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Potato (*Solanum tuberosum* L.) and Bean (*Phaseolus vulgaris* L.) in Sole Intercropping: Effects on Light Interception and Radiation Use Efficiency

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Abstract

An investigation was carried out during three crop growing seasons (2005; 2006 and 2007) at the Technical Center of Potato (CTP) situated in the low valley of Medjerda river at Saida (Tunisia) to find out how potato and bean can grow and develop in an intercropping system rather than in sole cropping. Crop productivity of potato and bean intercropping systems was evaluated in terms of total dry matter production. The light interception and radiation use efficiency by this system were calculated in sole cropping and intercropping. Results showed that the total dry matter production (TDM) by potato in sole intercropping was higher than in sole cropping. This increase occurred during the three experiments from 3.60 to 4.75% compared to the potato in sole cropping. However, for bean in sole intercropping the TDM was significantly lower ($P < 0.05$) than in sole cropping. This decrease had varied from 48.9 to 63.1%. Intercropping potato with bean had actually reduced the radiation interception by both crops. This reduction was in the three experiments (2005; 2006 and 2007), respectively equal to (20.9; 9.4 and 4.8%) for potato and equivalent to (50.4; 58.7 and 44.8%) for bean. Radiation Use Efficiency for potato in sole intercropping has improved from 7.7 to 23.6%.

Keywords: potato, bean, intercropping, light interception, radiation use efficiency.

1. Introduction

Intercropping is the practice of cultivating two or more crops in the same land at the same time or within the same period. It differs from sole cropping which restrains the cultivation of one crop grown alone. Intercropping has been associated with such advantages as better use of environmental resources (Midmore, 1993; Black & Ong, 2000), greater yield stability (Jarenyama et al., 2000; Li et al., 2001; Tsubo & Walker, 2002; Awal et al., 2006; Zhang et al., 2007) and higher total dry matter production (Hauggaard-Nielsen et al., 2001; Thorsted et al., 2006; Gao et al., 2009). The improvement of the use of plant resources depends on microclimate modification created by the two crops selected for intercropping. Likewise, the efficiency of intercropping systems is highly dependent on farming techniques, mainly the spatial and temporal distribution of crops (Batugal et al., 1990; Jieming & Midmore, 1990) and their orientation in the plot (Tsubo et al., 2001). These parameters have a direct effect on light interception and on the dry matter production efficiency (Marshall & Willey, 1983). Similarly, the high productivity of intercropping is often explained by processes above the soil surface, such as the improvement of light interception and radiation use efficiency although, there is little available information in regard to the light interception and radiation use on intercropping potato-bean. Nevertheless, Sharaiha and Battikhi (2002) found that in the intercropping system of potato-corn, the lower light interception by the intercrop potato gave beneficial effect on yield. Awal et al. (2006) and Zhang et al. (2008) showed that the additional radiation intercepted in sole intercropping facilitates greater dry matter accumulation and may lead to more yields. In fact, Intercropping improved the radiation interception by a crop particularly during the early stages of growth (Harris, 1990; Awal et al., 2006; Jahansooz et al., 2007). Intercropping has proved to be more efficient than sole cropping in radiation use efficiency (Marshall & Willey, 1983). However, in sole intercropping, the RUE is estimated for the whole system (Willey, 1990; Tsubo et al., 2001). It is very difficult to estimate the RUE of each component of an intercrop (Ozier-Lafontaine et al., 1997). As a result, numerous models for partitioning radiation interception by each component in an intercrop have been developed (Marshall & Willey 1983; Wallace et al., 1990; Wallace et al., 1991; Keating & Carberry, 1993; Tsubo & Walker, 2002). Likewise, many studies have been conducted in potato and bean for radiation interception and radiation use efficiency in different regions under sole cropping. However, any information on the light interception and on the radiation use efficiency for potato and bean in sole intercropping has been reported. Therefore, the objective of this study was to investigate light interception and radiation use efficiency of potato and bean in sole intercropping with respective sole cropping, considering the changes with growth years. The results will be important for evaluating such intercropping pattern in semiarid region on the low valley of Medjerda river.

2. Materials and Methods

2.1 Experimental Site

The experiment was carried out at the Technical Centre of Potato situated in the low valley of Medjerda river at Saida, Tunisia (10° EST, 37° N, Alt. 328 m), during three seasons 2005, 2006 and 2007. The climate is semi arid. The annual rainfall average is about 450 mm, concentrated from December to April with irregular distribution. The soil had a clay-loam texture with 180 mm m^{-1} total available water and 2 g l^{-1} water salinity. The bulk density varies from 1.34 to 1.60 in from the surface to the depth (Rezig, 2010).

2.2 Plant Material

The plant material is composed of one variety of potato *"Solanum tuberosum L."* (Spunta) and one variety of green bean *"Phaseolus vulgaris L."* (Belna). In the first experiment (2005), potato planting was conducted on March 23 with a mechanical planter machine. The Planting density was 41,667 plants ha^{-1}. For bean, the planting was done manually a week after (between 02 and 04 April) with a planting density of 120,000 plants ha^{-1}. Concerning, the second experiment (2006), the same technique has been practiced. In addition, the potato planting was completed on 12th February 2006 and the bean seedlings were done 34 days after. Finally, for the third experiment (2007), the potato planting was conducted on 01st February 2007 and the bean seedlings were made on 20th March 2007.


(a)
(b)

Figure 1. Sole intercropping potato and bean, before (a) and after bean flooring (b)

2.3 Experimental Design

The experiment covered five treatments, potato and bean in sole intercropping (S1); potato in sole cropping (S2); potato in sole intercropping (S3); bean in sole cropping (S4) and bean in sole intercropping (S5). The adopted experimental design was random block with three replications. Every elementary plot had 10 m length and 4.8 m width. So, an elementary plot of potato in sole cropping is composed of 5 rows spaced 80 cm with 30 cm spacing between the plantations on the line. An elementary plot of bean in sole cropping is composed of 9 rows spaced of 80 cm. Finally, an elementary plot of potato and bean in sole intercropping is composed of 4 lines of bean in intercropping 5 rows of potato (Figure 1).

2.4 Field Measurements

2.4.1 Climatic Data

Climate data were recorded daily by the mean of an automatic agrometeorological station. Collected data were minimum and maximum temperatures (Tmin and Tmax), minimum and maximum air relative humidities (HRmin and HRmax), wind speed (V) and rainfall (P) during the three growing seasons (2005; 2006 and 2007). Reference evapotranspiration (ET_0) and solar radiation "MJ m^{-2} d^{-1} (Rs) were estimated by the MABIA-ET0 software (Jabloun & Sahli, 2008) using the FAO-Penman-Monteith approach (Allen et al., 1998). The daily Rs were used to calculate the daily photosynthetically active radiation incident (PAR0).

2.4.2 Leaf Area Index (LAI) and Total Dry Matter Production (TDM)

The observations were made on leaf area index and total dry matter (g m^{-2}). In 2005, potato were harvested for growth analysis at 53, 60, 67, 74, 81, 90, 95 days after planting potato (DAPP) and bean were collected at 44, 51, 58, 65, 72, 81, 86, 92, 99 days after sowing bean (DASB). In 2006, the sampling was achieved at 55, 61, 67, 74, 86, 95, 103, 110 DAPP and 27, 33, 40, 52, 61, 69, 76, 85, 98 DASB. In 2007, plants were collected at 55, 62, 71, 77, 83, 91, 98, 105, 112, 120 DAPP and 15, 24, 30, 36, 44, 51, 58, 65, 73, 78, 89, 96 DASB. At each sampling, three plants by plot (potato and/or bean) were collected. After separation of the plant organs, leaf area index and fresh weight were measured. The weightings were made using a precision balance (Sartorius, Model PB3001). Leaf area was measured using a LICOR LI 3100 leaf-area meter then all material was dried at 65 ° C to constant weight.

Growing degree days (GDD), based on air temperatures were used as the explanatory variable in the regression analysis (LAI and TDM) and accumulated from the date of planting. For each day, GDD was calculated according to the following formula:

$$\mathrm{GDD} = \frac{(\mathrm{Tmax+Tmin})}{(\mathrm{Tmin})} - \mathrm{Tb} \tag{1}$$

Where Tmax and Tmin are daily maximum and minimum air temperature, respectively, and Tb is the base temperature. A base temperature (Tb) of 10°C was used as the minimum temperature for bean growth (Basoccu, 1990) and the Tb for potato was equal to 7°C (Sands et al., 1979).

2.5 Theoretical Formulations

2.5.1 Estimation of the Daily Radiation Interception

Photosynthetically active radiation absorbed by potato and bean in sole cropping was calculated using the formula of Beer (Manrique et al., 1991):

$$\mathrm{PARabs} = \mathrm{PAR0}\,(1 - e^{(-K*\mathrm{LAI})}) \tag{2}$$

Where PAR0 is photosynthetically active radiation incident, which is equal to half the solar radiation (Monteith & Unsworth, 1990).

In the sole intercropping, PAR absorbed by each culture is the most difficult component to measure. Conventional methods of measuring radiation intercepted for a culture cannot be applied to the components of the intercropping because of the heterogeneity of the environment due to overlapping leaves of two cultures. So, in this study we used the model of radiation interception through a cereal–legume intercrop proposed by Tsubo and Walker (2002).

There are two canopy layers in bean–potato intercropping, so the boundaries are determined by the canopy heights of the bean and potato crops. When the potato crop canopy is taller than the bean crop canopy, the upper turbid layer only comprises the potato turbid medium while the lower turbid layer consists of both potato and bean turbid mediums. The fraction of radiation intercepted by the potato crop in the first turbid layer (F_{PC1}) is given by:

$$\mathrm{FPC1} = 1 - e^{(-\mathrm{KP}*\mathrm{LAIPC1})} \tag{3}$$

Where LAIPC1 is potato leaf area index (LAI) in the upper turbid layer, and KP is the potato crop canopy extinction coefficient. The KP was equal to 0.57 (Manrique et al., 1991).

According to the equation described by Keating and Carberry (1993), the fraction of radiation intercepted by potato and bean in the lower turbid layer (F_{PC2} and F_B, respectively) are given by:

$$\mathrm{FPC2} = \frac{(\mathrm{KP}*\mathrm{LAIPC2})}{(\mathrm{KP}*\mathrm{LAIPC2})+(\mathrm{KB}*\mathrm{LAIB})} * [\,1 - e^{(-\,\mathrm{KP}\,*\,\mathrm{LAIPC2}\,-\,\mathrm{KB}\,*\,\mathrm{LAIB})}] \tag{4}$$

$$\mathrm{FB} = \frac{(\mathrm{KB}*\mathrm{LAIB})}{(\mathrm{KP}*\mathrm{LAIPC2})+(\mathrm{KB}*\mathrm{LAIB})} * [\,1 - e^{(-\,\mathrm{KP}\,*\,\mathrm{LAIPC2}\,-\,\mathrm{KB}\,*\,\mathrm{LAIB})}] \tag{5}$$

Where LAIPC2 and LAIB are potato and bean LAI in the lower turbid layer and KB is the bean crop canopy extinction coefficient. The KB was equal to 0.84 (Tesfaye et al., 2006).

Assuming that leaves are randomly distributed in the canopies, LAIPC1 and LAIPC2 can be calculated as follows:

$$\mathrm{LAIPC1} = (1 - \mathrm{n}) * \mathrm{LAIPC} \tag{6}$$

$$\mathrm{LAIPC2} = \mathrm{n} * \mathrm{LAIPC} \tag{7}$$

Where n is the ratio of plant (or canopy) heights of bean to potato and LAI_{PC} is total potato LAI.

2.5.2 Estimation of the Radiation Use Efficiency

Radiation use efficiency (RUE) of potato and bean (RUEP and RUEB, respectively) was calculated by

$$\mathrm{RUEP} = \frac{\mathrm{TDM}}{((\mathrm{PAR0})*(\mathrm{FPC1}+\mathrm{FPC2}))} \tag{8}$$

$$\mathrm{RUEB} = \frac{\mathrm{TDM}}{((\mathrm{PAR0})*(\mathrm{FB}))} \tag{9}$$

2.6 Statistical Analysis

The results were subjected to variance analysis of one factor by General Linear Model (GLM). This analysis was performed using SPSS 10.0 software. The ensemble was completed by multiple comparisons of means with Student Newman Keuls test (S-N-K).

3. Results

3.1 Leaf Area Index

The evolution of potato Leaf area index (LAI) in sole cropping (S2) and in sole intercropping (S3) and for bean in sole cropping (S4) and in sole intercropping (S5) was given in Figure 2.

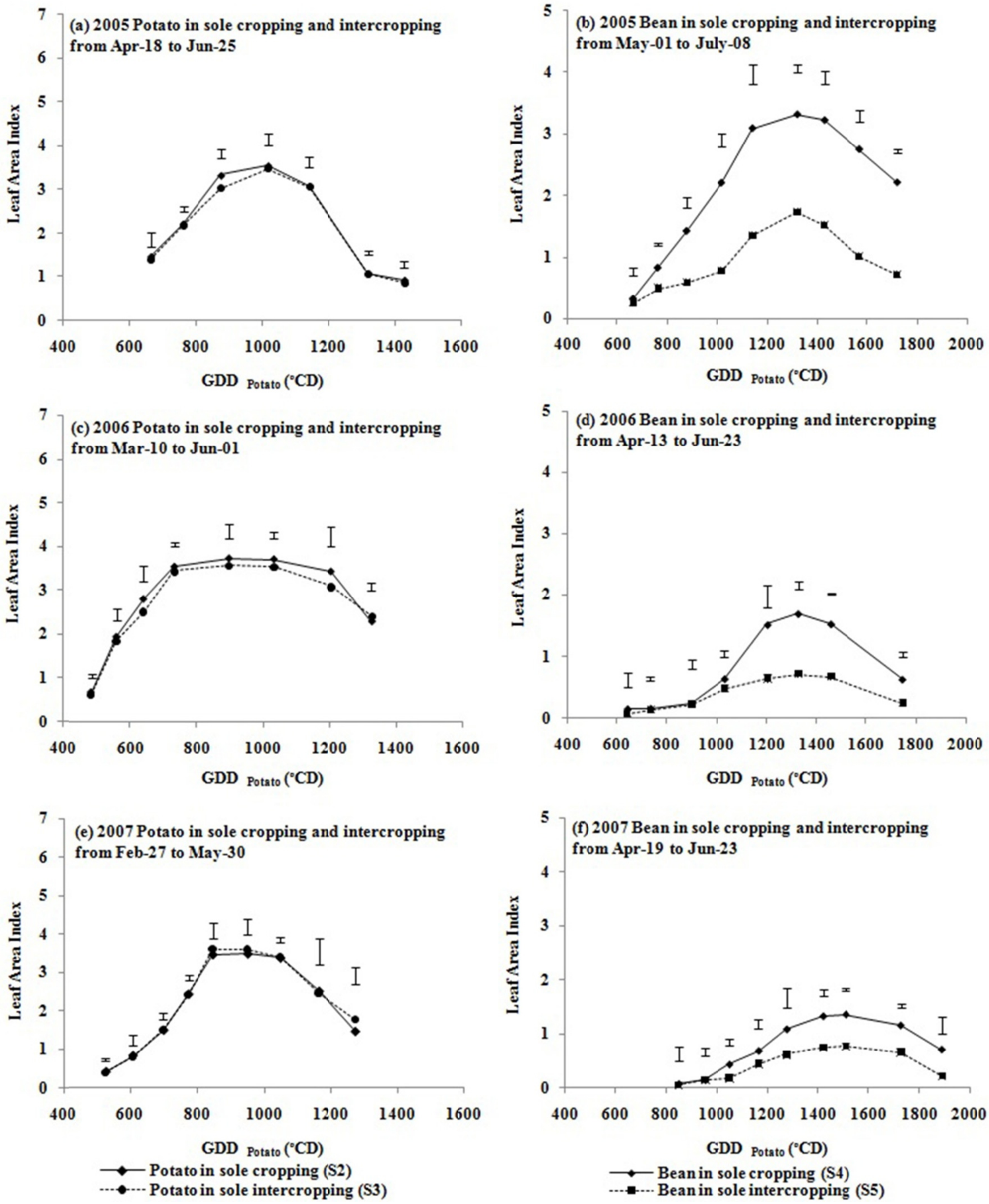

Figure 2. Leaf area index of potato in sole cropping (S2) and in sole intercropping (S3) in 2005; 2006 and 2007 ((a), (c) and (e)) and for bean in sole cropping (S4) and in sole intercropping (S5) in 2005; 2006 and 2007 ((b), (d) and (f)). The vertical bars represent the smallest significant difference at 5% (LSD)

In fact, from emergence to 70th day after planting potato (GDD accumulated between 847 and 1016 ° CD), a rapid increase in the LAI was noticed (the period of vegetative growth). Then, from 70th to 85th (GDD accumulated between 875 and 1141 ° CD), a phase during which the LAI was stable. Finally, a decrease phase to harvest.

For potato, variance analysis showed that there was no significant effect ($P > 0.05$) of intercropping in the evolution of LAI. So, for the three experiments (2005, 2006 and 2007), the maximum value of potato Leaf area index (LAI_{max}) in sole intercropping was respectively equal to (3.5, 3.5 and 3.4) and it was respectively equivalent to (3.4, 3.7 and 3.4) for potato in sole cropping. However for bean, there was significant effect ($P < 0.05$) of intercropping on the evolution of LAI. As a result, for the three experiments the LAI_{max} of bean in sole cropping (3.1, 1.7 and 1.3) was significantly higher ($P < 0.05$) than in sole intercropping (1.4, 0.7 and 0.8).

3.2 Total Dry Matter Production

The variations of cumulative total dry matter production (TDM) by potato in sole cropping (S2), potato in sole intercropping (S3), bean in sole cropping (S4) and bean in sole intercropping (S5) were shown in Figure 3.

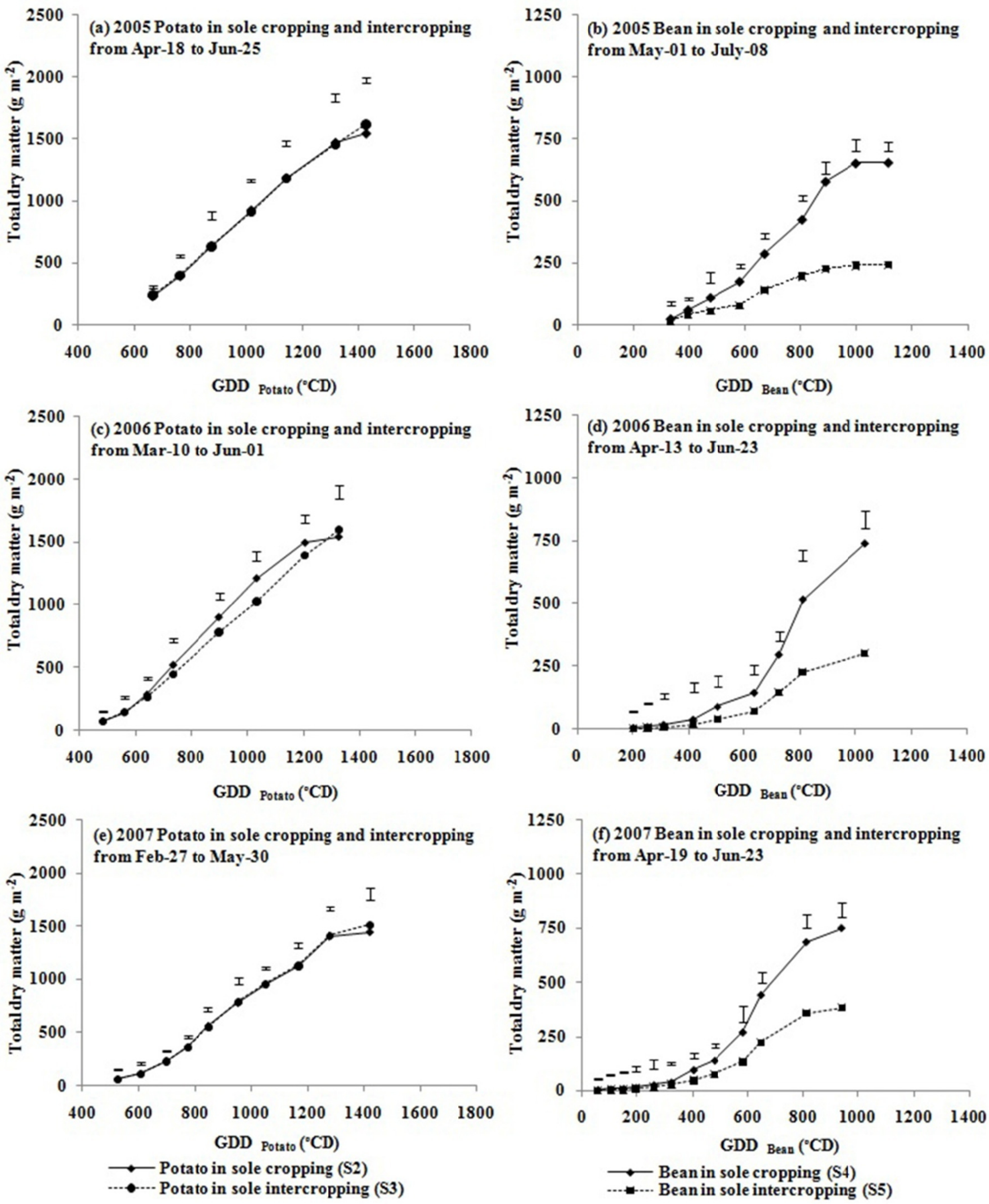

Figure 3. Total dry matter production of potato in sole cropping (S2) and in sole intercropping (S3) in 2005; 2006 and 2007 ((a), (c) and (e)) and for bean in sole cropping (S4) and in sole intercropping (S5) in 2005; 2006 and 2007 ((b), (d) and (f)). The vertical bars represent the smallest significant difference at 5% (LSD)

For potato, variance analysis showed that there was no significant effect ($P > 0.05$) of intercropping in the TDM production. Moreover, the TDM production by potato in sole intercropping was higher than in sole cropping. So for the experiments, S3 had respectively the greatest TDM values (1620.7; 1599.6 and 1512.1 g m^{-2}) in 2005; 2006 and 2007. The TDM production by potato in sole cropping for the three experiments was respectively equal to 1543.8; 1541.9 and 1443.7 g m^{-2}.

However, for bean, variance analysis showed that there was a significant effect ($P < 0.05$) of intercropping in the TDM production. Conversely, the TDM production of bean in sole intercropping was significantly lower than in sole cropping. So, for the three experiments, bean in sole intercropping had respectively the lowest TDM values (242.3; 299.9 and 382.2 g m^{-2}) in (2005; 2006 and 2007). The TDM production by bean in sole cropping for the three experiments was respectively equal to 655.8; 740.9 and 749.2 g m^{-2}.

3.3 Radiation Interception

The daily evolution of the intercepted radiation (PAR abs) by potato and bean in sole cropping (S2 and S4) and in sole intercropping (S3 and S5) during the three experiments (2005; 2006 and 2007) was given in Figure 4.

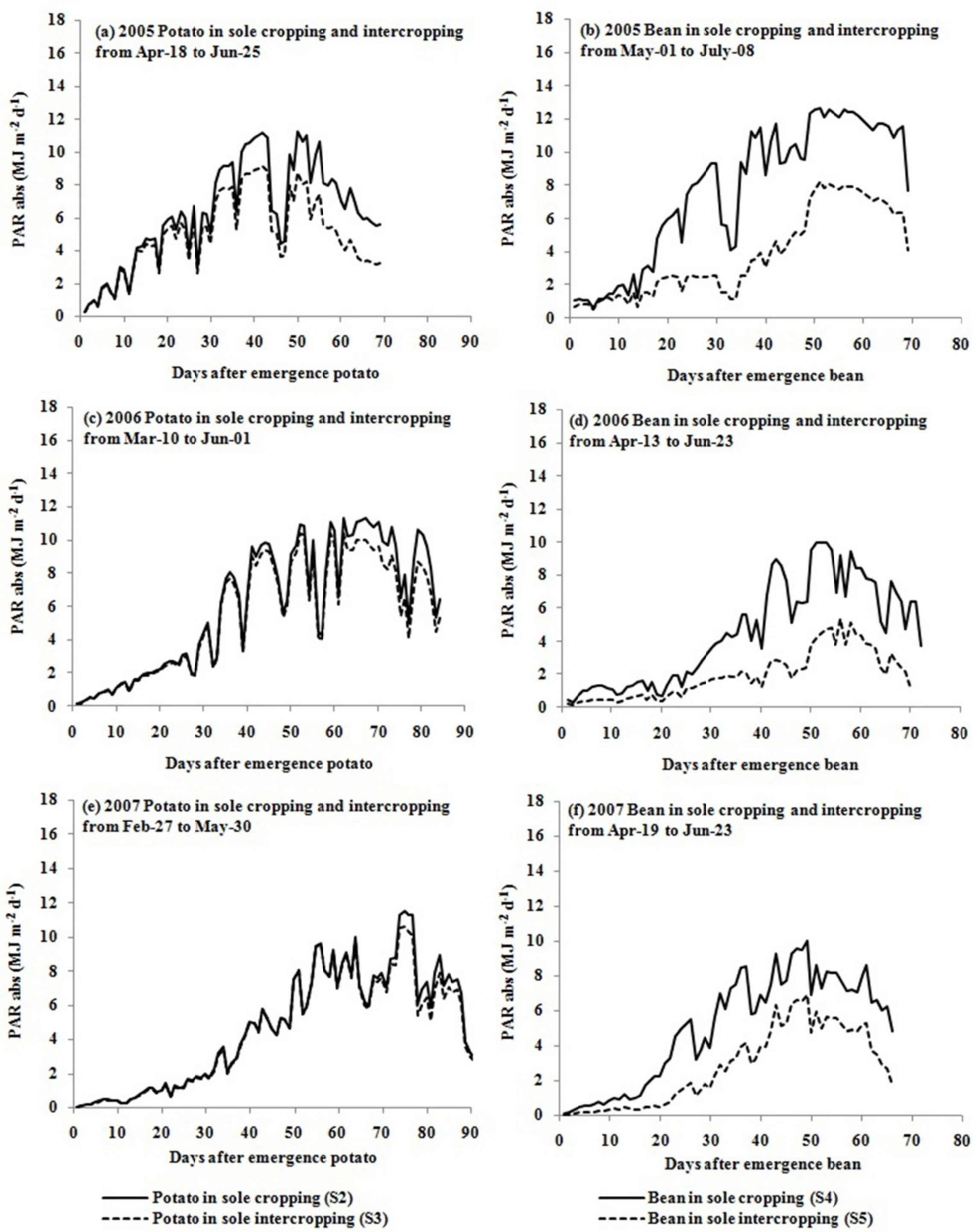

Figure 4. Time course of estimated daily light interception (PAR abs) in sole potato (S2) and bean (S4) and in intercrops potato and bean (S3 and S5) during the LAI measurement periods from 2005 to 2007

In fact, we observed that the daily PAR abs by the two cropping systems potato in sole cropping and intercropping (S2 and S3) was variable through the years. In the first experiment, the curves illustrating the daily evolution of PAR abs by S2 and S3 followed the same pace and were superimposed. Moreover, since the bean emergence (coincides with the 12th day of the potato emergence), the daily PAR abs by the S3 was lower than of the S2. Therefore, the cumulative amount of photosynthetic active radiation absorbed by S2 was (434.5 MJ m^{-2}) against (343.4 MJ m^{-2}) by S3, which means a reduction of 20.9%. Similarly, for the second experiment, the daily evolution of PAR abs by the two systems (S2) and (S3) appears to be the same from the 1st to the 42nd day of the potato emergence, but from this date, the daily PAR abs by the S2 became more important than the S3. As a result, the cumulative amount of intercepted radiation absorbed by S2 was (506 MJ m^{-2}) against (458.4 MJ m^{-2}) by S3, which means a reduction of 9.4%. For the third experiment, the results were consistent with those above, except for the reduction of the daily PAR abs by S3 which began in the 55th day after the potato emergence (coincides with the bean emergence). So, the amount of photosynthetic active radiation absorbed by S3 was equal to (407.1 MJ m^{-2}). In part against, for the S2, the quantity of the cumulative PAR abs was equal to (427.6 MJ m^{-2}), which means a reduction of 4.8%.

For the three experiments (2005; 2006 and 2007), the cumulative PAR abs by the S4 was greater than by the S5. In 2005, the cumulative PAR abs by the S4 was equal to (531.5 MJ m^{-2}) whereas it was only (263.2 MJ m^{-2}) in S5, which means a reduction of 50.4%. In 2006, the reduction of the cumulative PAR abs between S4 and S5 was equal to 58.7%. Therefore, the cumulative PAR abs has varied from 326.5 MJ m^{-2} in (S4) to 134.8 MJ m^{-2} in (S5). For the third experiment, the reduction of the cumulative PAR abs between S4 and S5 was less important than the previous experiment and it was equal to 44.8%. From these results, we observed that the introduction of bean in intercropping with potato led to a reduction in the PAR abs by potato and bean in sole intercropping on one hand and on the other hand, this reduction was more important in the potato than in the bean and varied from the date of bean plantation.

3.4 Radiation Use Efficiency

The relationship between the cumulative total dry matter production (TDM) and the cumulative intercepted radiation (PAR abs) for both cropping systems (S2 and S3) and during the three experiments is presented in Figure 5 (a, c and e). In fact, for potato in sole cropping, the TDM production increases linearly with the cumulative PAR abs. The slope of this line was radiation use efficiency (RUE). RUE has varied from 3.45 g MJ^{-1} in 2005 to 3.15 g MJ^{-1} in 2006. Moreover, during the third experiment, it was equal to 3.37 g MJ^{-1}. Likewise, for potato in sole intercropping, the TDM production was proportional to the cumulative PAR abs during the vegetative and early reproductive phases. So, for the three experiments the RUE of S3 was respectively equal to (4.22; 3.21 and 3.55 g MJ^{-1}). We observed that the RUE of potato in sole intercropping was higher than recorded in sole cropping. Variance analysis showed that there was a significant effect ($P < 0.05$) of intercropping on the RUE between S2 and S3 for the three experiments. We observed that the introduction of bean in sole intercropping with potato has improved the RUE by 23.6% during the first experiment and by 7.7% for the second and third season.

The relationship between the cumulative TDM and cumulative PAR abs for bean in sole cropping (S4) and bean in sole intercropping (S5) during the three measurement campaigns was shown in Figure 5 (b, d and f). From these results, we observed that for bean in sole cropping, the TDM production increases linearly with the cumulative PAR abs. thus, the RUE has varied from 1.34 g MJ^{-1} in 2005 to 2.09 g MJ^{-1} in 2006. In the third experiment, RUE was equal to 2.24 g MJ^{-1}. Also, for bean in sole intercropping, the TDM production was proportional to the cumulative PAR abs. Consequently, for the three experiments the RUE of S5 was respectively equal to 1.13; 2.30 and 2.19 g MJ^{-1}. We noticed that the RUE of S4 was higher than the S5. However, the variance analysis showed that there was no significant effect ($P > 0.05$) of intercropping on the RUE between S4 and S5 for the three experiments.

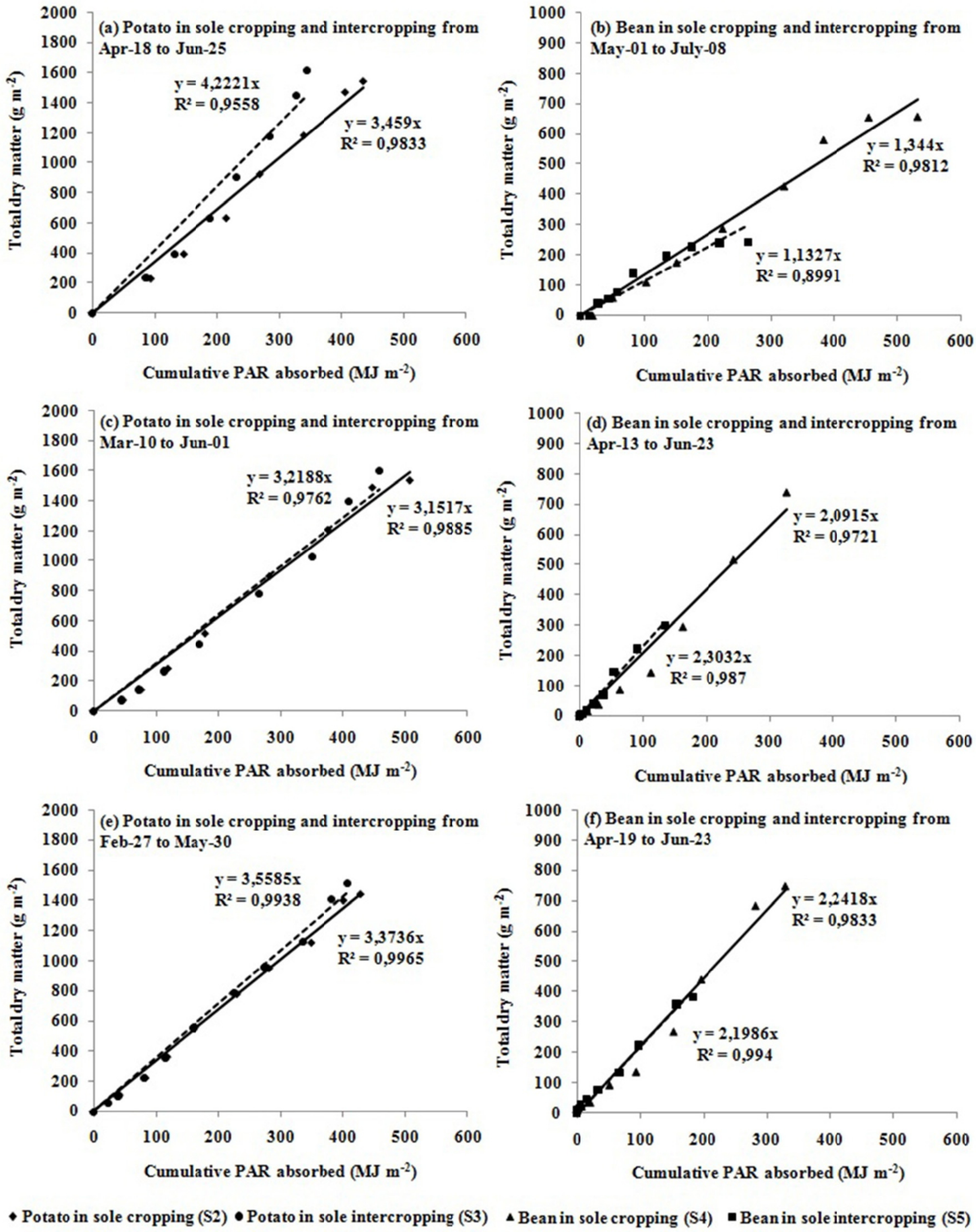

Figure 5. Radiation use efficiency of potato in sole cropping and in sole intercropping in 2005; 2006 and 2007 ((a), (c) and (e)) and for bean in sole cropping and in sole intercropping in 2005; 2006 and 2007 ((b), (d) and (f))

3.5 Discussion

For the three experiments, results showed that the TDM production of potato in sole cropping was lower than in sole intercropping. Nevertheless, for the bean, total dry matter production in sole cropping was significantly ($P < 0.05$) higher than in sole intercropping. From these results, we found that the bean in sole intercropping was dominated by the potato. These results were in agreement with those of Tsay et al. (1988a, 1988b). These authors observed that in the intercropping system cassava-soybean, the total dry matter production (TDM) of soybean in sole intercropping was higher than in sole cropping. However, for cassava in sole intercropping, the TDM production was reduced throughout the growth period compared to sole cropping. Similarly, these authors reported that the percentage of tuber dry matter accumulation was higher in cassava sole intercropping than in sole cropping. Marshall and Willey (1983) showed that the TDM production of the intercropped millet in the intercropping system millet-peanut was higher than the monoculture. Likewise, these results are consistent with those of Clark and Francis (1985). These authors reported that in the maize-bean intercropping system, the two varieties of bean intercropped with maize have achieved only 39 and 35% of their yield in monoculture. Mukhala et al. (1999) reported that in the maize-bean intercropping system, the yield of bean in sole intercropping was reduced respectively from 59%, 66% and 72% at low, medium and high density of maize. Also, Santalla et al. (2001) observed in intercropping system maize-bean, a yield reduction of 55% for bean in sole intercropping. Similarly, Oluwasemire et al. (2002) who have studied two intercropping systems millet-cowpea and millet-sorghum-cowpea affirmed that the millet was the dominant crop. In fact, the total dry matter production of cowpea and sorghum in sole intercropping was lower than those in sole cropping. Likeness, from these results, we observed that the intercropping system potato-bean has reduced the PAR abs by potato and bean in sole intercropping compared to that in sole cropping. This reduction was more important when the two crops were planted during the same period. These results were in accord with those of Zhang et al. (2008). These authors found in intercropping system wheat-cotton that the cumulative PAR abs by wheat and cotton in sole intercropping was a lesser amount than in sole cropping. However, we note that the bean intercropped with potato has improved the potato RUE of 23.6% during the first experiment (2005) and of 7.7% for the two experiments (2006 and 2007). Nevertheless, statistical analysis showed that no significant differences in the RUE between bean in sole cropping and intercropping. Indeed, reducing the total amount of PAR absorbed by the intercrop bean resulted in a reduction in the production of total dry biomass. From these results, we found that the bean in sole intercropping was dominated by the potato. It appears clear that this improvement of potato radiation use efficiency derives from further efficient use of the intercepted radiation. This is consistent with the literature, which indicates that the RUE of dominant component crops is generally not affected in sole intercropping. Willey, (1990) affirmed that the RUE of groundnut was 46% higher in sole intercropping with millet than groundnut in sole cropping. In the same way, Matthews et al. (1991) confirmed that the RUE of groundnut was higher in sole intercropping with sorghum than groundnut alone. Even so, in the study of Harris et al. (1987) on sorghum–groundnut intercropping, intercropped sorghum had 20% lower RUE than sole cropped sorghum, though by contrast intercropped groundnut had about 20% higher RUE than sole cropped groundnut. The decreased RUE of sorghum and the increased RUE of groundnut resulted in no intercrop yield advantage under that situation (Keating & Carberry, 1993).

4. Conclusion

The main findings in this study were as follows: firstly, the TDM production of potato in sole intercropping was higher than in sole cropping. Thus, the intercropping system potato-bean increased the TDM of the potato intercrop. However, for the bean intercrop, the TDM production was significantly lower than in sole cropping. It's can be concluded that bean in sole intercropping was dominated by potato. Secondly, the intercrop potato and bean intercepted less PAR energy than in the sole cropping. This decline in PAR abs in sole intercropping was more important when the two crops were planted in the same date. Thirdly, the intercrop potato used radiant energy more efficiently and had greater RUE than the sole cropping. As a result, the intercropping system potato-bean has improved the RUE of potato in sole intercropping.

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