ha)
First season									
80% ETo	Intercrop	213.00	10.13	691.61	0.93	147.20	91.80	34.73	4.65
	Sole maize	211.66	10.56	658.32	0.96	143.40	95.73	35.76	4.77
	mean	212.33	10.35	674.96	0.94	145.30	93.76	35.25	4.71
100% ETo	Intercrop	264.33	14.46	1121.36	1.08	185.33	166.03	40.53	9.03
	Sole maize	266.33	14.90	1081.62	1.07	183.06	156.33	40.73	8.95
	mean	265.33	14.68	1101.49	1.07	184.20	161.18	40.63	8.99
120% ETo	Intercrop	265.33	14.86	1100.04	1.08	186.43	173.96	39.46	9.13
	Sole maize	269.00	14.53	1062.38	1.05	188.40	169.43	40.70	8.91
	mean	267.16	14.70	1081.21	1.06	187.41	171.70	40.08	9.02
Average of cropping systems	Intercrop	247.55	13.15	971.00	1.03	172.98	143.93	38.24	7.60
	Sole maize	249.00	13.33	934.10	1.03	171.62	140.50	39.06	7.54
L.S.D. 0.05 Applied irrigation water F-test 0.05 Cropping systems L.S.D. 0.05 Interaction		35.49 N.S. N.S.	3.55 N.S. N.S.	24.03 * 32.25	0.06 N.S. N.S.	35.36 N.S. N.S.	14.68 N.S. N.S.	3.64 N.S. N.S.	2.23 N.S. N.S.
Maize sole planting (recommended)		266.16	14.33	1084.92	1.05	182.66	169.15	39.33	9.02
Second season									
80% ETo	Intercrop	223.33	12.52	803.67	1.00	158.13	106.20	36.92	5.05
	Sole maize	224.00	12.00	772.22	0.99	154.96	112.40	37.47	5.08
	mean	223.66	12.26	787.94	0.99	156.55	109.30	37.19	5.06
100% ETo	Intercrop	288.00	16.20	1168.32	1.11	195.33	195.26	41.13	9.37
	Sole maize	284.33	15.43	1141.02	1.09	198.73	180.70	41.45	9.32
	mean	286.16	15.81	1154.67	1.10	197.03	187.98	41.29	9.34
120% ETo	Intercrop	287.66	15.83	1180.63	1.08	200.10	196.53	41.73	9.44
	Sole maize	287.66	15.36	1160.62	1.10	196.56	182.86	40.46	9.29
	mean	287.66	15.60	1170.62	1.09	198.33	189.70	41.09	9.36
Average of cropping systems	Intercrop	266.33	14.85	1050.87	1.06	184.52	166.00	39.93	7.95
	Sole maize	265.33	14.26	1024.62	1.06	183.42	158.65	39.79	7.89
L.S.D. 0.05 Applied irrigation water F-test 0.05 Cropping systems L.S.D. 0.05 Interaction		44.40 N.S. N.S.	3.06 N.S. N.S.	19.06 * 24.73	0.05 N.S. N.S.	37.35 N.S. N.S.	15.33 N.S. N.S.	2.92 N.S. N.S.	2.86 N.S. N.S.
Maize sole planting (recommended)		284.33	15.06	1138.65	1.11	202.16	190.93	40.66	9.26

The recommended applied irrigation water level (100% ETo) recorded higher all the studied maize traits (without significant differences between 100 and 120% ETo) compared with those of the lowest one (80% ETo) in both seasons. Therefore, it is expected that total leaf size became smaller with the lowest application of applied irrigation water as a result of lowering cellular turgor pressure (Kramer and Boyer, 1995) that inhibiting cell division in the meristem and cell expansion in the elongation zone (Avramova *et al*., 2015). Carbon assimilation in leaves, photoassimilate (mainly sucrose) transport in the phloem, and carbohydrate inter conversion and transport between the maternal tissues and developing kernels are important steps which determine grain filling and yield formation (Ning *et al*., 2018a). If the root zone is lacking sufficient water, many cobs will be empty or will contain only a few grains (Udom and Kamalu, 2019). It seems that the improvement of soil water conditions by application of 20% irrigation water over the recommended applied irrigation water did not achieve significant increments for all the studied maize traits. These results probably due to the recommended applied irrigation water level (100% ETo) had a higher total account of rhizobia in the rhizosphere of maize (Table 2) that positively reflected on some chemical and phytohormones contents in ear leaf (Figure 1) through root architecture and thereby lower insect infestation (Table 3) at 60 days from sowing than the other levels of irrigation water.

It is important to mention that the recommended applied irrigation water level (100% ETo) recorded lower infestation with all the studied insects and SMV infection on maize leaves which positively reflected on maize yield. According to Slman *et al.* (2006), if the aphid population is common enough, grain production is reduced through partial prevention of pollination. Additionally, water is one of the strongest factors that control leaf area through the leaf cell expansion (Muller *et al.,* 2011), where Ren *et al.* (2014) reported that the maximum grain-filling rate decreased under waterlogging. These results are in accordance with those obtained by Pandit *et al.* (2017) who revealed that loss of grain production in the dry season is connected to shortages of water used for irrigation. Also, Pandit *et al.* (2018) found that the loss of yield varied from 30–90% depending on the crop stage and the degree and duration of water stress. Loss of normal root architecture overall leads to a reduction in grain yield per ha (Sah *et al.*, 2020).

b- Cropping systems

All the studied maize traits (except topmost ear leaf area/plant) were significantly affected by the cropping systems in both seasons (Table 6). As a result of intercropping, topmost ear leaf area/plant was increased by 3.95 and 2.56% in the first and second seasons, respectively, compared with sole maize. Although the spatial arrangement of maize plants under intercropping and sole plantings was similar, intercropped maize benefited fixed N by cowpea which positively reflected on N content in maize leaves compared with sole planting (Figure 1). These results probably due to intercropped maize plants had higher water consumptive use than sole maize (Table 1) which positively reflected on topmost ear leaf area/plant. It is known that the amount of water required for maize depends on the evaporative demand of the environment (Wright and Bell, 1992). According to Abdel-Wahab *et al.* (2016), intercropping cowpea with maize enhanced the efficiency of cowpea plant to fix atmospheric N_2 that increased soil N availability and facilitated N uptake for intercropped maize. Consequently, the transfer of high total soluble sugars to developing kernels is an important factor to increase grain filling. Also, intercropping cowpea with maize may be increased organic carbon in rhizosphere of maize roots that led to increase in total soluble sugars in maize leaves compared with sole planting, where N fertilization stimulated glucose, fructose, and sucrose biosynthesis as indicated by the greater ear leaf (Ning *et al.*, 2018b).

Moreover, intercropping cowpea with maize resulted in an increase in total amino acids in maize leaves compared with sole planting (Figure 1). Root-synthesized amino acids are transported in the xylem to mature source leaves, where they are used for metabolism, stored, or loaded into the phloem to supply sinks with N (Atkins *et al.*, 1983). If one of the essential amino acids is limiting, the deficiency results in a negative N balance (Berg *et al.*, 2002). It seems that the biologically fixed N by cowpea roots improved essential amino acids in maize tissues which positively reflected on kernel growth. N deficiency is known to effectively perturb many metabolic processes in plants, e.g., chlorophyll biosynthesis, reduction in protein synthesis in most plants and thereby inhibit net photosynthesis rate indirectly, and decline in free amino acids (Epstein and Bloom, 2005). Photosynthesis and subsequent respiration provide the energy required for the synthesis of amino acids (Nunes-Nesi *et al.*, 2010). With respect to leaf zeatin content, intercropping cowpea with maize improved zeatin content in maize leaves as compared with sole planting (Figure 1). These results may be due to zeatin works as a growth regulator where it increases dry matter accumulation in the grains during the filling period. These results are in accordance with those obtained by Abdel-Wahab *et al.* (2016) who indicated that grain yield of maize was increased by intercropping with cowpea although maize plant density was identical with maize sole planting. Also, Jata *et al.* (2018) showed that short-duration grain legumes promote growth and yield of the major intercrop.

c- The interaction between applied irrigation water and cropping systems

Topmost ear leaf area/plant was significantly affected by the interaction between applied irrigation water and cropping systems in both seasons, meanwhile the other traits were not affected (Table 6). Intercropping cowpea with maize that received the recommended applied irrigation water level (100% ETo) recorded higher topmost ear leaf area/plant compared with the other treatments. These results could be due to low water consumptive use (Table 1) that positively affected infestation with aphids, jassids and cotton leafworm (Table 3) through increased endogenous BA and JA contents of maize leaves (Figure 1). So, it is expected that this biological situation improved topmost ear leaf area/plant that has increased in size due to the availability of carbon that resulted from the intercropped cowpea plants. In other words, maize plants positively interacted with the recommended applied irrigation water level (100% ETo) to reduce leaf senescence by intercropped cowpea plants. This leads to increase in total soluble sugars in topmost ear leaf of maize plants (Figure 1). Plants exposed to a CO_2-enriched environment show higher concentrations of carbohydrates including starch and soluble sugars (Robinson *et al.*, 2012). On the other hand, sole maize with application of the lowest applied irrigation water level (80% ETo) had lower topmost ear leaf area/plant than the other treatments. It seems that the water shortage is the main reason for reducing the topmost ear leaf area/plant, despite soil N availability. Meanwhile, intercropping cowpea with maize significantly increased topmost ear leaf area/plant under water shortage conditions, which indicates that intercropping legumes with maize enhanced resistance to water stress (Metwally *et al.*, 2019). It is important to mention that increasing applied irrigation water level from 100 to 120% ETo did not increase topmost ear leaf area/plant under intercropping and sole plantings. These results may be due to the highest applied irrigation water level (120% ETo) recorded high infestation with aphids, jassids and cotton leaf worm under intercropping and sole plantings (Table 3) as a result of deficiency of oxygen availability to the root of maize which negatively reflected on topmost ear leaf area/plant during growth and development. These data show that each of these factors act dependently on topmost ear leaf area/plant.

2- Cowpea crop

a- Applied irrigation water

Plant height, number of branches/plant and forage yield/ha were significantly affected by applied irrigation water levels in both seasons (Table 7). The highest irrigation water level (120% ETo) gave higher plant height, number of branches/plant and forage yield/ha than the lowest applied irrigation water level (80% ETo) in both seasons. Cowpea had a rapid root growth to gain available soil water in arid and semiarid regions (Steel and Summerfield, 1985).

Table 7 : Effect of applied irrigation water levels and cropping systems, as well as their interaction on plant height, number of branches/plant and cowpea forage yield (2016 and 2017 seasons)

Irrigation water treatments	Cropping systems	Plant height (m)	Branches/plant (no.)	Forage yield (t/ha)
First season				
80% ETo	Intercrop	2.20	3.33	5.90
	Sole cowpea	2.10	3.35	12.91
	mean	2.15	3.34	9.41
100% ETo	Intercrop	2.84	3.61	8.87
	Sole cowpea	2.55	3.81	19.10
	mean	2.69	3.71	13.99
120% ETo	Intercrop	2.78	3.59	8.17
	Sole cowpea	2.47	3.78	18.63
	mean	2.63	3.68	13.40
Average of cropping systems	Intercrop	2.61	3.51	7.65
	Sole cowpea	2.37	3.65	16.88
L.S.D. 0.05 Applied irrigation water		0.47	0.23	1.87
F-test 0.05 Cropping systems		0.21	0.11	1.49
L.S.D. 0.05 Interaction		N.S.	0.29	2.22
Second season				
80% ETo	Intercrop	2.24	3.44	5.25
	Sole cowpea	2.16	3.40	11.80
	mean	2.20	3.42	8.52
100% ETo	Intercrop	2.94	3.73	7.74
	Sole cowpea	2.63	3.93	18.16
	mean	2.78	3.83	12.95
120% ETo	Intercrop	2.89	3.71	7.20
	Sole cowpea	2.58	3.89	17.34
	mean	2.73	3.80	12.27
Average of cropping systems	Intercrop	2.69	3.62	6.73
	Sole cowpea	2.46	3.74	15.77
L.S.D. 0.05 Applied irrigation water		0.51	0.34	1.81
F-test 0.05 Cropping systems		0.19	0.11	1.36
L.S.D. 0.05 Interaction		0.66	0.42	2.03

It is important to mention that there are no significant differences between the recommended and the highest applied irrigation water levels (100 and 120% ETo, respectively) for the studied traits. Increasing applied irrigation water level from 80 to 100% ETo increased plant height by 25.11 and 26.36%, number of branches/plant by 11.07 and 11.98% and forage yield/ha by 48.67 and 51.99% in 2016 and 2017 seasons, respectively. Certainly, water is needed for the photosynthetic process of cowpea, maintenance of turgor and cooling of leaves. The lowest applied irrigation water level (80% ETo) may be reduced the availability of CO_2 in the leaf tissues, and thus limited the production of assimilates can occur in C3 plants (Monclus *et al*., 2006). When water supply becomes inadequate, stomata will close, affecting CO_2 assimilation and transpiration (Taiz and Zeiger, 2010).

On the other hand, increasing applied irrigation water to 20% over the recommended did not increase cowpea forage yield where there was the stability of productivity between them despite the increased amount of irrigation water. This result could be due to the highest applied irrigation water level (120% ETo) retained leaf moisture longer with cooler canopy temperatures which increased insect infestation compared with other levels of applied irrigation water (Table 4). In addition, increasing the applied irrigation water levels from 100 to 120% ETo did not increase SMV infection in cowpea plants (Table 5) and also is expected that low dry matter accumulation was occurred due to the roots immersion. Flooded plants accumulated less root total non-structural carbohydrates when subjected to leafhoppers feeding (Barta *et al*., 2002) which leads to little dry matter accumulation during growth and development. These results are in agreement with Boukar *et al.* (2019) who reported the productivity of cowpea could be hampered under drought conditions.

b- Cropping systems

Plant height, number of branches/plant and forage yield/ha were significantly affected by the cropping systems in the two seasons (Table 7). Intercropping cowpea with maize gave a lower number of branches/plant and forage yield/ha than those of sole planting; the converse was true for plant height. In general, intercropping cowpea with maize decreased forage yield/ha by 54.68 and 57.32% in 2016 and 2017 seasons, respectively, compared with those of sole planting. These results probably due to the number of intercropped cowpea plants per unit area occupied 50% of sole planting. Also, intercropping cowpea with maize could be increased interspecific competition between the intercrops for basic growth resources as reported by Abdel-Wahab *et al.* (2016). Although intercropping cowpea with maize reduced infestation with aphids, jassids, leaf miner fly and Hawaiian beet webworm, as well as SMV infection compared with sole planting (Tables 4 and 5), the decrease in cowpea plant density to 50% of sole planting was the major reason for decreasing forage yield/ha under intercropping.

c- The interaction between applied irrigation water levels and cropping systems

The number of branches/plant and forage yield/ha were significantly affected by the interaction between applied irrigation water levels and cropping systems in both seasons, meanwhile plant height was affected in the second season only (Table 7). Sole cowpea that received the highest applied irrigation water level (100% ETo) had the highest number of branches/plant and forage yield/ha compared with the other treatments. These results may be attributed to the recommended applied irrigation water level (100% ETo) satisfied growth and development cowpea requirements which positively reflected on metabolism during growth and development. It is likely that the efficiency of the photosynthetic process of either intercropped or sole cowpea plant was enhanced with increasing applied irrigation water from 80 to 100% of the recommended applied irrigation water then decreased by applying the highest water irrigation as a result of increased leaf moisture that attracted jassids, leaf miner fly and Hawaiian beet webworm (Table 4). These data reveal that cropping systems differently responded to applied irrigation water levels for number of branches/plant and forage yield/ha in both seasons, and for plant height in the second season.

VII- Competitive relationships

1- Water use effieincy (WUE)

WUE of intercropping cowpea with maize and sole plantings of both crops under the studied applied irrigation water levels are shown in Figure (3). WUE of maize ranged from 0.89 to 1.75 and from 0.83 to 1.81 kg/mm in the first and second seasons, respectively. Sole maize that received 100% ETo recorded the highest WUE, meanwhile, the highest WUE of intercropped maize was obtained by application of 120% ETo.

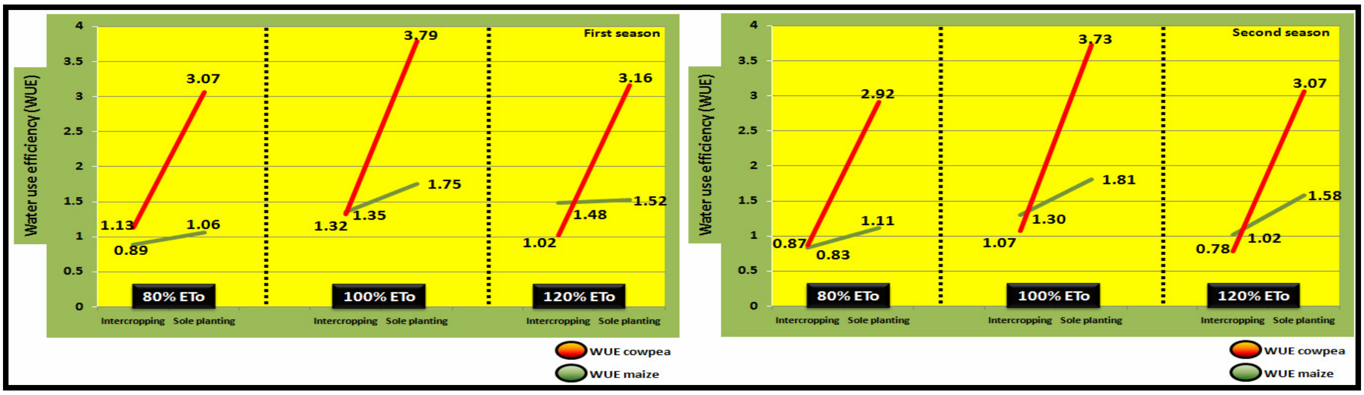

Fig. 3 : Water use effieincy (WUE) of intercropping cowpea with maize and sole plantings of both crops under the studied applied irrigation water levels.

These results indicate that WUE of maize was increased by increasing applied irrigation water level from 80 to 120% ETo under intercropping conditions probably due to higher N fixed by cowpea than sole maize (Table 2), which increased water consumptive use (Table 1). With respect to cowpea, WUE of this crop ranged from 1.13 to 3.79 and from 0.87 to 3.73 kg/mm in the first and second seasons, respectively. Sole cowpea that received 100% ETo recorded the highest WUE, meanwhile, the highest WUE of intercropped cowpea was obtained by application of 100% ETo. These results show that WUE of cowpea was decreased by increasing applied irrigation water level from 100 to 120% ETo under intercropping and sole plantings. This indicates that intercropping cowpea with maize did not increase cowpea's ability to benefit from the highest applied irrigation water (120% ETo).

2- Water equivalent ratio (WER)

WER ranged from 1.07 to 1.20 in the first season and it ranged from 0.90 to 1.04 in the second one (Figure 4). The values of WER of intercropping were higher than one (except 120% ETo in the second season). Increasing the applied irrigation water level from 80 to 120% ETo decreased WER under intercropping cowpea with maize in both seasons. The highest WER was achieved by intercropping cowpea with maize that received 80% ETo followed by intercropping cowpea with maize that received 100% ETo. These results show that intercropping cowpea with maize that received 80 or 100% ETo had yield advantage meanwhile intercropping cowpea with maize that received 120% ETo had yield disadvantage.

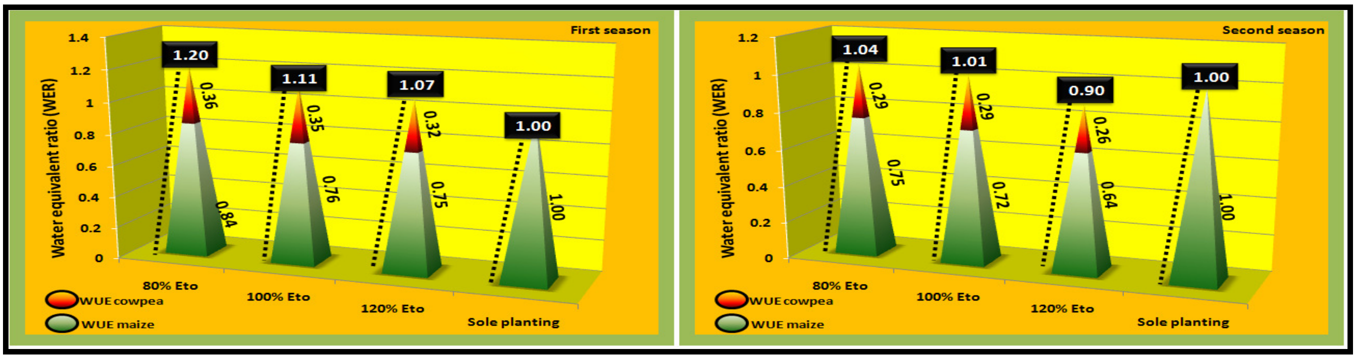

Fig. 4 : Water equivalent ratio (WER) of intercropping cowpea with maize and sole plantings of both crops under the studied applied irrigation water levels.

3- Land equivalent ratio (LER)

The values of land equivalent ratio (LER) were estimated by using data of recommended sole plantings of both crops. 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 (Vendemeer, 1989). It can be used both for replacement and additives series of intercropping. The results obtained strongly coincided with the definition of LER. LER values were greater than one for intercropping cowpea with maize that received the recommended or the highest applied irrigation water level (100 or 120% ETo, respectively) in both seasons (Figure 5). LER ranged from 0.81 by intercropping cowpea with maize that received the lowest applied irrigation water level (80% ETo) to 1.46 by intercropping cowpea with maize that received the recommended applied irrigation water level (100% ETo) in the first season.

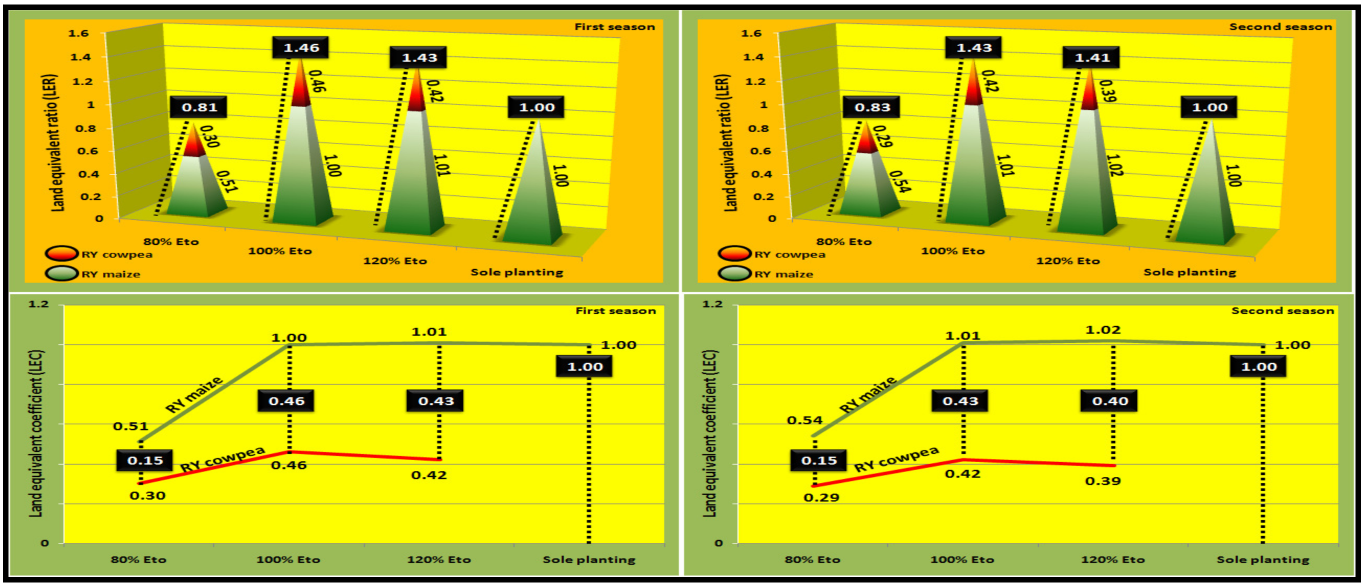

Fig. 5 : Competitive relationships of intercropping cowpea with maize and sole plantings.

Also, LER ranged from 0.83 by intercropping cowpea with maize that received the lowest applied irrigation water level (80% ETo) to 1.43 by intercropping cowpea with maize that received the recommended applied irrigation water level (100% ETo) in the second season. LER of 1.46 indicates that the planted area to sole plantings would need to be 46% greater than the planted area to interplant to produce the same combined yields (i.e. 46% more land would be required as a sole crop to produce the same yield as interplanting). The advantage of the highest LER by intercropping cowpea with maize that received the recommended applied irrigation water level (100% ETo) probably due to intercropping had some facilitative interactions through different mechanisms to reduce inter and intra-specific competition between cowpea and maize, respectively, for available resources by increasing applied irrigation water level from 80 to 100% ETo of under intercropping conditions. These results are harmony with Abdel-Wahab *et al.* (2016) who showed that intercropping cowpea with maize had yield advantage than sole planting.

4- Land equivalent coefficient (LEC)

Land equivalent coefficient (LEC) is a measure of interaction concerned with the strength of the relationship. Land equivalent coefficient (LEC) is used for a two- crop mixture the minimum expected productivity coefficient (PC) is 25 percent, that is, a yield advantage is obtained if LEC value was exceeded 0.25. LEC values were greater than 0.25 for intercropping cowpea with maize that received the recommended or the highest applied irrigation water level (100 or 120% ETo, respectively) in both seasons (Figure 5). LEC ranged from 0.15 by intercropping cowpea with maize that received the lowest applied irrigation water level (80% ETo) to 0.46 by intercropping cowpea with maize that received the recommended applied irrigation water level (100% ETo) in the first season. Also, LEC ranged from 0.15 by intercropping cowpea with maize that received the lowest applied irrigation water level (80% ETo) to 0.43 by intercropping cowpea with maize that received the recommended applied irrigation water level (100% ETo) in the second season. A yield advantage occurred because the component crops differed in their utilization of growth resources in such a way that when they are grown in association, they are able to complement each other and to work better overall use environmental resources than when they were grown separately.

VIII- Economic evaluation

Data in Table (8) show economic evaluation of intercropping cowpea with maize after treated with water treatments in both seasons.

1- Total return

Total return ranged from 2098.30 to 2101.63 USD/ha in the first season. Also, total return ranged from 1184.98 to 2131.97 USD/ha in the second one. Intercropping cowpea with maize that received 100% ETo had higher total return than the other treatments in both seasons. These results show that intercropping cowpea with maize that received the recommended applied irrigation water level (100% ETo) increasd total return by 16.49 and 15.11% in the first and second seasons, respectively, as compared with recommended sole planting of maize.

2- Net return

Net return ranged from 134.33 to 1063.63 USD/ha in the first season. Also, net return ranged from 192.67 to 1093.97 USD/ha in the second one. Intercropping cowpea with maize that received 100% ETo had higher net return than the other treatments in both seasons. These results show that intercropping cowpea with maize that received the recommended applied irrigation water level (100% ETo) increased net return by 11.84 and 9.50% in the first and second seasons, respectively, as compared with recommended sole planting of maize.

These results indicate that intercropping cowpea with maize that received the recommended applied irrigation water level (100% ETo) was more profitable and should be recommended at the same area.

Table 8 : Economic evaluation of intercropping cowpea with maize under three applied irrigation water levels in both seasons.

Treatments	**Income of maize (USD/ha)**	**Income of cowpea (USD/ha)**	**Total return (USD/ha)**	**Financial costs (USD/ha)**	**Net return (USD/ha)**
First season					
Intercropping cowpea with maize 80% ETo	930.00	196.64	1126.64	992.31	134.33
100% ETo	1806.00	295.63	2101.63	1038.00	1063.63
120% ETo	1826.00	272.30	2098.30	1049.42	1048.88
Sole maize (recommended) 100% ETo	1804.00	---	1804.00	853.00	951.00
Second season					
Intercropping cowpea with maize 80% ETo	1010.00	174.98	1184.98	992.31	192.67
100%ETo	1874.00	257.97	2131.97	1038.00	1093.97
120% ETo	1888.00	239.97	2127.97	1049.42	1078.55
Sole maize (recommended) 100% ETo	1852.00	---	1852.00	853.00	999.00

Conclusion

Growing two rows of maize on beds 140 cm width (one row/side) with growing two rows of cowpea in middle of maize beds with the application of the recommended applied irrigation water level of maize (100% ETo) reduced aphids, jassids and cotton leafworm on maize leaves, and jassids, leaf miner fly and Hawaiian beet webworm on cowpea leaves, as well as increased maize grain yield per ha and water and land usages, as well as economic return. This treatment increased water, land usages and economic return compared with sole maize.

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