Asian Journal of Crop Science

ISSN 1994-7879

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Asian Journal of Crop Science 5 (4): 378-392, 2013
ISSN 1994-7879 / DOI: 10.3923/ajcs.2013.378.392

Light Interception and Radiation Use Efficiency from a Field of Potato (*Solanum tuberosum* L.) and Sulla (*Hedysarum coronarium* L.) Intercropping in Tunisia

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ABSTRACT

An investigation was carried out at the Technical Centre of Potato situated in the low valley of Medjerda River at Saida to determine whether intercropping increased production for small-scale farming in a semi-arid region (Tunisia). Crop productivity of potato and sulla intercropping systems was evaluated in terms of Total Dry Matter production (TDM). The effect of radiation interception and Radiation Use Efficiency (RUE) by these systems was measured to determine their productivity. Field trials were carried out during two crop growing seasons (2006-2007) and (2008-2009). Intercropping had no significant effect on the total dry matter production of potato and sulla. However, it increased the dry biomass of the intercropping system. This increase occurred during the two campaigns (2006-2007) and (2008-2009), respectively from 12.5 to 14.8% compared to the potato in sole cropping. Intercropping potato with sulla reduced the radiation interception by both crops. This reduction was in the two experiments, respectively (from 12.6 to 16.2%) and (from 3.5 to 17.4%) for both crops. Radiation Use Efficiency of potato in sole intercropping was improved from 11.2 to 11.4%. For sulla in sole intercropping, RUE has been improved only during the first experiment by 19.4%. From these results, it has been concluded that potato-sulla intercropping can be recommended to small-scale farmers in this semi-arid region.

Key words: Sulla, potato, intercropping system, radiation use efficiency

INTRODUCTION

The main advantage of intercropping is further efficiency in using the available resources and the increased productivity compared to each sole crop (Zhang and Li, 2003; Szumigalski and Van Acker, 2006; Andersen *et al.*, 2007; Launay *et al.*, 2009; Mucheru-Muna *et al.*, 2010). Ifenkwe and Odurukwe (1990) found that, during the rainy-season, only 8% of the potato is grown in sole cropping, while 46% is in sole intercropping with maize and 23% by intercropping system of maize-cowpea. Theoretical and experimental approaches for the radiation interception quantification in sole cropping are well established and have been used in both temperate and tropical environments in recent decades (Monteith, 1994). These approaches supposed that the canopy is a heterogeneous arrangement of leaves randomly distributed and the spatial variation of the canopy radiation transmission is limited. However, these conditions weren't similar in sole intercropping due to the variation of canopy structure. So, the methodological problems concerned on one hand, the characterizing of the spatial and temporal variation in radiation interception and on the other hand, the partitioning of radiation interception between the components of intercrop. Several studies were carried out on the radiation interception and use of intercropping system (Reddy and Willey, 1981; Sivakumar and Virmani, 1984; Natarajan and Willey, 1985). The majority of these studies focused on the radiation interception and use by the all intercropping system. However, only a few models based on the distribution of light interception for each crop of intercropping system were reported by Wallace *et al.* (1990) and Sinoquet and Bonhomme (1992). Ozier-Lafontaine *et al.* (1997) examined the two models (geometric and statistical) of radiation interception in intercropping system of maize and sorghum. They verified that both models predict the radiation intercepted by the canopy of the intercropping system with high accuracy. Rohrig *et al.* (1999) and Mariscal *et al.* (2000) reported that the instantaneous transmission of radiation in the early stages of plant development, or a canopy containing widely spaced plants, the geometric method can be more accurate than the statistical method. However, the statistical method can be used to model the transmission of daily radiation. Tsubo and Walker (2002) indicated that the two model (instantaneous and daily) for radiation transmission were validated with high accuracy through the alternate intercrop canopy. Many researchers have been interested in the light interception and radiation use efficiency by the all intercropping system of potato-sulla (Rezig *et al.*, 2008, 2010). However, any information on the light interception and radiation use efficiency in potato and sulla under sole intercropping has been reported. Therefore, the objective of this study was to investigate the radiation interception and radiation use efficiency of potato and sulla 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.

MATERIALS AND METHODS

Experimental site: The experiment was carried out at the Technical Centre of Potato (CTP) situated in the low valley of Medjerda River at Saida, Tunisia (10°EST, 37°N, Alt. 328 m), during two seasons (2006-2007) and (2008-2009). The climate is semi arid. The rainfall annual 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 *et al.*, 2010).

Plant material: Plant material is composed of one variety of potato (Spunta) and one variety of sulla (Bikra 21). In the first experimentation (2006-2007), sulla seedling has been achieved in December 21, 2006 to a depth of 1.5 to 2 cm. The dose is 25 kg ha^{-1}. Potato plantation has been achieved in February 12, 2007 to a depth of 10 to 15 cm. This date corresponds to the three leaves stage of the sulla. Potato plantation density is 41667 plants ha^{-1}. Concerning the second experiment (2008-2009), the same technical itinerary has been practiced. Otherwise the sulla seedling has been achieved in December 01, 2008 and the potato plantation has been achieved in March 15, 2009.

Experimental design: Three experimental treatments were implemented, namely potato-sulla intercropping system (M1), potato sole cropping (M2) and sulla sole cropping (M4). An experimental

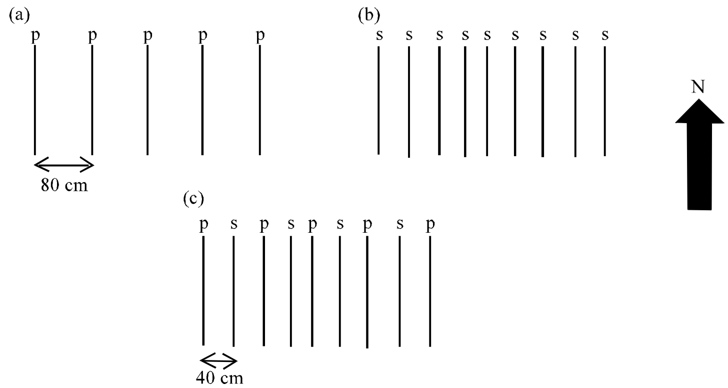

Fig. 1(a-c): Experimental plot, (a) Sole potato, (b) Sole sulla and (c) Sole intercropping potato-sulla

plot of (M1) is composed of 5 rows of potato (M3) intercropped with 4 lines of sulla (M5). An experimental plot of (M2) is composed of 5 rows spaced 80 cm with 30 cm spacing within the line and an experimental plot of (M4) is made up of 9 rows spaced of 40 cm (Fig. 1). The adopted experimental design was that of randomized complete blocks with three replications. Every experimental plot had 10 m length and 4.8 m width.

Theoretical formulations

Leaf area index and total dry matter production: The observations were made on leaf area and total dry matter (g m^{-2}). Plants were harvested for growth analysis at 52, 56, 62, 69, 75, 83, 90, 96, 103, 111 DAP (potato) and 110, 114, 120, 127, 133, 141 DAS (sulla) in (2006-2007) and at 48, 55, 62, 71, 76, 83, 90, 104, 118 DAP (potato) and 107, 115, 122, 129, 138 and 143 DAS (sulla) in (2008-2009).

At each sampling, three plants by plot (potato and/or sulla) were collected. After separation of the plant organs, leaf area 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.

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

$$PAR_{abs} = PAR_0 (1-e^{-k\,LAI}) \quad (1)$$

Where, PAR_0 is photosynthetically active radiation incident, which is equal to half the solar radiation (Monteith and Unsworth, 1990). Moreover, in the sole intercropping, PAR absorbed by each culture, PAR_{abs}, is the most difficult to measure component. 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, was used in this study the model of radiation interception through a cereal-legume intercrop proposed by Tsubo and Walker (2002).

There are two canopy layers in sulla-potato intercropping, so the boundaries are determined by the canopy heights of the sulla and potato crops. When the sulla crop canopy is taller than the potato crop canopy, the upper turbid layer only comprises the sulla turbid medium while the lower turbid layer consists of both sulla and potato turbid mediums. The fraction of radiation intercepted by the sulla crop in the first turbid layer (F_{SC1}) is given by:

$$F_{SC1} = 1\text{-}e^{(-KS * LAI_{SC1})} \quad (2)$$

where, LAI_{SC1} is sulla Leaf Area Index (LAI) in the upper turbid layer and K_S is a sulla crop canopy extinction coefficient. According to the equation described by Keating and Carberry (1993), the fraction of radiation intercepted by sulla and potato in the lower turbid layer (F_{SC2} and F_p, respectively) is given by:

$$F_{SC2} = \frac{K_S * LAI_{SC2}}{K_S * LAI_{SC2} + K_P * LAI_P} * [1\text{- } e\,(\text{-}\, KS * LAI_{SC2} \text{ - } KP * LAI_P)] \quad (3)$$

$$F_P = \frac{K_P * LAI_P}{K_S * LAI_{SC2} + K_P * LAI_P} * [1\text{- } e\,(\text{-}\, KS * LAI_{SC2} \text{ - } KP * LAI_P)] \quad (4)$$

where, LAI_{SC2} and LAI_P are sulla and potato LAI in the lower turbid layer and K_P is a potato crop canopy extinction coefficient. Assuming that leaves are randomly distributed in the canopies, LAI_{SC1} and LAI_{SC2} can be calculated as follows:

$$LAI_{SC1} = (1\text{-}n) * LAI_{SC} \quad (5)$$

$$LAI_{SC2} = n * LAI_{SC} \quad (6)$$

where, n is the ratio of plant (or canopy) heights of potato to sulla and LAI_{SC} is total sulla LAI.

Estimation of the radiation use efficiency: Radiation Use Efficiency (RUE) of sulla and potato (RUE_S and RUE_P, respectively) is calculated by:

$$RUE_S = \frac{TDM}{PAR_0 * (F_{SC1} + F_{SC2})} \quad (7)$$

$$RUE_P = \frac{TDM}{PAR_0 * F_P} \quad (8)$$

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

RESULTS

Leaf area index: Figure 2 showed the evolution of Leaf Area Index (LAI) of potato and sulla in sole intercropping (M1), potato in sole cropping (M2) and potato in sole intercropping (M3), during the two cropping seasons 2006-2007 (a) and 2008-2009 (b) Table 1-2.

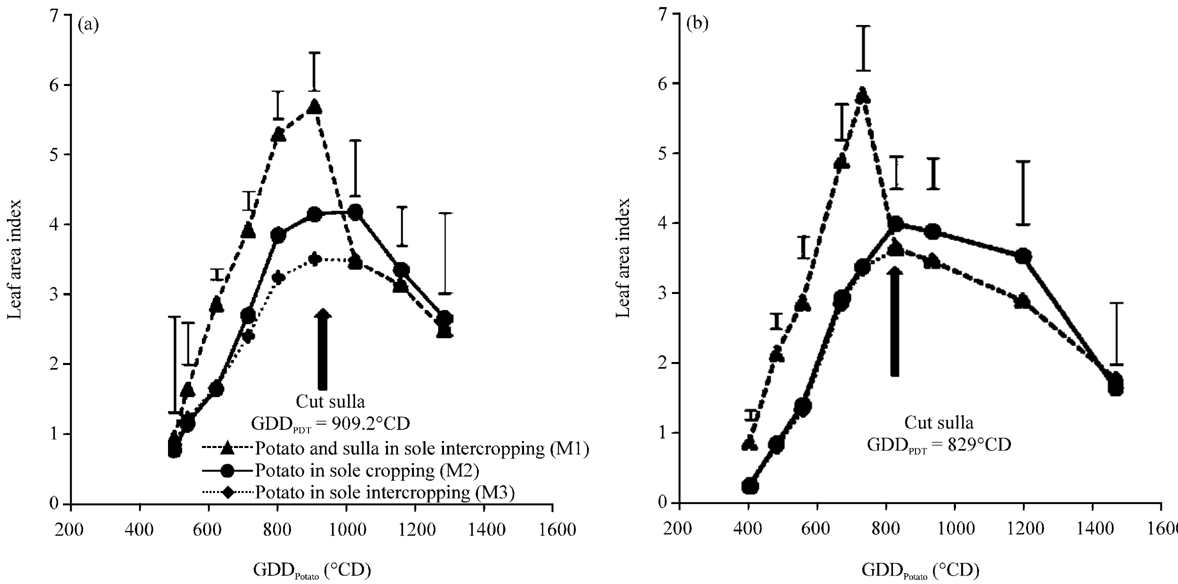

Fig. 2(a-b): Leaf area index of potato and sulla in sole intercropping (M1), potato in sole cropping (M2) and potato in sole intercropping (M3), during the two cropping seasons (a) 2006-2007 and (b) 2008-2009, the vertical bars represent the least significant difference at 5% (LSD)

Table 1: Leaf area index of potato and sulla in sole intercropping (M1), potato in sole cropping (M2) and potato in sole intercropping (M3), during the cropping season 2006-2007 (C1)

	Leaf area index (LAI)								
	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
GDD_{potato} (°CD)	504.10	543.70	627.50	719.30	804.30	909.20	1027.10	1161.30	1285.60
M1	0.93[a]	1.64[a]	2.84[a]	3.91[a]	5.30[a]	5.69[a]	3.47[b]	3.12[a]	2.48[a]
M2	0.75[a]	1.15[a]	1.65[b]	2.70[b]	3.84[b]	4.14[b]	4.18[a]	3.35[a]	2.65[a]
M3	0.83[a]	1.23[a]	1.67[b]	2.39[c]	3.23[c]	3.51[c]	3.47[b]	3.12[a]	2.48[a]
LSD (5%)	1.37	0.58	0.16	0.27	0.41	0.56	0.81	0.55	1.15

C1: Cropping seasons (2006-2007), GDD: Growing degree days, LSD: Least significant difference

Table 2: Leaf area index of potato and sulla in sole intercropping (M1), potato in sole cropping (M2) and potato in sole intercropping (M3), during the cropping season 2008-2009 (C2)

	Leaf area index (LAI)								
	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
GDD_{potato} (°CD)	405.10	481.05	558.75	672.25	733.25	829.20	936.70	1199.80	1471.60
M1	0.87[a]	2.14[a]	2.87[a]	4.90[a]	5.84[a]	3.65[a]	3.47[a]	2.90[a]	1.77[a]
M2	0.24[b]	0.85[b]	1.40[b]	2.95[b]	3.38[b]	3.99[a]	3.89[a]	3.54[a]	1.63[a]
M3	0.25[b]	0.81[b]	1.33[b]	2.84[b]	3.36[b]	3.65[a]	3.47[a]	2.90[a]	1.77[a]
LSD (5%)	0.12	0.21	0.31	0.52	0.64	0.46	0.45	0.90	0.87

C2: Cropping seasons (2008-2009), GDD: Growing degree days, LSD: Least significant difference

Indeed, from emergence to 65th day after planting potato (GDD accumulated between 670 and 712°CD), a rapid increase in the LAI was noticed (the period of vegetative

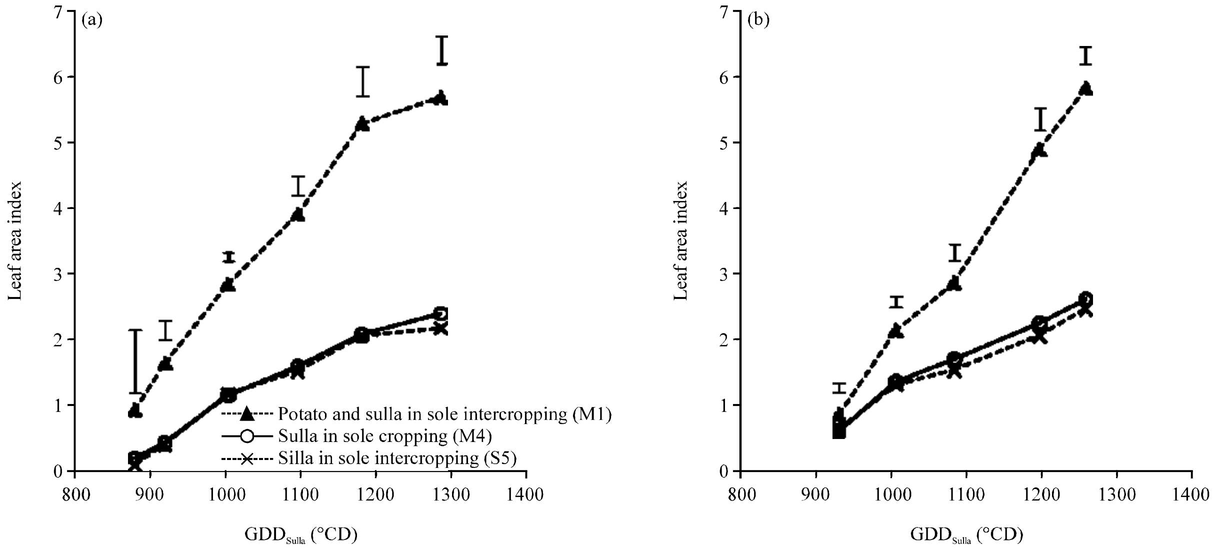

Fig. 3(a-b): Leaf area index of potato and sulla in sole intercropping (M1), sulla in sole cropping (M4) and sulla in sole intercropping (M5), during the two cropping seasons, (a) 2006-2007 and (b) 2008-2009, the vertical bars represent the least significant difference at 5% (LSD)

growth). Then, from 65th to 85th (GDD accumulated between 940 and 1027°CD), a phase during which the LAI was stable. Finally, decrease phase to harvest.

For both experiments, results showed that, from the potato emergence to the first cut of sulla (829°CD<GDD_{PDT}<909°CD), the potato-sulla intercropping system (M1) had a higher LAI than in sole cropping (M2) and in sole intercropping (M3). However, for potato in sole cropping and intercropping, the effect of intercropping was significant during the first experiment ($p<0.05$) only from the 69th (GDD_{PDT} = 719°CD) to the 90th day after planting potato (GDD_{PDT} = 1027°CD). Thus, the LAI_{max} of potato in sole cropping (4.18) was significant ($p<0.05$) higher than in sole intercropping (3.47). In the second experiment, no significant ($p>0.05$) difference was found between M2 and M3. The LAI_{max} of potato in sole cropping and intercropping was equal to (3.99 and 3.65).

Similarly, for the sulla and for the two experiments (Fig. 3), no significant ($p>0.05$) difference was found between M4 and M5. The LAI_{max} of sulla in sole cropping and intercropping was respectively equal to (2.3 and 2.1) in 2007 and equivalent to (2.6 and 2.4) in 2009.

Total dry matter production: The variations of total dry matter production of potato and sulla in sole intercropping (M1), potato in sole cropping (M2) and potato in sole intercropping (M3), during the two cropping seasons 2006-2007 (a) and 2008-2009 (b) were shown in Fig. 4 and Table 3. Variance analysis showed that there was a significant effect ($p<0.05$) of intercropping on TDM production. Moreover, the TDM production in M1 was significantly higher than in M2 and in M4. So, the potato-sulla intercropping had the greatest TDM production in the first experiment and was equal to 1628.4 g m^{-2}. Similarly for the second experiment and it was equivalent to 1653.7 g m^{-2}.

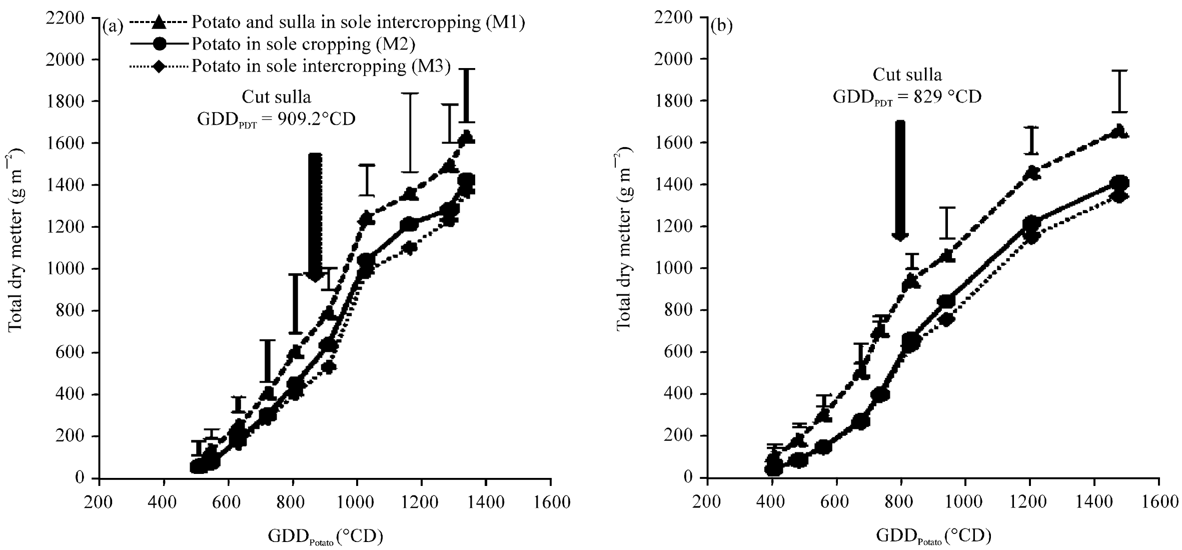

Fig. 4(a-b): Total dry matter production of potato and sulla in sole intercropping (M1), potato in sole cropping (M2) and potato in sole intercropping (M3), during the season, (a) 2006-2007 and (b) 2008-2009, the vertical bars represent the least significant difference at 5% (LSD)

Table 3: Leaf area index of potato and sulla in sole intercropping (M1), sulla in sole cropping (M4) and sulla in sole intercropping (M5), during the two cropping seasons 2006-2007 (C1) and 2008-2009 (C2)

	Leaf area index (LAI)										
	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1
GDD_{sulla} (°CD)	879.50	930.90	919.20	1006.90	1002.90	1084.60	1094.70	1198.10	1179.70	1259.10	1284.60
M1	0.93^a	0.87^a	1.60^a	2.10^a	2.84^a	2.80^a	3.90^a	4.90^a	5.20^a	5.80^a	5.60^a
M4	0.20^b	0.62^b	0.43^b	1.36^b	1.18^b	1.70^b	1.58^b	2.20^b	2.08^b	2.60^b	2.30^b
M5	0.10^b	0.62^b	0.40^b	1.32^b	1.17^b	1.50^b	1.52^b	2.00^b	2.06^b	2.40^b	2.10^b
LSD (5%)	0.65	0.15	0.29	0.17	0.14	0.26	0.29	0.32	0.45	0.26	0.43

C1: Cropping seasons (2006-2007), C2: Cropping seasons (2008-2009), GDD: Growing degree days, LSD: Least significant difference

For potato in sole cropping (M2) and in sole intercropping (M3), no significant differences ($p>0.05$) were found in the TDM production. For the both experiments, the TDM production by M3 was, respectively equal to (1368.6, 1347.7 g m^{-2}) and it was, respectively equivalent to (1424.5, 1408.5 g m^{-2}) in M2.

Figure 5 and Table 4 and 5 showed the evolution of the total dry matter production of potato and sulla in sole intercropping (M1), sulla in sole cropping (M4) and sulla in sole intercropping (M5), during the two cropping seasons 2006-2007 (a) and 2008-2009 (b).

Similarly, for sulla, no significant differences ($p>0.05$) were found between the TDM production by M4 and M5. It was for the both seasons respectively equal to (259.7, 306 g m^{-2}) by M5 and it was respectively equivalent to (249.4, 316.7 g m^{-2}) in M4.

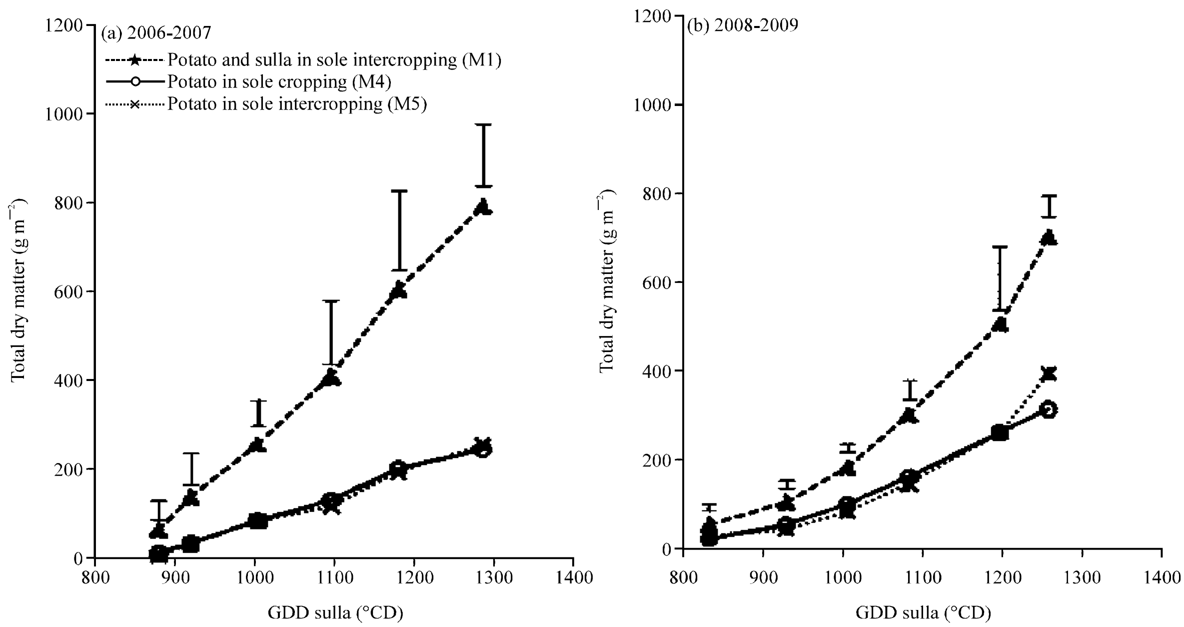

Fig. 5(a-b): Total dry matter production of potato and sulla in sole intercropping (M1), sulla in sole cropping (M4) and sulla in sole intercropping (M5), during the season, (a) 2006-2007 and (b) 2008-2009, the vertical bars represent the least significant difference at 5% (LSD)

Table 4: Total dry matter production of potato and sulla in sole intercropping (M1), potato in sole cropping (M2) and potato in sole intercropping (M3), during the cropping season 2006-2007 (C1)

	Total dry matter (TDM)									
	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
GDD_{potato} (°CD)	504.1	543.7	627.5	719.3	804.3	909.2	1027.1	1161.3	1285.6	1335.3
M1	67.2^{a}	139.7^{a}	258.7^{a}	410.4^{a}	605.5^{a}	793.8^{a}	1246.4^{a}	1359.5^{a}	1490.2^{a}	1628.4^{a}
M2	63.9^{a}	80.3^{c}	191.8^{b}	309.5^{a}	454.4^{b}	641.4^{b}	1043.3^{b}	1213.4^{a}b	1285.0^{b}	1424.5^{b}
M3	57.0^{a}	102.8^{b}	170.9^{b}	290.3^{a}	408.5^{b}	534.0^{a}	986.7^{b}	1099.7^{b}	1230.4^{b}	1368.6^{b}
LSD (5%)	63.3	43.4	73.3	193.6	278.4	109.4	146.2	378.3	184.9	250.7

C1: Cropping seasons (2006-2007), GDD: Growing degree days, LSD: Least significant difference

Table 5: Total dry matter production of potato and sulla in sole intercropping (M1), potato in sole cropping (M2) and potato in sole intercropping (M3), during the cropping season 2008-2009 (C2)

	Total dry matter (TDM)									
	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
GDD_{potato}(°CD)	306.9	405.1	481.1	558.8	672.3	733.3	829.2	936.7	1199.8	1471.6
M1	54.9^{a}	105.0^{a}	184.9^{a}	303.9^{a}	508.9^{a}	703.8^{a}	940.4^{a}	1063.8^{a}	1457.5^{a}	1653.7^{a}
M2	31.3^{b}	46.4^{b}	87.8^{b}	151.1^{b}	275.0^{b}	403.6^{b}	664.1^{b}	844.5^{b}	1217.2^{b}	1408.5^{b}
M3	30.9^{b}	46.1^{b}	86.3^{b}	148.0^{b}	265.1^{b}	397.7^{b}	634.3^{b}	757.8^{c}	1151.4^{c}	1347.7^{b}
LSD (5%)	10.5	15.9	13.5	53.1	97.0	29.5	74.8	140.9	127.3	195.6

C2: Cropping seasons (2008-2009), GDD: Growing degree days, LSD: Least significant difference

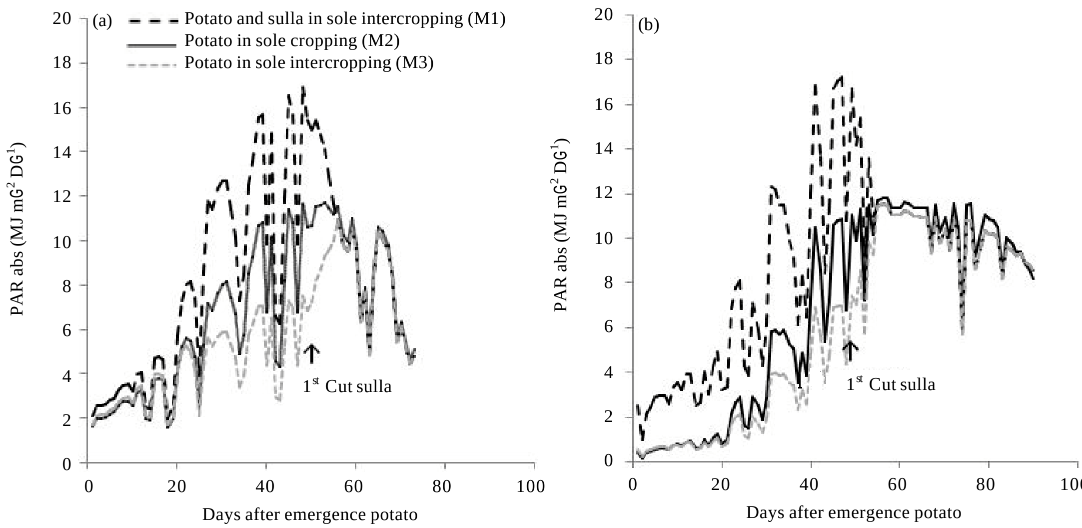

Fig. 6(a-b): Daily radiation interception of potato and sulla in sole intercropping (M1), potato in sole cropping (M2) and potato in sole intercropping (M3), during the two cropping seasons, (a) 2006-2007 and (b) 2008-2009

Table 6: Total dry matter production of potato and sulla in sole intercropping (M1), sulla in sole cropping (M4) and sulla in sole intercropping (M5), during the two cropping seasons 2006-2007 (C1) and 2008-2009 (C2)

	Total dry matter (TDM)											
	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
GDD_{sulla} (°CD)	879.5	832.7	919.2	930.9	1002.9	1006.9	1094.7	1084.6	1179.7	1198.1	1284.6	1259.1
M1	67.2^a	54.9^a	139.7^a	105.0^a	258.7^a	184.9^a	410.4^a	303.9^a	605.5^a	508.9^a	793.8^a	703.8^a
M4	15.5^b	24.7^b	37.0^b	56.8^b	87.2^b	101.2^b	133.4^b	163.7^b	206.4^b	263.5^b	249.3^b	316.7^b
M5	10.2^b	23.9^b	36.8^b	58.9^b	87.8^b	98.6^b	120.0^b	155.8^b	196.9^b	243.8^b	259.7^b	306.0^b
LSD (5%)	43.8	12.1	69.6	17.8	58.9	20.3	141.1	42.6	176.2	142.5	138.1	45.8

C1: Cropping seasons (2006-2007), C2: Cropping seasons (2008-2009), GDD: Growing degree days, LSD: Least significant difference

Radiation interception: The daily evolution of the radiation interception (PAR abs) by potato and sulla in sole intercropping (M1), potato in sole cropping (M2) and potato in sole intercropping (M3), during the two cropping seasons 2006-2007 (a) and 2008-2009 (b) was given in Fig. 6 and Table 6.

In fact, we observed that the daily PAR abs by the two cropping systems potato in sole cropping and intercropping (M2 and M3) was variable through the years. In fact, during the first experiment, the daily PAR abs by M2 was significantly higher than by M3. However, from the first cut of sulla (52nd day after potato emergence) to the potato harvest, the daily PAR abs by the two cropping systems was equal. Thus, throughout the development cycle of the potato, M2 has absorbed 496.1 MJ m^{-2}, in part next to the M3 which has absorbed only 415.8 MJ m^{-2} that is a reduction of 16.2%. Similarly, the results obtained during the second experiment were consistent with those of the first season. Indeed, during the early stages of the potato development, the daily PAR abs by M2 was significantly higher than by M3. However, from the first cut of sulla (48th day

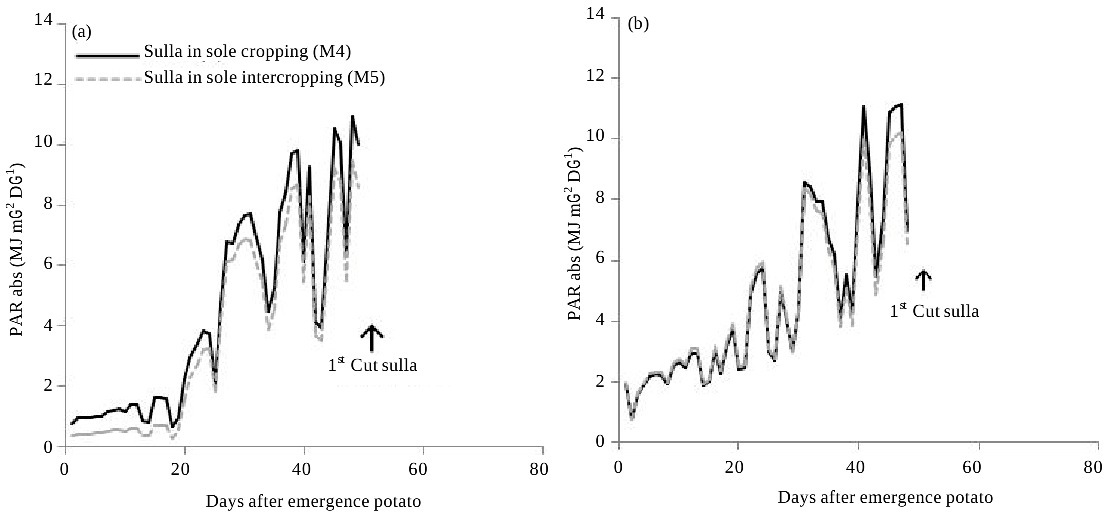

Fig. 7(a-b): Daily radiation interception of sulla in sole cropping (M4) and sulla in sole intercropping (M5), during the two cropping seasons, (a) 2006-2007 and (b) 2008-2009

after potato emergence), the daily PAR abs by M2 was equal to that by M3. Therefore, the cumulative amount of photosynthetic active radiation absorbed by M3 was (524.5 MJ m^{-2}) against (599.6 MJ m^{-2}) by M2, which means a reduction of 12.6%.

Figure 7 showed the Daily evolution of PAR abs by sulla in sole cropping (M4) and by sulla in sole intercropping (M5), during the two cropping seasons 2006-2007 (a) and 2008-2009 (b). In (2006-2007), the cumulative PAR abs by M4 (226.4 MJ m^{-2}) was greater than by M5. As a result, the M5 has absorbed 186.1 MJ m^{-2}, which means a reduction of 17.4%.

Moreover, in (2008-2009) the daily PAR abs by the two cropping systems were almost equal. Thus, throughout the development cycle sulla; the both cropping systems (M4 and M5) accounted, respectively 250.7 and 241.9 MJ m^{-2}.

Radiation use efficiency: The relationship between the cumulative TDM production and cumulative PAR abs for both cropping systems (M2 and M3) and during the two experiments 2006-2007 (a) and 2008-2009 (b) was given in Fig. 8.

In fact, for M2, the TDM increases linearly with the cumulative PAR abs. The slope of this line was Radiation Use Efficiency (RUE). Indeed, it varied from 2.72 g MJ^{-1} (2006-2007) to 2.46 g MJ^{-1} (2008-2009). RUE was in the range of values 1.8 g MJ^{-1}<RUE<3.7 g MJ^{-1} found by other authors for this crop (Allen and Scott, 1980; Fahem and Haverkort, 1988; Fahem, 1991, Jefferies and Mackerron, 1989). Similarly, for M3, the cumulative production of TDM was proportional to the cumulative PAR abs during the vegetative and early reproductive phases. However, the RUE varied from 3.07 g MJ^{-1} in (2006-2007) to 2.77 g MJ^{-1} in (2008-2009).

Figure 9 showed the relationship between the cumulative TDM production and cumulative PAR abs for both cropping systems (M4 and M5) and during the two experiments 2006-2007 (a) and 2008-2009 (b).

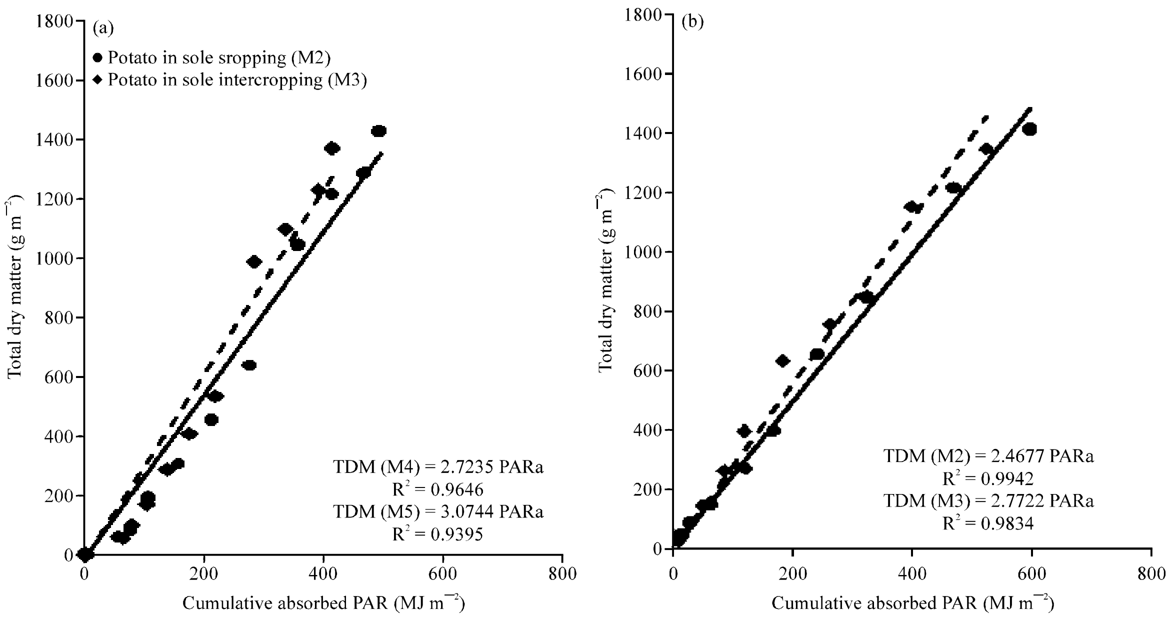

Fig. 8(a-b): Radiation use efficiency of potato in sole cropping (M2) and potato in sole intercropping (M3), during the two cropping seasons, (a) 2006-2007 and (b) 2008-2009

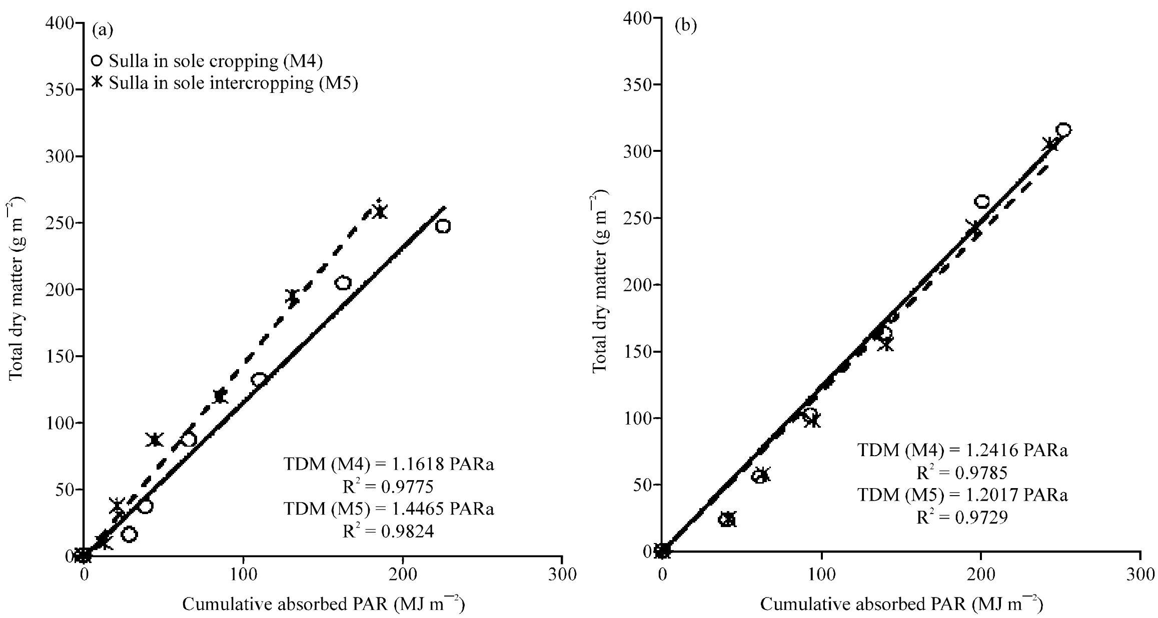

Fig. 9(a-b): Radiation use efficiency of sulla in sole cropping (M4) and sulla in sole intercropping (M5), during the two cropping seasons, (a) 2006-2007 and (b) 2008-2009

In the first experiment (2006-2007), the RUE of sulla in sole intercropping (1.44 g MJ^{-1}) was greater than in sole cropping (1.16 g MJ^{-1}). As result, an increase of 19.4% in RUE was recorded. However, in (2008-2009), the two cropping systems (M4 and M5) have the same RUE and were equal to 1.2 g MJ^{-1}.

DISCUSSION

For both experiments, results showed that the TDM production by the intercrop potato and sulla was not affected by the intercropping system compared to sole cropping. Thus, it had increased the TDM of the intercropping system. These results are consistent with several researchers who have reported that the total dry production by intercropping was higher than in sole cropping (Hauggaard-Nielsen *et al.*, 2001; Thorsted *et al.*, 2006). Similarly, Gao *et al.* (2009) studied an intercropping system of maize and wheat. They reported that the dry biomass in intercropping is slightly higher than in sole cropping.

The intercropping system potato-sulla has reduced the radiation useful for photosynthesis absorbed (PAR abs) by potato in sole intercropping compared to that in sole cropping. This reduction has varied during the two experiments (2007 and 2009), respectively, from 16.2 to 12.6%. However, it has increased the total radiation absorbed by the intercropping system and this increase varied from 17.6% in 2007 to 21.7% in 2009. These results are consistent with those of Opoku-Ameyaw and Harris (2001) for the intercropping system potato-cabbage. Indeed, these authors reported that cabbage has reduced the amount of radiation intercepted by potato in sole intercropping compared to sole cropping. Likewise, these results are consistent with numerous studies, mainly tropical. They showed that the intercropping system tends to intercept more PAR than mono cultures. As such, Sivakumar and Virmani (1980) for the intercropping maize-pigeon pea and (Tsubo *et al.*, 2001) for the intercropping maize reached the same results. Similarly, Zhang *et al.* (2008) found that the total radiation intercepted by the intercropping system wheat-cotton was significantly higher than by wheat and cotton in sole cropping.

The RUE of potato in sole cropping and intercropping was greater in first experiment (2.72; 3.07 g MJ^{-1}) than in the second (2.46, 2.77 g MJ^{-1}). In this context, Varlet-Grancher *et al.* (1982) said that the radiation useful for photosynthesis absorbed throughout the growing cycle depends on its time and its place in relation to the evolution of the incident radiation (PAR_0) in the year. Thus, throughout the potato development, the cumulative PAR_0 was much higher during the second experiment (1137 MJ m^{-2}) than in the first campaign (1001 MJ m^{-2}). Likewise, the cumulative PAR abs was more important during the second campaign than in the first campaign. However, the cumulative TDM production of the two systems (M2 and M3) was the lowest. This explains the low efficiencies marked during the second experiment.

Similarly, from these results we observed that in the two measurement campaigns, the RUE of potato in sole intercropping is greater than in sole cropping. Indeed, M3 tends to produce the same amount of TDM than M2, nevertheless it has absorbed a smaller amount of radiation. Potato in sole intercropping intercepted less radiation per row (from 415.8 to 524.5 MJ m^{-2}) than in the sole cropping (from 496.1 to 599.6 MJ m^{-2}) but used it more efficiently. This is can be explained by the temporal (different crop duration) and spatial (changing pattern cycle) complementarities between potato and sulla in sole intercropping. Initially, sulla dominated the intercrop and depressed the growth of potato, but after sulla cutting the intercropping system allowed compensatory growth to potato. On the whole, the obtained benefits were predominantly due to potato which was able to produce similar growth in sole cropping (from 1408.5 to 1424.6 g m^{-2}) than in sole intercropping (from 1347.7 to 1368.6 g m^{-2}), even when shaded by sulla. These findings are in agreement with those of Marshall and Willey (1983) who have studied an intercropping system comprising three rows of groundnut alternating with one row of millet. They have observed that the groundnut in sole intercropping intercepted less radiation than in sole cropping but produced the same total dry matter production. They have concluded that this improvement in radiation use efficiency was due to a more efficient use of radiation interception in sole cropping. Harris and Natarajan (1987) have also considered an intercrop comprising one row of sorghum between two rows of groundnut. They, too, confirmed that the improvement in radiation use efficiency was appropriate to a more efficient use of radiation interception in sole cropping.

A similar result was reported by Tsubo and Walker (2002) who indicated that the beans had 12.5% greater RUE in intercropping than in sole cropping.

CONCLUSION

The main findings in this study were as follows: Firstly, no differences in TDM were found between the potato and sulla in sole cropping and intercropping. Thus, it had increased the TDM of the intercropping system. This increase was observed during the two seasons (2006-2007) and (2008-2009) respectively from 12.5 to 14.8% compared to the potato in sole cropping. Secondly, the intercrop potato and sulla intercepted less PAR energy than in the sole cropping but it had increased the total PAR energy intercepted by the intercropping system. This increase had varied from 17.6% in (2006-2007) to 21.7% in (2008-2009). Thirdly, potato and sulla intercrop used radiant energy more efficiently and had greater RUE than the sole cropping.

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