MICROENVIRONMENTAL EFFECTS ON POTATO AND BEAN YIELDS GROWN UNDER INTERCROPPING SYSTEM

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This experiment was carried out at the Faculty of Agriculture Research Station – University of Mu´tah – during summer growing season of 2002, to evaluate the effect of the following micro environmental factors: light interception, air and soil heat unit, soil moisture storage (SMS), evapotranspiraton (ET) and water use efficiency (WUE) on the yields of two potato varieties (Berca and Frisia) - Solanum tuberosum – and bean (local variety) – Phaseolus vulgaris – as they are grown under 1:2 and 2:2 intercropping row arrangement and sole cropping. In addition, land equivalent ratio (LER) was determined to assess the efficiency of intercropping system. The yields of the two potato varieties and bean were higher under intercropping than sole cropping, especially when they are grown under 2:2 row arrangement, where potato "Berca" and,"Frisia" gave an increase in yield of 63.9%, and 70.7% respectively, while bean gave an increase in yield of 70.9%, and 57%, as it was grown with potato "Berca" and,"Frisia" respectively, over the yields of their sole crops. The higher intercropped yields of the two potato varieties "Berca" and "Frisia" were associated with significant reductions in the values of light interception air and soil heat unit compared to the values obtained by the two potato varieties "Berca" and "Frisia" grown under sole cropping. On the contrary, the higher intercropped bean yield production was associated with significant higher values of light interception, air and soil heat unit as compared to the values obtained by bean sole crop. Additionally, the values of SMS and ET for potato and bean grown under intercropping tended to be lower than the values obtained by their sole crop. Moreover, WUE values of potato and bean grown in association were significantly higher than the values of WUE obtained by their sole crop. Further more, the values of total (LER) for potato and bean grown under intercropping were higher than one, which indicates the superiority of intercropping system over the sole cropping system. However, the highest total LER was obtained when both crops were grown under 2:2 intercropping row arrangement, where they gave an increase in the range of 64% to 67% as compared to sole cropping system.

Key words: *intercropping, potato, bean, microenvironment, land equivalent ratio*

Intercropping is the agricultural practice of cultivating two or more crops in the same piece of land at the same time or within the same season. It differs from sole cropping which entails the cultivation of one crop grown alone in pure stands. Throughout time and in many parts of the world, intercrop has been used to improve crop utilization of available sun light, water and nutrients [Willey, 1979].

The improvement of utilization plant resources depend on microclimate modification created by the two crops selected for intercropping, row arrangement [Sharaiha and Battikhi 2002, Sharaiha and Hadidi, 2007], climate [Batugal et al, 1990] and soil type [Dongmei et al 2007]. Unfortunately, there is little available information in regard to the effect of plant resources utilization on intercropping yield production, especially for potato and bean grown in association under different row arrangements. However, certain reports indicated that lower light interception obtained by potato grown with corn, gave beneficial effect on potato yield [Sharaiha and Battikhi, 2002, Batugal et al., 1990 and Midmore, 1990]. On the other hand, the yield of potato per plant was reduced [Kuruppuarachchi, 1990], as well as yield of faba bean [Sharaiha and Gliessman, 1992] under certain shaded treatments compared to that of un-shaded. Furthermore, the effect of temperature on intercropped potato yield is variable according to potato variety [Haris, 1990].

Lower temperature associated with high irradiation under short photoperiod promotes tuber initiation and bulking at the expense of top growth (Midmore 1990). Moreover, Sharaiha and Kluson (1994) reported that both air and soil temperatures were increased when faba bean was intercropped with peas and lettuce and thus increasing faba bean yield as compared to its sole crop.

Additionally, higher yield production of potato was not affected by evapotranspiration and soil moisture storage when it was neither intercropped with faba bean [Al-Qahwaji, 1995], nor with corn [Sharaiha and Battikhi 2002] On the contrary, Soetedje et al (1998) indicated that higher evapotranspiration of intercropped peas and canola was related to their higher yield production as compared to their sole crop, while Jeiming and Midmore (1990) found that higher yields of corn intercropped with potato were due to higher soil moisture storage caused by decreased demand of water after potato maturity. Moreover, water use efficiency was higher under intercropping system than sole cropping system as it was indicated by Al-Qahwaji (1995), Soetedje et al (1998), Sharaiha and Battikhi (2002), Tiruneh (2004), and Sharaiha and Hadidi (2007). However, opposite results were obtained by Anthony et al (2008) in their study on land equivalent ratio light interception and water use in annual intercrops in the presence or absence of in-crop herbicides. These conflicting results are calling for more research in this area.

Therefore, this study was conducted with the objective of investigating the effect of the following micro environmental factors: air and soil temperatures, light interception, soil moisture storage, evapotranspiration, and water use efficiency on the yields of potato and bean as they are grown under intercropping and sole cropping.

MATERIAL AND METHOD

An experiment was carried out during summer growing season of 2002 in Rabba at the Faculty of Agriculture Research Station, University of Mu'tah. The station is located at altitude of 31.2°N, 35.5°E, with an elevation of 920 m above sea level, and 120 km South of Amman. The soil texture is clay loam; the climate is semi-arid with mean annual precipitation of 326mm and mean annual temperature of 16.2°C. Two varieties of potato - *Solanum tuberosum L.* - (Berca and Frisia) and one variety of bean - *Phaseolus vulgaris L.* - (local bush bean variety) were planted on March 15th under intercropping and sole cropping. A randomized complete block design with three replications was used. The treatments included: 1- pure stand of potato "Berca"; 2- pure stand of potato "Frisia"; 3- pure stand of bean; 4- 2:1 potato "Berca" /bean intercropping row arrangement; 5- 2:1 potato "Frisia" /bean intercropping row arrangement; 6- 2:2 potato "Berca" /bean intercropping row arrangement; 7- 2:2 potato "Frisia" /bean intercropping row arrangement. Each treatment plot consisted of six rows 75cm apart and 4 meters long. Spacing between plants within row was 35cm and 15 cm for potato and bean, respectively. Compost poultry manure was applied one week before planting at the rate of 15Mt.ha-¹. Weeds were kept under control manually. Surface laterals of 16mm diameter were installed on every planting row to deliver water to plants. In line, drippers with 40cm spacing and 4 liters per hour per dripper discharge rate were used for irrigation. The amount of water added was recorded by water flow meter. Soil moisture measurements were taken at 7.5, 22.5, 45 and 75cm soil depth. In addition, gravimetric method was used to support neutron probe readings for the two first layers. Two access tubes (90cm long) of two inches diameter were installed within the row between two adjacent potato and bean plants under intercropping treatments, while one access tube was installed for each sole crop. Calibration for different soil layers was correlated with soil moisture counts of neutron probe with gravimetric soil moisture samples. Linear regression equation for calibration of neutron probe for the third layer was Pv% = 38.30 CR- 22.08 and that for the fourth layer was Pv% = 29.88 CR – 15.23, where Pv% is a volumetric moisture content and CR (count ratio) is a neutron probe reading in the field. Crop evapotranspiration (ET) and soil moisture storage (SMS) were calculated by using the following equations: - ET= R + I + DSi – DP. Where R : is the amount of rainfall and it was = 0, I : is the amount of irrigation, Dsi : is the initial soil moisture content, and DP : is deep percolation and it was = 0.

SMS = $\sum$ [increase in soil moisture (+Δ s)]. Where Δs is the difference between two neutron probe readings for the soil moisture storage taken after irrigation by 16 hours and before each irrigation. While water use efficiency (WUE) was calculated by dividing yield over ET. Daily light and temperature (air and soil) measurements (taken between 11AM and 1PM) started 24 days after emergence using porometer and thermometer, respectively. However, temperatures were recorded as heat unit, using the 50-86F° method as described by Battikhi and Ghawi, (1987). The heat unit method should indicate which of the treatments provided best temperature for plant growth. Light measurement was taken at the lower, middle and the upper part of the stem (averages were calculated). Harvesting date was on July 10 -11 for potato, while for bean (green pod) started on May 26 – July 9. Yields of both crops were obtained from the middle three meters of the central four rows, for 2: 2 row combination and from the middle of the central three rows, for 1: 2 or 2: 1 row combinations. The land equivalent ratio (LER) was calculated for the combined intercropped yields and for the intercrop yield of each crop, as described by Willey (1979), who expressed the intercrop yield on a relative basis to a sole crop yield (i.e. where LER = 1). Analysis of variance for the

micro environmental values and yield data were determined. The Duncan's Multiple Range Test (DMRT) was then employed for means separation.

RESULTS AND DISCUSSIONS

Effect of light interception, soil and air heat unit on the yield of potato grown under sole croping and intercropping with bean

Table 1 shows the comparison between the averages of light interception, air and soil heat unit for two potato varieties "Berca" and "Frisia" grown under sole cropping and intercropping with bean. A reduction of light interception, air and soil heat unit were obtained under potato intercropping as compared to potato sole crop. The highest significant reduction was obtained when the two potato varieties were planted with bean under 2:2 row arrangement. However, the reductions of light interception, air and soil heat unit for potato "Berca" were 66.6 µmol.m² s², 256.2 and 183 respectively, while for potato "Frisia" the recorded reductions were 152.1µmol.m² s², 247.9 and 171.5 respectively, as compared to their sole crops *(table 1)*.

This could be explained by the higher vegetative growth of potato grown under intercropping than under sole cropping (data not shown). It seems that the effect of the associated bean crop – under compost poultry manure application - through fixing atmospheric nitrogen, might be beneficial in terms of an extra nitrogen contribution to potato vegetative growth during the same growing season, and consequently, was reflected on the potato tuber yield production. This fact has been pointed out by many researchers such as Sharaiha and Kkuson (1994) Danso et. al (1987), Ruschel et. al (1978), Lal et.al (1978) and Wahua and Miller (1978). However, the highest significant yields of the two potato varieties "Berca and Frisia" were obtained under 2:2 potato / bean intercropping row arrangement as compared to their sole crop.

Therefore, the nitrogen fixation by the associated bean crop and the shading effect created by more vegetative growth in addition to a reduction of air and soil heat unit *(table 1*) could be behind the higher significant yield of the two potato varieties. Similar results were obtained by Al-Qahwaji (1995) and sharaiha et. al (2004). Moreover, when the two potato varieties "Berca and Frisia" were grown under sole cropping and intercropping with bean, under the same row arrangement they gave insignificant differences in yields even though, the values of light interception and air temperature between the two potato varieties under each cropping system (2:1 potato bean intercropping; 2:2 potato bean intercropping and sole cropping) in most cases were significantly different, while soil temperatures were not significant.

This might indicate that soil temperature is one of the factors which play an important role in potato yield production. Similar results were obtained by Midmore (1990) who suggested that higher soil temperatures inhibit the conversion of sucrose to starch within the tuber and thus, affecting potato yield production.

Therefore, the insignificancy between the yields of two potato varieties under the same cropping system could be attributed to insignificant soil temperatures.

Effect of light interception, soil and air heat unit on the yield of bean grown under sole croping and intercropping with potato

When bean was intercropped with the two potato varieties "Berca" and "Frisia" under 1:2 and 2:2 row arrangement, the values of light interception, air and soil heat unit were higher than the values obtained by bean sole crop (*table 2*). However, the highest significant values were recorded when bean was planted with the two potato varieties "Berca" and "Frisia" under 2:2 row arrangement, where bean planted with potato "Berca" gave a significant average increase of light interception (by 247.5 µmol m^2s^2), air heat unit (by 27.4) and soil heat unit (by 59.6), while bean planted with potato "Frisia" under the same treatment gave an average significant increase of light interception (by 384.5µmol m^2s^2), air heat unit (by 39) and soil heat unit (by 170.1), over the same values obtained by bean sole crop. The higher values obtained by intercropped bean were due to a reduction in vegetative growth (data not shown) as bean was competed with the associated potato crop which is considered more effective in utilizing water and nutrients than bean crop and that was reflected on lower vegetative growth of intercropped bean.

Therefore, more incident radiation penetrate through bean leaves to soil surface as compared to bean sole crop (without competition) which have more vegetative growth and dense canopy with less incident radiation passes through all leaves along bean stem. This also explains the lower values of soil and air heat unit for bean sole crop as compared with intercropped bean. On the other hand, intercropped pod bean yields were significantly higher than yield of bean sole crop, especially when bean was planted with the two potato varieties "Berca" and "Frisia" under 2:2 row arrangement, giving an increase of 70.9% and 57% respectively, over the yield of bean grown as a sole crop *(table 2)*. Apparently, water and nutrition that were available for bean sole crop in the absence of competition with potato crop was expressed by more vegetative growth rather than flower and fruit set and consequently gave lower pod yield as compared to the yield obtained by bean planted with potato which has less vegetative growth but higher pod yields.

Similar results were obtained by Delouche (1980) who suggested that excess of water and nutrient prevent the ability of bean to flower, instead, vegetative growth was encouraged. Moreover, the yields of intercropped bean under the same row arrangement were not significantly different, this might indicates that the benefit of the two potato varieties to bean crop was the same as long as most micro environmental factors are not significantly different.

Table 1

Effect of light interception, air heat unit and soil heat unit on yields of two potato varieties as they are grown under intercropping and sole cropping

ROW ARRANGEMENTS	Average Light interception $\mu mol.m^{-2}s^{-1}$	Average Air heat unit	Average Soil heat Unit	YIELD TON / HA
2 rows potato Berca 1 row bean	1220.8 cd	2063.1 d	1253.0 b	3.786 b
2 rows potato Frisia 1 row bean	1305.0 ab	2231.5 c	1299.2 b	3.742 b
2 rows potato Berca 2 rows bean	1190.1 cd	2014.2 f	1181.7 b	4.540 a
2 rows potato Frisia 2 rows bean	1197.5 cd	2033.7 e	1205.0 b	4.390 a
Potato Berca Sole crop	1256.7 bc	2270.4 b	1364.7 a	2.770 c
Potato Frisia Sole crop	1349.6 a	2281.6 a	1376.5 a	2.571 c

Table 2

Effect of light interception, air heat unit and soil heat on bean yield grown under intercropping and sole cropping

ROW ARRANGEMENTS	Average Light interception $\mu mol.m^{-2}s^{-1}$	Average Air heat unit	Average Soil heat unit	Yield Ton / ha
1 row bean/ 2 rows potato Berca	1233.3 b	2o34.4 c	1354.1 ab	1.267 ab
1 row bean / 2 rows potato Frisia	1266.7 ab	2030.9 c	1369.6 ab	1.238 b
2 rows bean /2 row potato Berca	1288.0 ab	2051.4 b	1378.6 ab	1.6oo a
2 rows bean /2 row potato Frisia	1425.0 a	2063 a	1489.1 a	1.470 ab
Bean Sole crop	1o40.5 c	2024 c	1319 b	0.936 c

Effect of soil moisture storage (sms), evapotranspiration (et) and water use efficiency (wue) on the yield of potato grown under sole croping and intercropping with bean

Intercropping of both potato varieties "Berca" and "Frisia" with bean did not give any significant effect on SMS and ET as compared with their sole crops *(table 3*). However, the values of soil moisture storage and ET tended to be lower under intercropping than sole cropping. This was expected since the values of soil and air heat unit were significantly lower under potato intercropping as compared to potato sole cropping *(table 1)*.

These results are in agreement with the findings of Jeiming and Midmore (1990) in their review on potato intercropping practices in Western Hubei – China. On the other hand, yields of both potato varieties were higher under intercropping as compared to their sole cropping, especially when potato "Berca" and "Frisia" were grown with bean in 2:2 intercropping row arrangement where significant differences in yield were obtained under insignificant higher values of SMS and lower values of ET *(table 3)*.

However, the associated bean crop which is capable of fixing atmospheric nitrogen will have a beneficial effect on potato yield crop, in terms of nitrogen contribution during the same growing season especially when chemical fertilizer was not applied as it was explained earlier. A side from the lower insignificant values of SMS and ET obtained by potato intercropping, water use efficiency (WUE) was increased significantly *(table 3*). The highest significant values of WUE were recorded when the two potato varieties "Berca" and "Frisia" were planted with bean under 2:2 row arrangement, where the intercropped potato "Berca" gave an increase of 0.96 kg/m³, while the intercropped potato "Frisia"gave an increase of 0, 83 kg/m³, over the values of WUE obtained by both potato varieties grown under sole cropping system.

The higher values of WUE obtained under intercropping were due to the higher yields production of potato and to lower values of ET, since WUE is calculated by dividing yield over ET. Further more, it is believed that the higher yields of potato intercropping were due to the interactions among different significant and insignificant micro environmental factors involved in this study.

Effect of soil moisture storage (sms), evapotranspiration (et) and water use efficiency (wue) on the yield of bean grown under sole croping and intercropping with potato

There were no significant differences on soil moisture storage, and ET from intercropping bean as compared with bean sole crop *(table 4)*, even though, the differences in soil and air heat unit were significantly lower under bean intercropping than bean sole cropping *(table 2)*. It seems that the range of differences in soil and air heat unit for bean grown under the two cropping systems (intercropping and sole cropping) did not affect SMS and ET as long as irrigation was applied. On the other hand, bean yields were higher under intercropping than

sole bean cropping especially when bean was planted with the two potato varieties "Berca" and "Frisia" in 2:2 row arrangement where a significant increase of 0.664 ton/ha and 0.534 ton/ha respectively, over the yield of bean sole crop *(table 4*). Obviously the higher yield production of intercropped bean was not related to these two factors (ET and SMS).

Table 3

The effect of soil moisture storage (SMS) evapotranspiration (ET) and water use efficiency on the yields of two potato varieties under intercropping and sole cropping

Row arrangements	SMS mm	ET mm	WUE Kg/m^3	YIELD TON / HA
2 rows potato Berca 1 row bean	258.3 a	251.2 a	1.51 ab	3.786 b
2 rows potato Frisia 1 row bean	252.9 a	260.0 a	1.44 ab	3.742 b
2 rows potato Berca 2 rows bean	244.4 a	232.2 a	1.95 a	4.540 a
2 rows potato Frisia 2 rows bean	264.8 a	253.2 a	1.73 a	4.390 a
Potato Berca Sole crop	221.3 a	278.7 a	0.99 b	2.770 c
Potato Frisia Sole crop	275.6 a	284.7 a	0.90 b	2.571 c

Means followed by the same letter within the same column do not significantly differ using DMRT at 0.05 levels

Table 4

The effect of soil moisture storage (sms) evapotranspiration (et) and water use efficiency on the yield of bean under intercropping and sole cropping

ROW ARRANGEMENTS	SMS mm	ET mm	WUE Kg/m^3	YIELD TON / HA
1 row bean / 2 rows potato Berca	23.02 a	23.79 a	0.530 b	1.267 ab
1 row bean / 2 rows potato Frisa	23.41 a	23.00 a	0.541 b	1.238 b
2 rows bean/ 2 rows potato Berca	23.83 a	23.94 a	0.668 a	1.600a
2 rows bean/ 2 rows potato Frisa	23.90 a	23.66 a	0.621 a	1.470 a
Bean Sole crop	24.06 a	24.22 a	0.386 c	0.936c

Means followed by the same letter within the same column do not significantly differ using DMRT at 0.05 levels

Therefore, other factors such as the higher significant values of light interception, soil and air heat unit *(table 2)* might contribute to the higher yield production of bean as it was explained earlier.

Similar results were obtained by Vladiermeer (1989), who suggested that the above ground interaction had more effect on higher yield production than below

ground interaction. These results contradicted the findings of Midmore (1990), where irrigation was not applied, and agreed with the results obtained by Al-Qahwaji (1995) in his study on production function determination of row intercropping between broad bean and potato under Jordan Valley conditions. Moreover, WUE of intercropped bean was higher than sole bean.

The higher significant values of WUE were obtained when bean was planted with the two potato varieties "Berca" and "Frisia" in 2:2 row arrangements where bean planted with potato "Berca" gave an increase of 73% while bean planted with potato "Frisia" gave an increase of 60.9%, over the value of WUE obtained by bean sole crop. The higher values of WUE obtained under intercropping resulted from the higher yields of intercropped bean and the lower values of ET.

Efficiency of intercropping

For the purpose of evaluating the efficiency of intercropping treatments with the sole cropping treatments, the land equivalent ratio (LER) concept was used. The land equivalent ratio is defined by Willey (1979) as the relative land area under sole cropping that is required to produce the yield achieved under intercropping. As such, when 2:1 potato / bean intercropping is considered it means that potato is occupying 2/3 and bean 1/3 of the land and thus, the relative LER of potato is equal to 0.67 and the relative LER of bean is 0.33, respectively.

Therefore, the total LER equal to one. This indicates that intercropping is good as sole cropping. However, when the total LER is greater than one, this means that more land is required for sole cropping to produce what is producing under intercropping which in turn indicates the superiority of intercropping over sole cropping.

Thus, table (5) shows that intercropping treatments of potato and bean gave a total LER more than one. The increase in efficiency (LER) of intercropping treatments is the result of complimentary patterns of resource use by the component crops (Willey 1979; Trenbath, 1976). The efficiency of intercropping was affected by row arrangement where it gave higher values of LER under 2:2 potato / bean row arrangement than under 1:2 potato / bean row arrangement. This was expected since each intercropping row arrangement allowed for a special microenvironment, changing to a certain limit the light interception temperature and moisture *(tables 1, 2, 3 and 4)* in addition to nutrition(data not shown). The positive effect of potato and bean on each other under intercropping system is observed by their relative LER, specially under 2:2 row arrangement where the two potato varieties "Berca" and "Frisia" gave a relative LER of 0.819 and 0.854, respectively, higher than the expected value of relative LER for potato grown as a sole crop in one half of the land, where it is equal to 0.5. On the other hand, bean under the same treatment gave 0.855 and 0.785 as it was grown with potato "Berca" and "Frisia" respectively, higher than expected by 0.355 when bean was planted with potato "Berca" and 0.285 when bean was planted with potato "Frisia" as compared to bean sole crop grown in one half of the land. It is clear that both

crops were benefited from each other and this was termed by Willey 1979; and Gliessman 1998; as mutual cooperation.

The higher efficiency of intercropping potato and bean might be due to their better use of the available resources (light, water and nutrients) than under their sole cropping.

Table 5

The relative yields, relative LER and total LER of the two potato varieties (Berca and Frisia) and bean grown under intercropping system

ROW ARRANGEMENTS	RelativeYields kg ha^{-1} Potato - Bean	Relative LER Potato - Bea	Total LER
2 rows potato Berca 1 row bean	2.524 - 0.422	0.911 - 0.451	1.36
2 rows potato Frisia 1 row bean	2.495 - 0.413	0.970 - 0.441	1.41
2 rows potato Berca 2 rows bean	2.270 - 0.800	0.819 - 0.855	1.67
2 rows potato Frisia 2 rows bean	2.195 - 0.735	0.854 - 0.785	1.64

CONCLUSIONS

The results of this study indicated the beneficial effect of intercropping systems under Rabba region conditions and the following conclusions might be drawn.

Potato "Berca" and "Frisia" gave higher yields under intercropping system as compared to their sole cropping.

Potato "Berca" seems to have a beneficial effect on yield of bean when they are grown in 2:2 row combination.

Bean yield seems to have beneficial effect on both potato varieties "Berca" and "Frisia" when they are grown in 2:2 row combination.

A major cause of yield advantage of potato / bean / intercropping is the better use of resources (light, temperature and water) as a result of complementarily effects between the crops involved.

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