Bulgarian Journal of Agricultural Science, 28 (No 4) 2022, 647–657

Yield potential and land-use efficiency of onion *(Allium cepa* L.) intercropped with peanut (*Arachis hypogaea* L.) under organic soil fertility management in South-Kivu, Eastern DR Congo

Serge S. Ndjadi[1,2*], Pierre V. Vissoh[2], Roger K. Vumilia[3], Jean M. Mondo[1], Yannick Mugumaarhahama[1], Aliou Saidou[4], Gustave M. Nachigera[1] and Léonard E. Ahoton[5]

[1]*Department of Crop Science, Faculty of Agriculture and Environmental Studies, Université Evangélique en Afrique, BP.3323, Bukabu, South-Kivu, DR Congo*
[2]*University of Abomey Calavi, School of Economics of Socio-anthropology and Communication for Rural Development, Faculty of Agronomic Sciences, 01 BP 526 RP, Cotonou, Benin*
[3]*Institut National d'Etudes et de Recherches Agronomiques, BP 2037, Kinshasa, DR Congo*
[4]*University of Abomey Calavi, Soil Science Laboratory, School of Sciences and Crop Production Techniques, Faculty of Agronomic Sciences, 01 BP 526 RP, Cotonou, Benin*
[5]*University of Abomey Calavi, Plant Biology Laboratory, School of Sciences and Crop Production Techniques, Faculty of Agronomic Sciences, 01 BP 526 RP, Cotonou, Benin*
[*]*Corresponding author:* ndjadishakanye@gmail.com

Abstract

Ndjadi, S. S., Vissoh, P. V., Vumilia, R. K., Mondo, J. M., Mugumaarhahama, Y., Saidou, A., Nachigera, G. M. & Ahoton, L. E. (2022). Yield potential and land-use efficiency of onion *(Allium cepa* L.) intercropped with peanut (*Arachis hypogaea* L.) under organic soil fertility management in South-Kivu, Eastern DR Congo. *Bulg. J. Agric. Sci., 28 (4)*, 647–657

Intercropping and organic soil fertility are eco-friendly agricultural practices for sustainable agriculture. The aim of this study was to determine the yield potential and land-use efficiency of onion intercropped with groundnut under organic soil fertility management. A two-year field experiment was conducted in 2019 and 2020 under a complete factorial design with two crops and 2 varieties per crop (Bombay and creole for onion and A65 and JL24 for groundnut). Crops implementation was realized in sole and mixture under farmyard manure (FYM) single application, FYM seasonal application, FYM + NPK 1 – 1 – 2, and the control. The average yields were recorded while the intercropping efficiency was analysed using the land equivalent ratio (LER), competitiveness ratio, and aggressiveness index. Results showed that creole variety had the highest yield (17 $t.ha^{-1}$) across years. FYM under single and seasonal application effectively increased the onion yield with similar values (8 to 16 $t.ha^{-1}$). The LER analysis showed a yield gain for Bombay + A65 (total LER= 2.25) in 2019 and (2.38) in 2020 for Creole+A65. Analysis of competitiveness indices showed that the onion variety Bombay was more competitive than A65 (1.06). The same trend was recorded when onion variety Creole was intercropped with the same groundnut variety (1.93). FYM in single and seasonal application also affects the competitiveness of onion on groundnut (0.99 and 1.07). The present study shows that onion – groundnut intercropping under organic fertilizers could be a viable option to support the ecological intensification of onion cultivation in eastern DRC.

Keywords: Biological efficiency; Cropping system; ecological intensification; sustainability and vegetable production

Introduction

In South-Kivu Province, Eastern Democratic Republic of Congo (DRC), due to a favorable climate and high vegetable products' demand, vegetable production become a dynamic agricultural sub-sector (PNUD/DRC, 2012). Vegetable production contributes to the population food, nutritional and socioeconomic securities. The grown vegetables are diverse and include a range of crops such as tomato (*Solanum lycopersicum* L. var. *lycopersicum*), cabbage (*Brassica oleracea* var. *capitata*), eggplant (*Solanum melongena* L.*)*, onion (*Allium cepa* L.) and many others indigenous and exotic vegetable crops. These crops are mostly grown on small plots (~100 – 10 000 m^2), in pure culture and very few in intercropping. South-Kivu's vegetable productivity is low and the production unsatisfactory in meeting populations' needs (Ndjadi et al., 2020).

In addition to poor levels of production factors' control, vegetable production is subject to land insecurity, especially in peri-urban areas where vegetable production sites are gradually converted into settlements (Mushagalusa et al., 2015). Moreover, the permanent monocropping of the same crops by most of the vegetable growers across years not only leads to a drop in market prices, but also causes the soil fertility degradation, accentuates the prevalence of pests and diseases, and thus increases risks and reduces the farm resilience to external factors.

In South-Kivu as in other regions of the world, the onion is one of the major crops and bears significant nutritional, economic and therapeutic importance. It provides vitamins A, B, C, essential minerals, and is one of the richest sources of flavonoids. These attributes make the crop an important dietary supplement because of its flavor and taste. Onions are also a valuable source of income for most producers (Mitra et al., 2011; Li et al., 2016).

Despite the positive contributions of the onion production, its cropping system is highly vulnerable. For instance, there is a few research on its intercropping with other crops such as legume systems, soil fertility problems, and sensitivity to market trends, all of which constrains its production in eastern DRC. In South Kivu, the intensification of its pure cropping further increases this vulnerability. Yet in terms of resilience and sustainability, the pure cropping system is becoming questionable (Ndjadi et al., 2021). Indeed, some production constraints can be managed by integrated plant diversity, such as land tenure and soil fertility and sensitivity to market trends. In addition, diversified agro-systems are recognized as more resilient and sustainable cropping options than non-diversified agro-systems (Akwasi, 2014).

Legumes are in most cases intercropped with others crops. These species are mostly integrated in agrosystems based on cereals, roots and tubers, fruit trees, industrial crops and many others. It is noteworthy that in market gardening, this integration of legumes into vegetable cropping systems is seldom practiced although it bears potential for improving vegetable sutainability (Pfeiffer et al., 2015). For instance, the importance of legumes within agricultural systems is linked with their capacity to enrich soils with nitrogen, to ensure income diversification, and to facilitate optimal land-use.

Groundnut cultivation however, a widely grown crop in South-Kivu, constitutes an alternative to improve soil fertility, crop yield, secure cropping system and farm sustainability for most crops (Pypers et al., 2011) and should, therefore, be tested in onion farming system. Besides, proper farmland management should integrate diverse crop fertilization strategies by combining of a set of soil fertility management practices. This integrated fertilization plan exploits advantages offered by different options to ensure plant nutrition while improving and preserving the productive soil capacity and other natural resources. In this context, the fertilisation plan based on local and organic products should be promoted for sustainability and resilience of the cropping system in terms of fertilisation. Onion and groundnut intercropping systems exhibit advantages in N disponibilisation, diversification source of revenue, agroecological package for sustainable and resilient agriculture. However, their effects on yield potential and land use efficiency has not been addressed by research in recent years. This study is introduced in order to clarify onion and groundnut intercropping system and organic soil fertility management to increase onion yield and his land use efficiency in eastern DRC.

Materials and Methods

Site description

Field experiments were carried out during the long rainy season (September –January) of 2019 and 2020 at the Université Evangélique en Afrique research farm (02°18′56″ S latitude, 28°47′45, 9″ E longitude and at 1717 m above sea level). This research field is located at Kashusha, in Kabare "territoire", South Kivu Province, Eastern DRC.

The climate is tropical humid tempered by the altitude and the surrounding (Mondo et al., 2019). The soil is of the humic ferralsols, rich in iron and aluminum oxides, characterize by a low *CEC* of the remaining clays. The region is characterized by a bimodal rainfall regime and thus two major growing seasons: the long rainy season from September to February and the short season from February to June. The main climatic factors influencing agriculture are temperatures and rainfall. The region experiences annual average air temperatures of ~19^{o}C, with monthly averages ranging between 17.5 and 19^{o}C. However, the annual rainfall is ~1400-1500 mm, although currently there are climatic disturbances, resulting in irregular and erratic rainfall.

Experimental design and field management

The experiment was carried out under a complete factorial design with four factors including the cropping system (pure and mixture/intercropping), associated crops' varieties with 2 varieties per crop (for onion and groundnut), the fertilization (farmyard manure single application, farmyard manure seasonally application, farmyard manure + composite NPK 1 – 1 – 2 and the control) and the growing season (2019 and 2020). The organic manure used was a mixture of locally collected chicken manure and cow dung.

Varieties per crop species comprised an improved variety and a local landrace or formerly established variety in the farmer's cropping system. For the groundnut, the farmer's variety was A65 commonly referred to as "Red Beauty" (red color) and JL24 as the improved variety (white color) which is well appreciated for its seed size. Red Bombay and Red Creole were the two onion varieties used as planting material in this study. Both varieties are improved, but Red Bombay is the formerly established in the local onion farming systems. The field was established at the beginning of the rainy season, corresponding to the the 9th day of September, in both 2019 and 2020 growing seasons.

The experimental plot/unit had 9 m^2 (5 m × 1.8 m) and crop seeds were planted simultaneously in rows for both onion and groundnut.

At planting, intercropped plots comprised 4 rows of groundnut at spacing 40 cm × 20 cm and five planting rows for onion, spaced by 20 cm × 10.7 cm. In pure cultivation, the groundnut had four lines at 40 × 20 cm; 25 pots of one seed per row. The onion, on the other hand, had nine rows at spacing of 20 × 20 cm, each row bearing 25 plants. The number of onion plants in mixture was 235 compared to pure, 225, while for groundnut the number was 100 for both systems.

The density ratio is obtained by dividing the number of plants in mixture system by the number of plants in pure system. The density ratio is one groundnut to 1.04 onion. The density ratio is obtained by dividing the number of plants in mixture system by the number of plants in pure system.

About fertilization, in pure groundnut cultivation, the organic manure application as seasonal input was 20 t.ha^{-1}, FYM + composite NPK was 10 t ha^{-1} FYM, 50 kg ha^{-1} N, 75 kg ha^{-1} P and 50 kg ha^{-1} K while the single FYM input was 60 t ha^{-1}. For the pure onion cultivation, the seasonal FYM input was 25 t ha^{-1}, FYM + NPK composite input was 12.5 kg ha^{-1} FYM, 50 kg ha^{-1} N, 50 kg ha^{-1} P and 100 kg ha^{-1} K while the single FYM application was 75 t ha^{-1}. For intercropping, the seasonal FYM was 37 t ha^{-1}, for the FYM + NPK intercropping, the quantities applied were 12.5 t ha^{-1}, 100 kg ha^{-1}N, 75 kg ha^{-1} P and 125 kg ha^{-1} K respectively, while 110 t ha^{-1} of FYM was applied for the single application treatment. The farmyard manure used and the study site soil properties are presented in Table 1. The soil at the experimental site was acidic, low in organic manure, deficient in soil nitrogen, but with an acceptable cation exchange capacity (CEC) and a predominance of the clay.

Crop harvesting and intercropping system performance assessment

For onion, harvest was done on the 90th day after transplantation when more than 75% of the non-flowering plants were lying down. For groundnut, however, the harvest was carried out 120 days after sowing when 75% of the plants showed characteristic drying out. Onion bulbs and groundnut pods from the different treatments were weighed after harvest

Table 1. Soil physicochemical properties of the experimental site and farmyard manure (FYM) used for soil fertility improvement

Parameters	Soil	FYM	Methods of analysis and references
pH	4.42	6.40	Digital pH-meter
Organic Carbone, g kg^{-1}	8.7	23	Modified Walkley and Black protocol (Nelson and Sommers, 1996)
Nitrogen, g kg^{-1}	2.6	8.50	Modified Kjeldahl (Okalebo, 2012)
Phosphorous, mg P kg^{-1}	16.69	24.00	Spectrophotometer UV-Visible
CEC, cmol$_c$ kg^{-1}	6.1	–	
Potassium, cmol$_c$ kg^{-1}	0.39	0.48	Flame photometry
Clay, %	65	–	
Sand, %	16	–	
Silt, %	18	–	

Note: CEC: cation exchange capacity; FYM: farmyard manure

The biological efficiency of the onion – groundnut intercropping system was accessed using different indices:

(i) Land Equivalent Ratio (LER)

Land equivalent ratio (LER) is a measure of the land-use efficiency in an intercropping system. It assesses the efficiency of an intercropping in using environment resources compared with pure cropping (Adeniyan et al., 2014).

LER was calculated as follows:

$$LER = (LER_{Onion} + LER_{Groundnut}) \quad (1)$$

$$LER_{onion} = \frac{Y_{Ol}}{Y_O} \quad (2)$$

$$LER_{Groundnut} = \frac{Y_{pl}}{Y_p} \; , \quad (3)$$

where Y_O the yield of onion as sole crops, Yp is the yield of groundnut as sole crops, Y_{ol} is the yield of onion as intercrop and Ypl is the yield of onion as intercrop.

When LER > 1, the intercropping favors the growth and yield of the associated crop species. In opposite, when LER < 1, there is no intercropping gain and the interspecific competition is stronger than the interspecific interaction within an intercropping system.

(ii) Area Time Equivalent Ratio

The Area Time Equivalent Ratio (ATER) provides more realistic judgment of the yield advantage intercropping over pure cropping in terms of time taken by component crops in the intercropping systems (Bedoussac & Justes, 2011). ATER was evaluated using the following formula:

$$ATER = \frac{(LER_{Onion} * t_O) + (LER_{Groundnut} * t_G)}{T} \; , \quad (4)$$

where t_o is the onion growth cycle duration; t_G is the groundnut growth cycle duration and T is the duration in days of the species with the longest growing cycle.

ATER > 1 implies yield advantage from intercropping; ATER = 1 suggest no effect of intercropping; ATER < 1 indicates yield disadvantage as a consequence of crop intercropping.

(iii) Land-use Efficiency (LUE).

We evaluated the LUE as suggested by (Yaseen et al., 2014):

$$LUE = LER + \frac{ATER}{2} * 100 \quad (5)$$

The further the value obtained is from 100%, the system uses environmental resources efficiently in the elaboration of his yield.

(iv) Competitiveness ratio (CR)

The CR was used as an indicator to evaluate the competitive aptitude of associated crops (Uddin et al., 2014). It was calculated by the following formula:

$$CR_o = \left(\frac{LER_o}{LER_p *}\right) * \frac{Z_p}{Z_o *} \quad (6)$$

$$CR_p = \left(\frac{LER_p}{LER_o *}\right) * \frac{Z_o}{Z_p *} \quad (7)$$

Z_o represents the planting ratio of onion to groundnut in the intercropping whereas Z_p denotes that of groundnut to onion. If CR onion > 1, onion is more competitive than groundnut, and if CR onion < 1, then onion is less competitive than groundnut.

(v) Aggressivity

Aggressivity (A) was adopted as a competitive index to measure the extent at which the relative yield of one crop in the intercropping was higher than that of the other, as expressed in the following formula (Dong et al., 2018):

$$A_o = \left(\frac{Y_{ol}}{Y_{oo} * Z_{ol}}\right) - \left(\frac{Y_{pl}}{Y_{pp} * Z_{pl}}\right) \quad (8)$$

$$A_p = \left(\frac{Y_{pl}}{Y_{pp} * Z_{ol}}\right) - \left(\frac{\mathbf{Y_{ol}}}{\mathbf{Y_{oo} * Z_{ol}}}\right) \quad (9)$$

A_o and A_p are the onion and groundnut aggressivities; Y_{ol} and Y_{pl} represent the onion and groundnut yields in intercrop, respectively. If A_o or $A_p = 0$, then both crops in the intercropping system are equally competitive. A positive Ao denotes dominance of onion over groundnut, whereas when it is negative, it indicates that groundnut is the dominating species.

Statistical analysis

The onion variety with different combinations (mixture with groundnut varieties) was coupled to the system and constitute the factor cropping system to which the fertilizers were associated as another factor. Anova two – ways chosen in the R software (R, Development core, 2918) were used for statistical analysis. Whenever the analysis of variance p-values were significant, the Tukey HSD test was used to separate the computed means at 5% probability thresholds

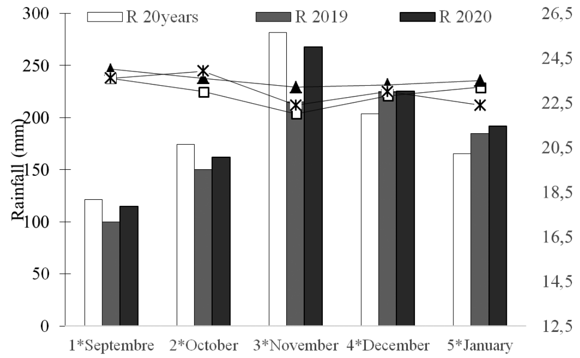
Results

Climate data collected at the meteorological station of Kavumu National Airport shows that the long rainy season of 2019 recorded a cumulative rainfall of 875 mm, an excess of 28 mm compared the last 20 years record (1998-2018) (847 mm) (Figure 1). In 2020, the rainfall amount was 962 mm, an excess of 87 mm compared with the 2019 rainfall. The highest rainfall intensities were observed in December (225 mm) and November (268 mm) for 2019 and 2020, respectively.

Throughout the study period, the average air temperature, gradually increasing to the maximum value (24°C) in September and then gradually decreasing to 22.4°C in November.

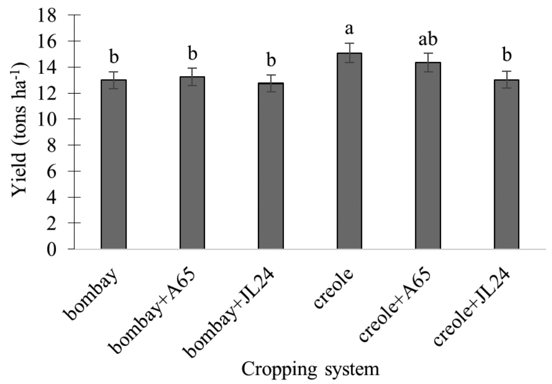
The analysis of variance (ANOVA) to assess effects of the cropping system, fertilizer and their interaction on onion bulb yields across two growing seasons indicated that the cropping system (p<0.01) and fertilizer (p<0.001) significantly affected the onion bulb yield. However, the interaction effect of these two factors was not significant (p>0.05).

For the cropping system, the variety Red Creole in sole culture had the highest bulb yield (15 tons ha^{-1}). This variety provided also the highest yield in intercropping system with the groundnut variety A65 (14.36 tons ha^{-1}). All other combinations were not significantly different (Figure 2).



R 20years: 20-year average rainfall; T20 years: 20-year average air temperature; R: rainfall; T: Air temperature

Fig. 1. Monthly total rainfalls and average air temperatures for the study period regarding the 20-year average data (1998-2018) trend



Bars with distinct letters indicate significant differences according to Tukey's test (P ≤ 0.05).

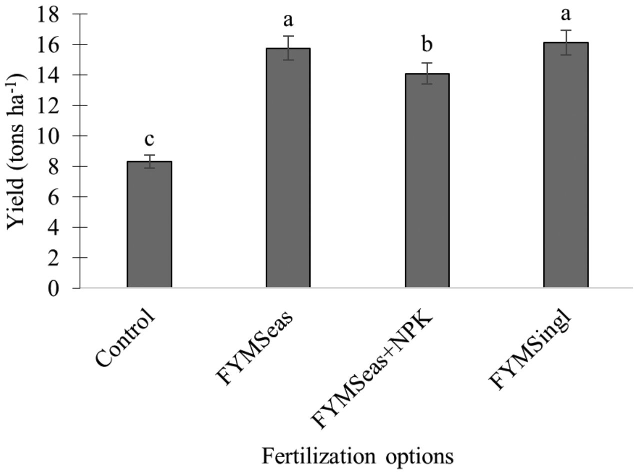
Fig 2. Effects on bulb yields of onion intercropped with groundnut in eastern DRC (average for two years)

Table 2. Effect of system, fertilizer and their interaction on Land Equivalent Ratio (LER) and Area Time Equivalent Ratio (ATER)

	2019				2020			
	LER			ATER	LER			ATER
Cropping System (A)	Onion	Peanut	Total		Onion	Peanut	Total	
Bombay+A65	1.11a	1.14a	2.25a	2.01a	0.89a	1.14a	2.03b	1.83b
Bombay+JL24	1.04b	1.11a	2.15b	1.93ab	0.93a	0.97a	1.90b	1.69b
Creole+A65	0.92b	1.06a	1.98b	1.78b	1.06a	1.31a	2.38a	2.14a
Creole+JL24	0.82b	1.11a	1.93b	1.75b	1.01a	1.01a	2.02b	1.80b
P-value (A)	p<0.05	ns	p<0.05	p<0.05	ns	ns	p<0.05	p<0.05
Fertilizers (B)								
Control	0.89b	1.14b	2.03b	1.83ab	1.75b	0.95b	1.81b	2.32a
FMYSeas	0.93ab	0.97b	1.90b	1.69b	0.88ab	0.92b	1.80b	1.61b
FMYSeas+NPK	1.06a	1.31a	2.38a	2.14a	1.01a	0.99a	1.99a	1.77b
FMYSingl	1.01a	1.01b	2.02b	1.80ab	1.01a	0.96b	1.97a	1.75b
P-value (B)	p<0.05	p<0.05	p<0.05	ns	p<0.05	p<0.05	p<0.05	p<0.05
P-value (A*B)	ns	ns	ns	ns	ns	ns	ns	ns

Mean values in the colons followed by the same superscript were not significantly different (P ≥ .05). FYMSeas : Farmyard manure seasonal application, FYMSeas+NPK: Farmyard manure seasonal application + NPK, FYMSingl: Farmyard manure single application

As mentioned above, onion bulb yields also varied with the applied fertilizer (Figure 3). The best onion bulb yield was obtained when applying the FYM as a seasonal and single application (16 tons ha^{-1}). The second best performance was recorded by combining FYM and composite NPK (14 tons ha^{-1}). Onion bulb yields were reduced by 50 and 43.8% respectively when these fertilization options were not applied (Figure 3).



Bars with distinct letters indicate significant differences according to Tukey's test (P ≤ 0.05).
FYMSeas: Farmyard manure seasonal application, FYMSeas+NPK: Farmyard manure seasonal application + NPK, FYMSingl: Farmyard manure single application

Fig. 3. Effect of the fertilization options on bulb yields of onion intercropped with groundnut in eastern DRC

From Table 2, the partial LER of onion increased significantly in 2019 (p<0.05) while there was no significant difference among all crop associations in 2020. The onion variety Bombay yield was higher in combination with the groundnut variety A65 (LER: 1.11) than all other combinations of onion with groundnut (Table 2). The partial LER obtained on groundnut showed the same yield gain trend for all cropping systems (p>0.05) in both years except for the Bombay+JL24 package (0.97) in 2020. Total LER recorded the highest value in 2019 for the Bombay + A65 package (2.25) and 2.38 for Creole + A65. Compared to the space-time exploitation, there was an outperformance of the Bombay + A65 pair (ATER: 2.01) in 2019, with as intermediary Bombay+JL24 (1.93) followed by two other crops pairs that were not statistically different. However, in 2020, space was better valorized in time by the Creole onion variety combined with the groundnut variety A65.

In terms of fertilization, it was observed that this factor affected the partial LER of the onion in 2019 and 2020 (p<0.05). The best values of these partial LERs (1.01 to 1.06) were obtained when applying the FYM in seasonal and single application option. The partial LER of groundnut also increased significantly (p<0.05) with applied fertilizers. For instance, applying FYM + NPK effectively improved groundnut production in intercropping system. A similar trend was recorded in 2019 for the total LER (2.38). In 2020, furthermore (Table 2), the highest total LER value (1.99 and 1.97) was obtained when combining NPK and FYM. The ATER (p<0.05) followed almost the same trend as the total LER in 2019 contrary to 2020 when no fertilization option was applied, increased this index (2.32).

Table 3. Overall competitive indices' variation with cropping system and fertilizers

	2019				2020			
	Competitive ratio(CR)		Agressivity		Competitive ratio(CR)		Agressivity	
System (A)	Onion	Peanut	Onion	Peanut	Onion	Peanut	Onion	Peanut
Bombay+A65	1.06a	1.02b	0.00	0.00	1.93	0.89	0.04	0.04
Bombay+JL24	0.97ab	1.08b	-0.05	0.05	1.03	1.02	-0.01	0.01
Creole+A65	0.91ab	1.13b	-0.16	0.16	1.01	1.03	-0.01	0.01
Creole+JL24	0.79b	1.34a	-0.28	0.28	1.21	0.93	0.10	-0.19
P-value (A)	p<0.05	p<0.05	Ns	ns	ns	ns	ns	ns
Fertilizers (B)								
Control	0.81b	1.31	-0.18	0.18	1.93a	0.95	0.02	-0.02
FMYSeas	0.99a	1.04	-0.08	0.08	1.02b	1.02	-0.03	0.01
FMYSeas+NPK	0.86ab	1.23	-0.12	0.12	1.09b	0.98	0.05	-0.05
FMYSingl	1.07a	0.99	-0.10	0.10	1.13b	0.92	0.08	-0.08
P-value (B)	p<0.05	ns	ns	ns	p<0.05	ns	ns	ns
P- value (A*B)	ns	ns	ns	ns	ns	ns	ns	ns

Mean values in the colons followed by the same superscript were not significantly different (P ≥ .05). FYMSeas: Farmyard manure seasonal application, FYMSeas+NPK: Farmyard manure seasonal application + NPK, FYMSingl: Farmyard manure single application

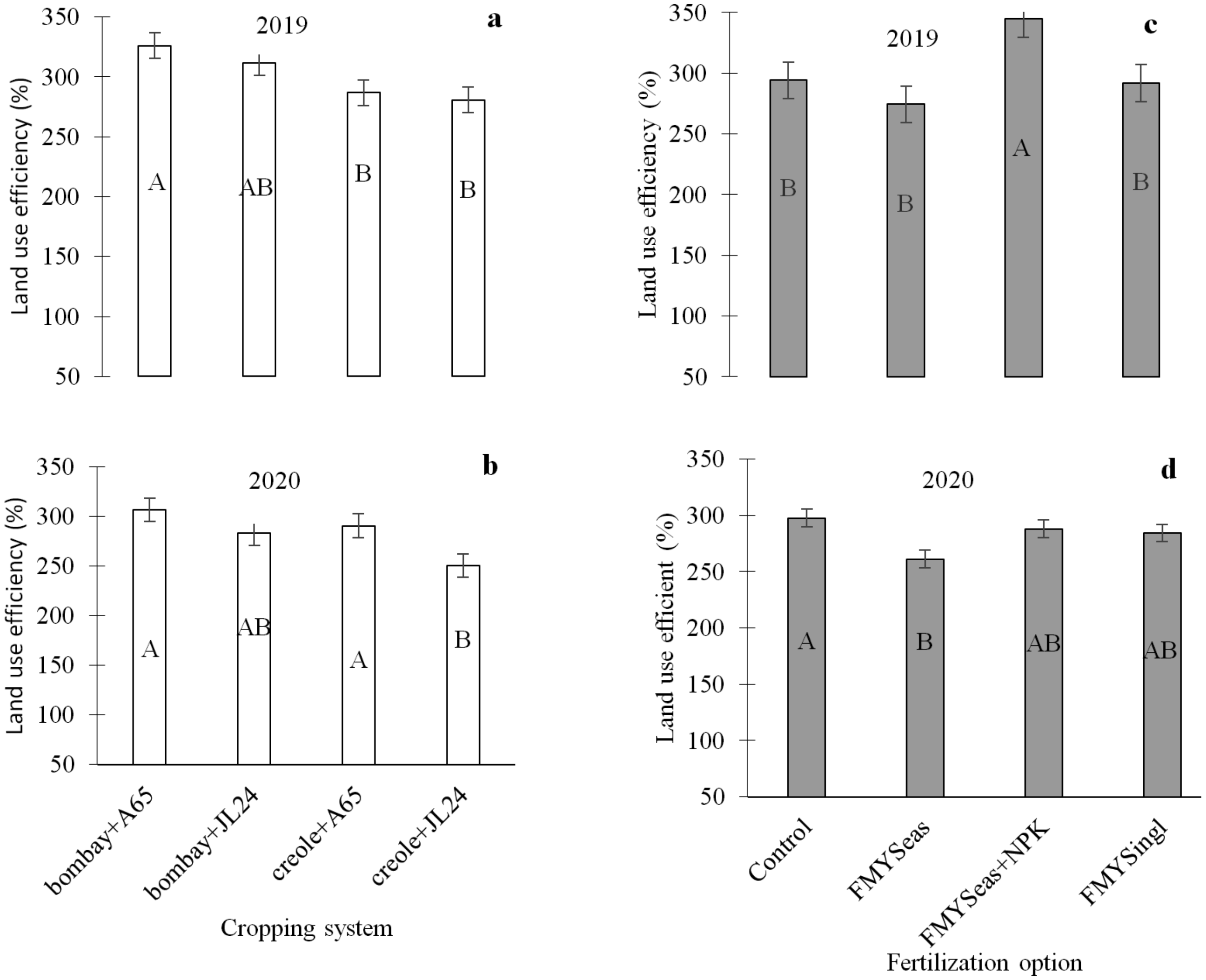


Fig. 4. Land-use efficiency: (a-b) as affected by cropping systems and (c-d) by fertilizers. FYMSeas: Farmyard manure seasonal application, FYMSeas+NPK: Farmyard manure seasonal application + NPK, FYMSingl: Farmyard manure single application

Fertilizers, cropping systems and their interaction had significant effects on the land-use efficiency of onion intercropped with peanut ($p< 0.05$) for both years (Figure 4).

Figure 4, c and d reveals that the land-use efficiency varied from 326 to 280% in the following order: Bombay + A65>Bombay+JL24>Creole+A65>Creole+JL24 in 2019. In 2020, the trend changed as follows: peanut variety A65 had similarly improved the land-use efficiency of the two onion varieties; followed by Bombay + JL24 and finally Creole+JL24.

Depending on the fertilizers, the differences in land-use efficiency for 2019 and 2020 ranged from 345 to 261%. In 2019, the highest LUE value was recorded on plots fertilized with farmyard manure combined with NPK while the lowest value was on farmyard manure in seasonal application (274%). In opposite, the non-application of fertilizers induced high land-use efficiency (298%). Overall, a higher land-use efficiency was observed in 2019 than in 2020 (Figure 4, c-d).

From Table 3 the cropping system had significantly affected ($p < 0.05$) both competitiveness indices of onion and peanut in 2019 where the onion variety Bombay was most competitive than the peanut variety A65 (1.06). The onion variety Creole was less competitive than the peanut variety JL24. The onion variety Bombay was less competitive when intercropped with the peanut variety JL24, as it was also the case when the onion variety Creole was intercropped with the peanut variety A65.

Differences among fertilizers were only significant on onion competitive ratio ($p < 0.05$). Farmyard manure in single and seasonal application highly affected onion competitiveness than others treatments. In 2020, onion was competitive than peanut when no fertilizer was applied. The analysis of aggressivity showed that peanut was globally the dominant crop but its dominance did not significantly affect the onion development. In some cases, both crops were equally competitive (Bombay+A65) when intercropped.

Discussion

Results on yield potential showed the superiority of the onion variety Creole under sole culture compared to Bombay and all onions grown under intercropping systems. This could be attributed to minimal competition in pure crop. It is important to point out that even the potential yield of the pure crop may be higher than that of the mixture crop, it is still considered vulnerable yield (Getahum et al., 2018). The pressure of some biotic or abiotic agents, the lack of biodiversity and the sensitivity to market trends are the source of this vulnerability (Raza et al., 2019). In his side, Bitew et al. (2019) indicated that when considering the agronomic yield of the sole crop in most cases, there is satisfaction, but when economic yields is analysed, the sole crop is seldom economically profitable. These authors reported that the cost of production of the sole crop is higher than in intercropping because labor use and other production costs are lower. However, the income from the accumulated products from a diversity of crops significantly improves the profitability of mixed cropping systems. These results are confirmed by many other studies, such as Filho et al. (2012) on tomato – lettuce; (Haan & Vasseur, 2014) on onion – lettuce; (Wang et al., 2014) on eggplant – garlic and (Ananda et al., 2017) on bean – cabbage.

We also found that the highest onion bulb yield was obtained with the seasonal application of farmyard manure and farmyard manure single application (16 t ha^{-1}). These results are similar to those obtained by Mofunanya et al. (2015) and Teshome et al. (2018). Soil fertility was, therefore, an important factor for achieving high vegetable productivity. However, in both agriculture and vegetable production, the sustainable agriculture approach supports fertilization based mainly on organic manures. The principle behind this kind of fertilization is based on feeding the soil to feed the plant and not feeding the plant directly through soluble fertilizers (Marzouka & Kassem, 2011). In addition to its positive effects in improving soil health, organic manures also improve the nutritional properties of crops after mineralization of the residue and contribute to securing producers' income (Brito et al., 2012). Moreover, in a production context where there are various risks and where efficiency and sustainability are more required, the way in which fertilizers are applied is also a factor of both technical and socio-economic efficiency. Results obtained in this study shows that Farmyard manure in single application highly contribute to onion bulb yield. It should be noted that it is possible to invest in organic fertilization directly with a significant input that can support long-term production to one season to another (Miassi & Dossa, 2018).

The results of this study on biological indices confirmed by those of land-use efficiency indicates that it is possible to combine the two crops without compromising individual yields. Indeed, in the intercropping system, it is recommended to combine species with different aerial and underground morphologies to limit competition for environmental resources (Alemayehu et al., 2016) especially nutrients, water and light.

Onion and groundnut are both crops that develop their useful products in the soil, but differ in root structure and function, allowing however to limit possible underground competition. Indeed, onion have a sparse, concentric, unbranched root architecture, but high mycorrhiza capacity (Mollavali et al., 2016). In these mycorrhizal associations, there is a direct exchange of water and nutrients between the two partners. The mycelium, which is very fine, explores a very large volume of soil, developing a much larger exchange surface and entering much smaller pores than roots and even absorbent bristles, which are larger (Fukasawa et al., 2020). The fungus also releases various molecules into the soil: enzymes, organic acids, glycoproteins, which increase the availability of nutrients and contribute to soil, structure (Verbruggen et al., 2013).

In contrast, the root system of groundnut, 20 – 30 cm in depth is leathery and more densely packed with numerous absorbing bristles (Mateva et al., 2020). Unlike onion, groundnut root architecture is excentric, which allows it to explore a wide range of soils (Lu et al., 2013). It is noteworthy that although onion and groundnut compete for the use of the soil mineral N pool, only the legume has the ability to access the atmospheric N pool and benefit the associated crop via symbiotic fixation (Didagbé et al., 2014). In addition, the residual effects of this biological N fixation can effectively benefit to the onion. Aerially, both crops were sown at the same date, but the onion was transplanted after

2 months, which already gave it a growth advantage over the groundnut. This advantage would not be compromised for the groundnut due to the leaf morphology of the onion. Indeed, the onion's leaves, which are very few in number, are vertical and intertwined, limiting to a maximum the possibilities of imposing a large soil cover and thus reducing competition for light with the groundnut.

These associated species use different biogeochemical pools of the same resource. Niche partitioning on a biogeochemical level typically applies to mixture systems between a legume and a non-nitrogen-fixing species (Mueller et al., 2012).

The spatial partitioning of a soil resource occurs particularly when associated species have highly differentiated rooting structure. This applies in particular to water and other soil nutrients for which the rooting structure and additional function determines nutrients extraction (Bedoussac et al., 2014). The complementarity of these two species for the use of light is also explained by complementary aerial architectures that allow the mixture system to enhance the value of the light resource in space both vertically in the canopy and in horizontally (Rusinamhodzi et al., 2012)..

To these elements are added the differences in height between the canopies, i.e. most often in these experimental conditions with different species and varieties, morphological variability emerges. Therefore, the optimization of light energy by capturing photosynthetically active radiation can be improved by using species with complementary aerial architectures (Vanlauwe et al., 2019). For example, it was found that the Bombay onion variety matched to the A65 groundnut variety. It should be noted here that Bombay has an erect aerial morphology whereas A65 is not very elongated. This had significantly limited competition and pressure on the environment's resources.

Although reflecting a negative effect of one species on the other, interspecific competition phenomena can induce a gain in yield when the associated species complement each other and use resources more efficiently than the corresponding monospecific crops. This occurs especially when the components do not compete strongly for the same resources (in time, space or chemical form), resulting in less interspecific competition than intraspecific competition.

During our experiments, it was also noted that onion density was reduced in sole culture due to cutworm attacks, while in intercropping; this pest had a low incidence (Cokola et al., 2021). Thus, overall, the increased efficiency of land use for onion intercropping would initially be explained by the spatial arrangement that allowed high density in a combined system, a density that did not negatively affect onion plant growth. Effective weed control, efficient soil moisture management, reduced cutworm attacks, and low competitiveness due to compatibility between the two species can explained largely the land-use efficiency.

Conclusions

The present study assessed the potential yield and land-use efficiency of onion intercropped with groundnut under organic soil fertility management options in prospects of a sustained agroecological transition in vegetable production in eastern DRC. The results showed that across the two experimental years, the sole culture of the onion variety Creole had highest bulb yields than all other tested cropping systems. We also found that single and seasonal organic fertilization option effectively improved the onion crop yield. There was an over performance of onion intercropped crops when A65, groundnut variety was integrated in both onion varieties. The competitive indices estimated (LER, competitive ratio and aggressivity) indicated that onion and groundnut are agro ecologically compatible. This compatibility was observed by the results on land-use efficiency. These results indicated that onion in combination with groundnut uses environmental resources efficiently in the elaboration of his yield. This constitutes a major alternative to promotes for improving and securing onion production and for establishing solid bases for sustainable vegetable production in eastern DRC. In prospects of sustainable agroecological transition, the results of this study provide a reference to applying this approach in studying others legumes intercropping systems with the important vegetables of the region.

Acknowledgements

Support for this research was made possible by a competitive capacity-building grant for training the next generation of scientists. This grant was provided by the Carnegie Cooperation of New York through the Regional University Forum for Capacity Building in Agriculture (RUFORUM).

References

Adeniyan, O., Aluko, O., Olanipekun, S., Olasoji, J. & **Aduramigba-Modupe V.** (2014). Growth and yield performance of cassava/maize intercrop under different plant population density of maize. *Journal of Agricultural Science*, *6(8),*

Akwasi, A. (2014). Teaching permaculture to ensure food security in rural South Africa: The Case Study of Tiger Kloof. *Journal of Human Ecology*, *47(3),* 251-255.

Alemayehu, A., Tamado, T., Nigusie, D., Yigzaw, D., Kinde, T. & **Wortmann C.** (2016). Maize-common bean-lupine intercrops productivity and profitability in maize-based cropping system of Northwestern Ethiopia. *Ethiopian Journal of Science and*

Technology, *9(2),* 69–85.

Ananda, A., Devi, A., Singh, A., Barik, S. & **Bairwa M.** (2017). Cabbage (*Brassica oleracea* L. var. *capitata*) cv. Rareball introduction with Knol Khol and Broad Bean intercropping: yield efficiency under foothills of Imphal-West. *The Pharma Innovation Journal*, *6(10),* 339-341.

Bedoussac, L. & **Justes, E.** (2011). A comparison of commonly used indices for evaluating species interactions and intercrop efficiency: Application to durum wheat–winter pea intercrops. *Field Crops Research*, *124(1),* 25–36.

Bitew, Y., Getachew, A., Enyew, A. & **Alemayehu, A.** (2019). Boosting land-use efficiency, profitability and productivity of finger millet by intercropping with grain legumes. *Cogent Food & Agriculture*, *5(1)*, 16-22.

Cokola, C., Ndjadi, S., Bisimwa, B., Ahoton, E. & **Francis, F.** (2021). First report of *Spodoptera frugiperda* (*Lepidoptera: Noctuidae*) on Onion (*Allium cepa* L.) in South Kivu, Eastern DR Congo. *Revista Brasileira de Entomologia*, *65(1),* e20200083.

De Haan, J. & **Vasseur, L.** (2014). Above and below ground interactions in monoculture and intercropping of onion and lettuce in greenhouse conditions. *American Journal of Plant Sciences*, *(5),* 3319-3327.0

Didagbé, O., Houngnandan, P., Sina, H., Zoundji, C., Kouelo, F. & **Moussa, L.** (2014). Response of groundnut (*Arachis hypogaea* L.) to exogenous *Bradyrhizobium sp* strains inoculation and phosphorus supply in two agroecological zones of Benin, West Africa. *Journal of Experimental Biology and Agricultural Sciences*, *2(6),* 623–633.

Dong, N., Tang, M., Zhang, W., Bao, X., Wang, Y. & **Li, L.** (2018). Temporal differentiation of crop growth as one of the drivers of intercropping yield advantage. *Scientific Report, 8,* (3110).

Filho, A., Braulio, L., Rezende, B., Barbosa, J. & **Grengeiro, L.** **(**2011). Agronomic efficiency of intercropping tomato and lettuce. *Annals of the Brazilian Academy of Sciences*, *83(3),* 1109-1119.

Fukasawa, Y., Savoury, M. & **Boddy, L.** (2020.) Ecological memory and relocation decisions in fungal mycelial networks: responses to quantity and location of new resources. *ISME Journal, 14,* 380–388.

Getahun, D., Getaneh, M. & **Habte, B.** (2018). Companion crops for intercropping with onion production in the dry season at fogera district of South Gondar Zone in Ethiopia. *International Journal of Research Studies in Agricultural Sciences*, *4(4),* 17-24.

Li, X., Zhou, Q., Sun, X. & **Ren, W.** (2016). Effects of cadmium on uptake and translocation of nutrient elements in different welsh onion (*Allium fistulosum* L.) cultivars. *Food Chemistry*, *194(101),* 110.

Lu, Z., Zhang, Z., Su, Y., Liu, C. & **Shi, G.** (2013). Cultivar variation in morphological response of groundnut roots to cadmium stress and its relation to cadmium accumulation. *Ecotoxicology and Environmental Safety*, *91,* 147–155.

Marzouka, H. & **Kassem, H.** (2011). Improving fruit quality, nutritional value, and yield of Zaghloul dates by the application of organic and/or mineral fertilizers. *Scientia Horticulturae*, *127(3),* 249-254.

Mateva, K., Hui, C., Mayes, S. & **Massawe, F.** (2020). Root foraging capacity in Bambara Groundnut (*Vigna Subterranea* (L.) Verdc.) Core parental lines depends on the root system architecture during the pre-flowering stage. *Plants*, *9*, 645.

Miassi, Y. & **Dossa, F.** (2018). Influence of the types of fertilizers on the economic performance of the market garden production in Parakou Town, Northern Benin. *Agriculture Research and Technology*, *15(2),* 555-944.

Mitra, J., Shrivastava, S. & **Rao, P.** (2011). Onion dehydration: a review. *Journal of Food Science and Technology*, *49(3),* 267–277.

Mofunanya, A., Ebigwai, J., Bello, O. & **Egbe, O.** (2015). Comparative study of the effects of organic and inorganic fertilizer on nutritional composition of (*Amaranthus spinosus* L.). *Asian Journal of Plant Sciences*, *14 (1),* 34-39.

Mollavali, M., Bolandnazar, S., Schwarz, D., Rohn, S., Riehle, P. & **Zaare, F.** (2016). Flavonol glucoside and antioxidant enzyme biosynthesis affected by mycorrhizal fungi in various cultivars of onion (*Allium cepa* L.). *Journal of Agricultural and Food Chemistry*, *64(1),* 71–77.

Mondo, J., Irenge, B., Ayagirwe, B., Dontsop-Nguezet, P., Katcho, & **Mushagalusa, G.** (2019). Determinants of adoption and farmers' preferences for Cassava Varieties in Kabare Territory, Eastern Democratic Republic of Congo. *American Journal of Rural Development*, *7 (2),* 44-52.

Mueller, K., Eissenstat, D., Hobbie, E., Oleksyn, J., Jagodzinski, A., Reich, P. & **Chorover, J.** (2012). Tree species effects on coupled cycles of carbon, nitrogen, and acidity in mineral soils at a common garden experiment. *Biogeochemistry, 111(1-3),* 601–614.

Mushagalusa, B., Birindwa, P., Muyambo, M., Kasanda, M. & **Nkulu, M.** (2015). Production des cultures maraichères à Lubumbashi: analyse comparative de la rentabilité de chou pommé et chou de chine. *International Journal of Innovation and Scientific Research* , *14(1),* 55-61.

Ndjadi, S., Ahoton, L., Kizungu, R., Saidou, A., Mugumaarhahama & **Mushagalusa, G.** (2021). Évaluation de la durabilité des exploitations maraîchères au Sud-Kivu, Est de la République démocratique du Congo. *Cahiers Agricultures*, *30(15*), 5-8, (FR).

Ndjadi, S., Vumilia, K., Ahoton, L., Aliou, S., Bello, D. & **Mushagalusa, N.** (2020). Typology and Prospects for the Improvement of Market Gardening Systems in South-Kivu, Eastern DR Congo. *Journal of Agricultural Science*, *12 (6),* 136-152.

Pfeiffer, A., Silva, E. & **Colquhoun, J.** (2015). Innovation in urban agricultural practices: Responding to diverse production environments. *Renewable Agriculture and Food Systems*, *1(30),*79–91.

PNUD/RDC (2012). Profil résume de la pauvreté et conditions de vie des ménages. Programme des Nations – Unies pour le Développement, Kinshasa, République Démocratique du Congo. Available at: https://www.cd.undp.org/content/rdc/fr/home/library/poverty/pauvrete-et-condition-de-vie-des menages11111111.html *(a*ccessed January 2021) (FR).

Pypers, P., Sanginga, J., Kasereka, B., Walangululu, M. &

Vanlauwe, B. (2011). Increased productivity through integrated soil fertility management in cassava-legume intercropping systems in the highlands of Sud-Kivu, DR Congo. *Field Crops Research*, 120, 76-85.

R Development Core Team (2018). R statistical software. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

Raza, M., Feng, L., Van der Werf, W., Cai, G., Khalid, M. & **Yang, W.** (2019). Narrow-wide-row planting pattern increases the radiation use efficiency and seed yield of intercrop species in relay-intercropping system. *Food and Energy Security, 8(3),* e170.

Rusinamhodzi, L., Corbeels, M., Nyamangara, J. & **Giller, K.** (2012). Maize–grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in central Mozambique. *Field Crop Research*, *136,* 12–22.

Teshome, S., Tana, T. & **Mohammed, W.** (2018). The response of Head Cabbage (*Brassica oleracea* L.) to Different Rates of Inorganic Nitrogen Fertilizer and Farmyard Manure at Bore, Southern Oromia, Ethiopia. *International Journal of Current Research and Academic Review*, *6(12),* 25-29.

Uddin, B., Naznin, S., Kawochar, M., Choudhury, R. & **Awal, M.** (2014). Productivity of wheat and groundnut in intercropping system. *Journal Exploratory Biosciences*, *5(2),* 19-26.

Vanlauwe, B., Hungria, M., Kanampiu, F. & **Giller, K.** (2019). The role of legumes in the sustainable intensification of African smallholder agriculture: Lessons learnt and challenges for the future. Agriculture, *Ecosystems and Environment*, *284,* 106583.

Verbruggen, E., van der Heijden, M., Rillig, M. & **Kiers, E.** (2012). Mycorrhizal fungal establishment in agricultural soils: factors determining inoculation success. *New Phytologist, 197(4),* 1104–1109.

Wang, M., Wu, C., Cheng, Z., Meng, H. & **Zhang, M.** (2014). Soil chemical property changes in eggplant/garlic relay intercropping systems under continuous cropping. *PLoS ONE*, *9(10),* e111040..

Yaseen, M., Singh, M. & **Ram, D.** (2014). Growth, yield and economics of vetiver (*Vetiveria zizanioides* L. Nash) under intercropping system. *Industrial Crops Products*, *61,* 417–421.

Received: **April, 15, 2021**; *Accepted*: **May, 22, 2021**; *Published*: **August, 2022**