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Effect of maize (*Zea mays* L.) - cowpea (*Vigna unguiculata* L.) intercropping on light distribution, soil temperature and soil moisture in arid environment

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Abstract

Sole crops and intercrops of maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L.) were studied at eight planting ratios of maize: cowpea (100:100, 50:100, 100:50, 25:75, 75:25, 50:50, 0:100 and 100:0) and two harvest times (milky stage and doughy stage). This experiment was carried during two years (2007 and 2008) on Research Center, University of Zabol, Iran, to investigate the influence of cowpea on the microclimate of their intercrop and sole maize (SM) as control. Measurements of photosynthetically active radiation (PAR), soil temperature (ST), soil moisture (SM) and crop yield were carried out to study the effects of intercropping on crop yield in a cowpea-maize intercropping system in Sistan at southeast of Iran. We found that intercropping increased the amount of absorption PAR compared to sole crop of maize. The highest amount of PAR was obtained at 100% cowpea + 100% maize with no significant difference to 100% cowpea + 50% maize. The lowest amount of PAR was obtained at 75% maize + 25% cowpea. Intercropping system had significant effects on soil temperature and soil moisture ($P<0.01$). The highest soil temperature was obtained at sole maize and the lowest temperature was at sole cowpea. Soil moisture was lowest at sole maize and highest at sole cowpea. LER (land equivalent ratio) values were greater in all intercropping systems with different planting ratios which indicated yield advantage of intercropping over sole cropping of maize. Results indicate that intercropping can increase light interception and increased shading in intercropping system compared to sole maize and reduce water evaporation and improve conservation of soil moisture. Based on high grain and suitable environmental condition, intercrop productivity compared to sole crop could be selected for improving the productivity of maize/cowpea mixture in the Southeast of Iran.

Key words: Intercropping system, cowpea-maize, land equivalent ratio (LER), photosynthetically active radiation (PAR), soil moisture, soil temperature.

Introduction

Multiple cropping (i.e. intercropping or mixed cropping) plays an important role in agriculture because of the effective utilization of resources, significantly enhancing crop productivity compared with that of monoculture crops [21]. Two or more crops planted together were known as intercropping system in order to maximize beneficial interactions. Intercropping is a sustainable soil management means in many developed and developing countries[11]. Introduction of a grain legume in cereal-based cropping system aims at increased productivity and profitability to achieve food and nutritional security and sustainability [42]. Cereals are commonly intercropped with legumes, in the hope that the former will benefit from the N-fixed by the later [3]. Other benefits include maximum resource utilization and income stability[2] and higher total returns [11]. Intercropping is widely accepted as a sustainable practice due to its yield advantage, high utilization efficiency of light and water, and pest and disease suppression [45, 47, 51, 54]. Legumes are valuable in improving yield, quality, and N and P nutrition of pearl millet [37]. Most studies on intercropping have focused on resource utilization, including water [40, 36], light [10] and nutrients [19], resulting in substantial yield advantage compared with sole cropping [20]. In the intercrop the degree of resource complementarily, the total yield and the participation of yield between the individual species is determined by both inter- and intraspecific competition, which again is influenced by the availability of environmental resources, the relative frequency of the species and the density of components[13]. However, the intercropped species might utilize the growth resources more efficiently than sole crops, and resources may thus support a greater number of plants. A number of mechanisms exist by which intercrops utilize plant growth resources such as light, water and nutrients more efficiently than the equivalent sole crops [1, 12, 16]. This occurs if the intercrop components are not competing for exactly the same ecological niches in time and space [29], and if interspecific competition is weaker than the intraspecific competition for a given factor [47, 51]. A yield advantage in species mixtures may occur when component crops differ in their use of growth resources in such a way, that when they are grown together they are able to complement each other and so, make better overall use of resources than when grown separately. A more efficient use of limiting resources in intercrops can occur whether the component crops use resources either at different times, in different parts of the soil profile or aerial canopy or in different forms [46, 51]. Water is the fundamental resource that defines life on this planet and is often scarce on land. Particularly in dry environments, soil water is a resource with a high degree of spatial and temporal heterogeneity [34]. In future, water will become increasingly scarce particularly in semi-arid regions. Therefore, global climate change may lead to higher potential evapotranspiration, decreasing precipitation and increasing frequency of high intensity rains. At the same time, water demand is most likely to grow due to higher population density and expanding areas of irrigation [14, 38]. Hence, there is an urgent need to use water more efficiently in this region. Knowledge and understanding of water uptake is important for the development of crop models, which have become important tools for agronomic research and crop management. Selection of suitable intercropping systems that use water in a complementary way is therefore crucial for successful agroforestry and intercropping in general [30]. A further constraint to the modeling of crop mixtures relates to the difficulties in determining water uptake and use by each component crop in a mixture. Earlier research on water use by crop mixtures or intercrops has, therefore, simply compared total water use of the sole and intercrops [26], without seeking to understand how the process of water partitioning proceeds. Water partitioning modules of the few published intercrop models also use somewhat simple assumptions. For example, all the component plants in a mixture extract water from a 'common pool', which would imply that a direct competition for water would occur in every zone of the soil profile, even if the root systems are clumped into localized zones of the soil profile [18]. These also provide a good canopy cover in the early stages to control soil loss through erosion especially on sloped lands and also to control weeds [17]. Intercropping can conserve soil water by providing shade, reducing wind speed and increasing infiltration with mulch layers and improved soil structure [44, 52]. The location of the different root systems in an intercropping system affects water uptake and the ability of each crop to compete for water resources [39]. The close relationship between intercepted solar radiation and total dry matter yields of crops is well documented [5, 25], the lower leaf area index leads to a reduction in light interception, biomass production and yield and to changes in the canopy microclimate. The productivity of each component of the crop association depends on its ability to capture light, water and nutrients, and on its response to microclimatic changes. The main factor regulating the soil temperature is the degree of soil cover and soil depth. In Australia, for example, it was predicted that mulch intercepting 80% and 50% of the incoming radiation would keep surface temperatures within 10 and 20%, respectively, of ambient air temperatures [32]. Surface soil temperatures, in a similar environment, fluctuated from near 20°C at night to over 50°C at midday in unmulched soil, whereas surface temperature of mulched soil ranged from near 20°C at night to 38°C during the day [6]. At a depth of 10 cm, midday temperatures were 30°C in the mulched soil and 36°C in the unmulched soil. Wet soils buffered soil temperature fluctuation more than dry soils. For an intercrop of leek and celery, light interception and soil cover were significantly increased compared with a leek monoculture. The use of land equivalent ratio (LER) as a measure for calculating the cropping advantage of intercrops over sole crops is simple, neglecting weed suppression; yield reliability, grain quality, and minimum profitable yield are all relevant factors for farmers' perspective [31]. A study indicates that LER of 1.25 can be interpreted as 25% greater yield for intercropping or as a 25% greater area requirement for the monocrop system [50].

We investigated the effect of planting ratios on soil moisture, soil temperature, light capture and yield of a maize/cowpea intercropping system. The hypotheses we tested were: (1) intercropping is better at light capture compared to sole maize, (2) intercropping is better at conservation of soil moisture and temperature compared to sole maize and (3) intercropping is better at yield advantages compared to sole crops.

Materials and Methods

Site: A factorial field experiment at randomized complete block design with four replications was carried out over two cropping seasons (2007 and 2008) on Research Center of University of Zabol, Iran (61° 41'E, 30° 54'N, altitude 483 m above sea level). Average of 30 years rainfall was 49 mm.

Crop management: Maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L.) were planted in an intercropping arrangement with 8 and 20 plants m^{-2}, respectively. Planting dates for the cropping seasons 2007 and 2008 were March 5. The experiment was carried out during 2007 and 2008 growing season (Figs 1-3) on a sandy loam soil (Table 1). All phosphorus (150 kg/ha) and potassium (100 kg/ha) and half of nitrogen (50 kg/ha) were applied at sowing while rest of nitrogen was applied at stem elongation stage. All other cultural practices including irrigation, thinning and weeding were kept normal and uniform for all the treatments. The treatment comprising the individual plot size was 7 m × 4 m. Maize variety K.S.C 704 and cowpea variety cv29005 were sown on two years (2007-2008) by hand. Inter-row spacing was 25 and

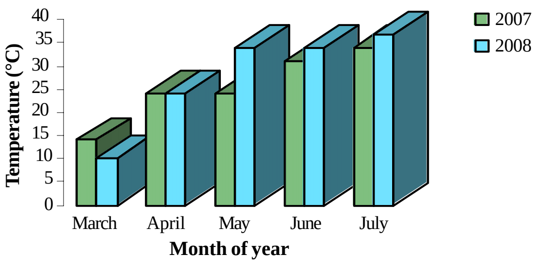

Figure 1. Means of temperature (ºC) at growth season.

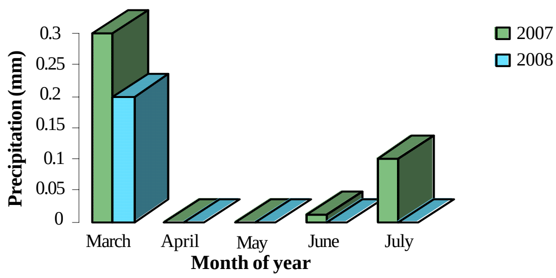

Figure 2. Means of precipitation (mm) at growth season.

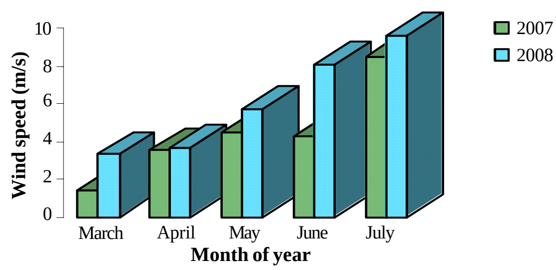

Figure 3. Means of wind speed (m/s) at growth season.

Table 1. Soil characteristics of the experiment area during the 2007 and 2008 growing seasons.

Year	Depth (cm)	pH	EC (mmohs/cm)	N (%)	P (ppm)	K (ppm)	Sand %	Silt%	Clay %
2007	0-20	8.0	7.8	0.053	7.8	190	63	20	17
2008	0-20	7.9	5.4	0.022	3.4	210	52	28	20

10 cm in the sole crops of maize and cowpea with a between row spacing of 50 cm. Initially 2-3 seeds were sown per hole. Twenty five days after sowing (25 March), seedlings were thinned to retain one healthy seedling per hole. Three hand weedings were done 20, 30 and 40 DAP.

Experimental design: The treatments were compared in a factorial experiment at RCBD design with eight levels of planting ratios 100:100 (M:C), 50:100 (m:C), 100:50 (M:c), 50:50 (m:c), 75:25 (M˝:c˝), 25:75 (m˝:C˝), 0:100 (C) and 100:0 (M), and two levels of maturity stages (milky stage and doughy stage) in four replication.

Quantification of soil moisture (SM) and temperature (ST): Soil moisture dynamics were studied during both years in all treatments, using TDR probes (three replications per treatment) that measured depth segments (0–20). The measurement system for the TDR used are based upon a cable tester (Tektronix 1502C) coupled to a handheld computer (Husky FS/2) [43]. Soil water content during the growing period was calculated for all treatments.

The soil layer above thermometers was used to record soil temperatures. The thermometers were buried in the soil horizontally (at 20 cm depth), between two plants in each of the maize and cowpea rows in a middle row. The measurement of temperature afternoon was made on relatively clear days.

Quantification of photosynthetic active radiation (PAR): The fraction of PAR intercepted was calculated by taking ten readings in rapid succession above the canopy and ten readings below the canopy at the soil surface using a Ceptometer CEP (Decagon Devices, Pullman, Washington State, and USA). The soil surface measurements were taken by placing the ceptometer at right angles to the plant rows.

Quantification of land equivalent ratio (LER): The land equivalent ratio (LER) was used to evaluate intercrop efficiencies in yield and nitrogen uptake of the plants with respect to sole crops. The LER defines yield as a function of area: $LER = ICa/MCa + ICb/MCb$, where IC and MC refer to intercrop and monocrop yields and the subscripts a and b indicate the component crop yields in the mixture.

Statistical analyses: The data on growth, yield and other parameters were analyzed by Fisher's analysis of variance technique and Duncan test at 0.05 probability level to compare the treatment means [41]. Data analyses were conducted using SAS[33] as a factorial experiment 8 × 2 with four replicates.

Results and Discussion

Photosynthetic active radiation (PAR): A characteristic pattern of light interception was found for each cropping systems (Figs 4 and 5). There was significant difference in light interception between the cowpea and maize pure stands compared to the intercrop. In both experiments, light interception by the cowpea monoculture increased linearly, reaching around 80% interception of PAR at the time of 95 DAP (day after planting). In contrast, the cowpea-maize intercropping and maize sole crop showed a lower light interception compared to cowpea sole crop, and sole crop of maize had the lowest light interception compared to other cropping systems. Additive design was absorbed of PAR higher than under replacement design (Fig. 6). The shapes of the light interception curves of the canopy of a cowpea-maize intercrop reflect the faster leaf area development and more horizontal growth habit of the cowpea leaves, and this explains the superior competitive ability of the intercrop canopy compared with the maize monoculture.

Difference in crop canopy within the intercropping systems also resulted in a significant reduction in the incoming PAR just above the crops from planting to maturity. Cowpea-maize intercropping system is widely adopted, because competition

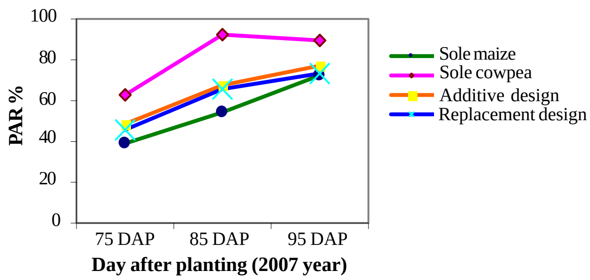

Figure 4. Variation of PAR in growth season at different cropping systems, year 2007.

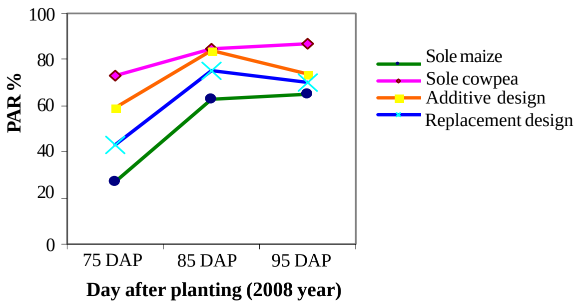

Figure 5. Variation of PAR in growth season at different cropping systems, year 2008.

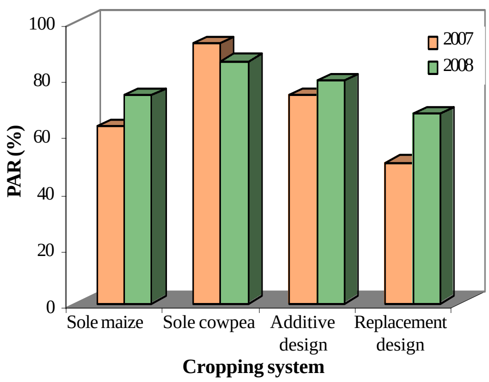

Figure 6. Variation of PAR at different cropping systems.

for light above ground and for water is less than in many other intercropping systems. A study showed that Paulownia-wheat intercropping systems had significantly higher energy gain (more radiation intercepted) and economical return than pure crop systems [22].

Soil moisture (SM): Analysis of variance showed that there were significant effects of cropping systems on soil moisture content (ANOVA data not shown). Soil moisture content in the soil was reduced dramatically in the sole crop of maize due to high evapotranspiration potential; on the contrary soil moisture content in the soil was increased dramatically in the sole crop of cowpea due to low evapotranspiration potential for growth period (Fig. 7). There was significant difference in soil water content between cropping systems in either the 0–20 cm soil layer, although maize sole crop plots tended to have the lowest soil water content in the 0–20 cm soil layer later in the growing season (75–95 days after emergence) (Figs 8 and 9). However, comparing cowpea SC, maize SC and cowpea-maize IC, the patterns of soil water distribution in the soil profiles differed supporting the null hypothesis. Cowpea provided better soil cover compared to sole maize, so water evaporation at soil surface was low and soil moisture high compared to sole maize. Distribution of root systems among species and cropping system influenced the water content down the soil profile. Comparing the soil water content of the soil layer the cowpea-maize IC tended to display the lowest differences followed by maize SC and the highest difference followed by cowpea SC, showing intermediate and greater differences (Figs 8 and 9). In the cowpea-maize IC plots, soil water content was average between cowpea and maize SC, compared between intercropping designs additive design had lower soil water content than replacement design (Figs 8 and 9). The reason of this difference was increased use of water by two plants at additive design compared to replacement design. Comparing water contents of the soil layer (0–20 cm) under all cropping treatments, differences between soil layers were lower under the cowpea-maize IC than under cowpea and higher than under maize SC (Fig. 7). Thus, in the cowpea-maize intercrop, there might be a more fully exploitation of the soil moisture profile than in sole maize. Similar findings were shown by other researcher[15], including greater water use efficiency in a pea-barley intercrop than in either of the sole crops.

Maximum values of soil moisture were recorded at 85 DAP and water contents were lowest at 95 DAP. Values of soil water content under the sole maize crop were similar to those in the cowpea-maize system (replacement design).

In summary, the measured soil water contents in the sole maize system were lower than those in the intercropping systems, especially when compared with the additive design of intercropping. In intercropping system (especially additive series) water uptake from soil surface layers increased due to increased root density in the upper layers, thus decreasing water dissipated by evaporation.

Soil temperature (ST): Soil temperature was significantly affected by cropping systems (data not shown). There was a significant difference between cropping systems (ANOVA data not shown). Above ground temperatures for maize photosynthesis [28, 48] and root temperatures for root growth and germination of maize [47] have different requirements. Soil temperatures and related air temperatures may therefore influence growth and development differently, although effect on root temperature requirements is appreciably less when shade involved [23]. The results indicate that soil temperature in cropping systems could be developed into an operational methodology for understanding shading gradients in space (Figs 10-12). Intercropping systems compared to sole crop of cowpea had higher soil temperature, on the contrary the highest ST was obtained at sole maize. Additive design of intercropping has the lower ST than replacement design. The highest ST was at sole maize and the lowest one at sole cowpea, and intercropping has intermediate ST compared to both sole crops. At the additive design of intercropping the maize was higher than cowpea, differences in maize height and ratio would have had more influence, particularly at high ratio of planting (100:100, cowpea:maize) and there was more shading in the soil surface compared to other planting ratios, and this shading caused low evaporation of soil surface and high moisture in soil causing low soil temperature.

In addition to this, significant soil temperature reduction of intercropped compared to sole maize may also have resulted from the shading effect of both crops (cowpea and maize). Increasing shading at the additive design of intercropping may also have been responsible for the reduction of the soil temperature. One reason for observing difference between the cropping systems could be the shading effect at intercropping (special additive design) compared to sole maize. A significant alley cropping effect on soil temperature was reported by Monteith [24], in a semi-arid tropical region soil temperature (the depth of the soil temperature measured was not reported by the authors) was always greater in the center of the alley than beneath the two hedges, up to 80 days after sowing of pearl millet between hedges of *Leucaena leucocephala* Lam. Soil temperature in additive design was higher than in replacement design; reason of this was possibly decrease of water content in upper soil layers because additive design increased consumption of soil water compared to replacement design.

Land equivalent ratio (LER): Higher LER in intercropping treatments indicated yield advantage over monocropping due to better land utilization. Partial LER of cowpea decreased as the proportion of maize increased in mix- proportions (Table 2). Higher LER in intercropping treatments indicated yield advantage over monocropping due to better land utilization (Table 2). The mean LER values were always greater than 1.0 (Table 2). Advantage from non-legume–legume intercropping systems have been reported previously in crops such as wheat and legume [4], pea and barley [8], field bean and wheat [7], maize and faba bean [21] and grasses and legumes [35].

The highest LER was obtained by sowing the crop in additive design in a ratio of MC (2.26 at one year and 2.23 at two years) and the lowest LER was obtained by sowing the crops in replacement design of mc (1.27 at one year and 1.04 at two years). LER values were greater than 1.0 in all intercropping systems with different planting ratios which indicated yield advantage of intercropping over sole cropping of maize. When LER is greater than 1.0, the intercropping favors the growth and yield of the species. In contrast, when LER is lower than 1.0, the intercropping negatively affects the growth and yield of plants grown in

Table 2. Means of LER of maize and cowpea as influenced by different planting ratios and harvest time based on Duncan test.

Year	2007-2008			2008-2009		
Planting ratio	LER			LER		
Maize: Cowpea	Maize	Cowpea	Total LER	Maize	Cowpea	Total LER
100:100	1.17b	1.09b	2.26a	0.76a	1.47a	2.23a
100:50	1.21b	0.41d	1.62c	0.84a	0.42bc	1.27bc
50:100	0.64c	1.32a	1.96b	0.70ab	1.46a	2.17a
50:50	0.63c	0.64c	1.27e	0.53b	0.60b	1.14bc
25:75	0.31d	1.07b	1.38d	0.14c	1.31a	1.46b
75:25	1.28a	0.32d	1.60c	0.82a	0.22c	1.04c
Harvest time						
Milky stage	0.86a	0.81a	1.67a	0.63a	0.79b	1.42b
Doughy stage	0.88a	0.81a	1.69a	0.64a	1.05a	1.69a
C.V. (%)	5.7	13.2	6.19	14.28	13.27	12.27

Any two means not sharing a common letter differ significantly from each other at 5% probability; LER (Land equivalent ratio), C.V.(Coefficient of Variation).

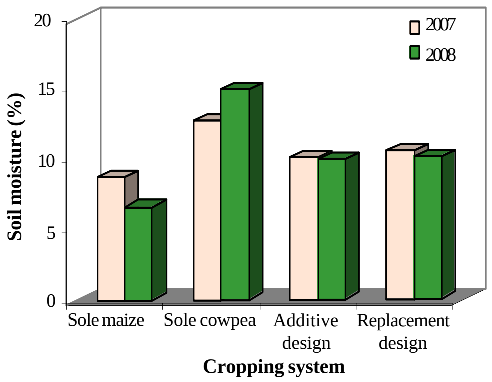

Figure 7. Variation of soil moisture (SM) at different cropping systems.

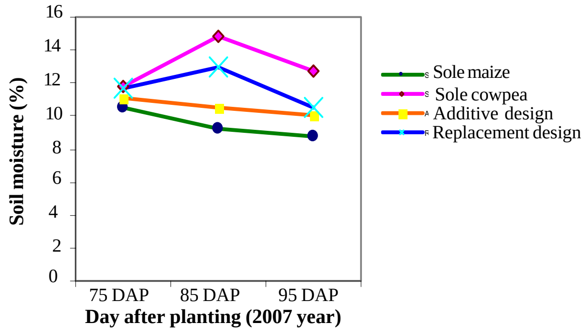

Figure 8. Variation of soil moisture (SM) in growth season at different cropping systems, year 2007.

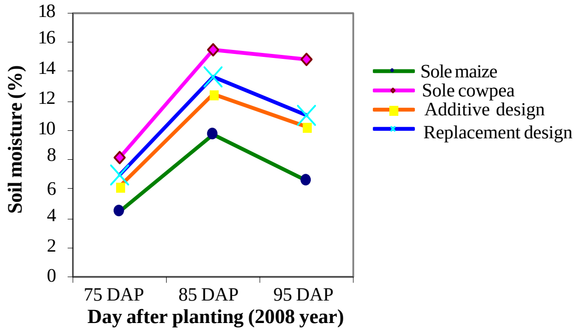

Figure 9. Variation of soil moisture (SM) in growth season at different cropping systems, year 2008.

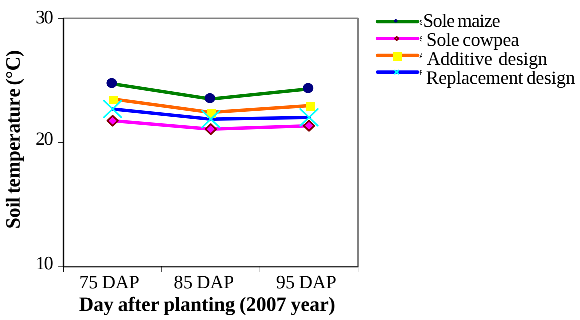

Figure 10. Variation of soil temperature (ST) in growth season at different cropping systems, year 2007.

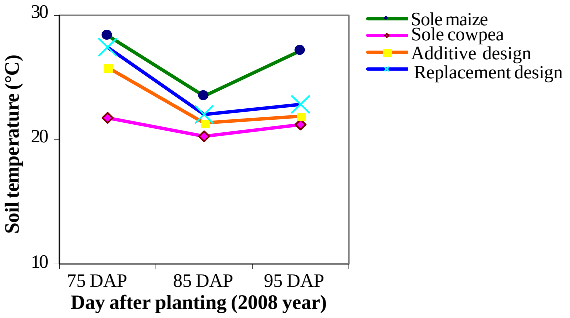

Figure 11. Variation of soil temperature (ST) in gowth season at different cropping systems, year 2008.

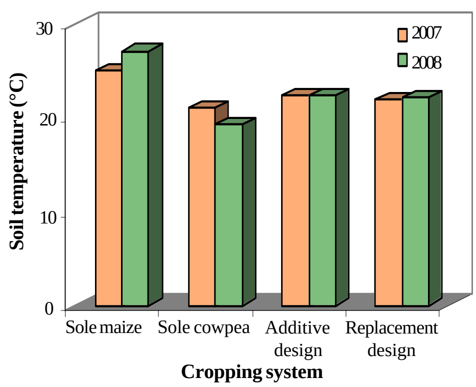

Figure 12. Variation of soil temperature (ST) at different cropping systems.

mixtures [9]. So intercropping showed an advantage over sole cropping at all two harvesting dates; in general there was a trend for LER values to increase with the later harvest dates. The LER values were greater than 1.0, indicating a more efficient utilization of plant growth factors by intercrops compared to sole crops [51]. Comparing partial LER values, maize was clearly the dominant component of the intercrop, displaying a considerably greater competitive ability to acquire growth limiting factors than cowpea. The calculated mean value of LER for grain yield (1.68 at 2007 and 1.55 at 2008 year) was higher than 1.0, which indicates a benefit of intercropping. Thus, it can be suggested that complementary facilitation dominates over competitive interference. Facilitative root interactions are most likely to be of importance in nutrient-poor soils and low input agro-ecosystems due to critical interspecific competition or facilitation for plant growth factors[27]. Because of the spatial and temporal differences in the growth factors and different crop species, intercropped plants could better utilize nutrients from soils compared with monocropped plants [49, 53].

Conclusions

From the above it can be concluded that there are opportunities for improving the productivity of cowpea/maize in the southeast of Iran at the arid ecological zone. Intercropping is the best cropping system, because at this system light interception, soil moisture, soil temperature and yield were higher compared to sole crops. Microclimatic variation in intercropping system have caused favorable environmental conditions, ready for growth and high yield compared to sole crops. The cowpea-maize intercropping exploited more stored water than a sole maize crop; the beneficial effects of the intercropping (reduced evaporation and crop transpiration) appeared to greatly compensate the interception and uptake losses near the cowpea canopy. It is evident from the results, that cowpea and cowpea-maize intercropping are more effective in improving soil water retention compared to sole maize. Thus 100% maize + 100% cowpea planting ratio had the highest LER at two years, and additive design absorbed higher PAR than replacement design. Evaporation from the soil surface decreased due to shading in this treatment (100% maize + 100% cowpea) and increased the amount of water potentially available for transpiration and growth.

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