B A S E *Biotechnol. Agron. Soc. Environ.* 2020 **24**(3), 142-155 OPEN ACCESS

Growth and yield performance of *Vigna radiata* (L.) R.Wilczek influenced by altitude, nitrogen dose, planting pattern and time of sowing under sole and intercropping with maize

Muhammad Arshad [(1)], Sajjad Ahmad [(2)], Ghulam Abbas Shah [(3)], Rab Nawaz [(4)], Shaukat Ali [(5)]

[(1)] Karakoram International University. Department of Agriculture and Food Technology. 15100 Gilgit (Pakistan). E-mail: dr.arshad@kiu.edu.pk, arshad4humanity@yahoo.com
[(2)] COMSATS University Islamabad. Department of Environmental Sciences. Vehari Campus (Pakistan).
[(3)] PMAS-Arid Agriculture University. Department of Agronomy. Murree Road Rawalpindi (Pakistan).
[(4)] The University of Lahore. Department of Environmental Sciences. Lahore (Pakistan).
[(5)] Karakoram International University. Department of Environmental Sciences. 15100 Gilgit (Pakistan).

Received 5 March 2019, accepted 1 April 2020, available online 14 May 2020.

Description of the subject. Mungbean (*Vigna radiata* [L.] R.Wilczek) is an important summer leguminous crop. It is widely grown in South Asia to fulfill the human nutritious demand of protein, minerals, vitamins and bioactive constituents. It is well suited to be intercropped with cereals in N limited soil to enhance crop productivity through biological nitrogen fixation.
Objectives. This paper assesses the impacts of altitude, nitrogen dose, planting pattern and time of sowing on growth and yield parameters of mungbean intercropped with maize in comparison to their sole counterpart.
Method. Three-year experiments (2015, 2016 & 2017) were conducted to assess growth and yield performance of mungbean and maize under different environmental conditions and management practices including altitude (1,500; 1,800 and 2,200 m), nitrogen dose (28, 56, 113 $kg \cdot ha^{-1}$), planting pattern (alternate single row and alternate double row), cropping systems (sole and intercropping), and sowing time of intercropping with maize (simultaneous and staggered). Sole plots of maize and mungbean were also established separately. A Randomized Complete Block Design was used with three replicates. Growth and yield components of mungbean *i.e.*, plant height, leaf area per plant, thousands grain weight, grain yield, biological yield and harvest index were measured. Maize plants were sampled at maturity for computing its grain yield.
Results. Orthogonal contrast analysis showed a significant variation in plant height due to year and altitude, leaf area per plant due to intercropping, year and altitude, thousands grain weight due to intercropping, planting pattern and time of intercropping with maize, grain yield due to intercropping, year, altitude and planting pattern, biological yield due to year, altitude and planting pattern, and harvest index due to year and altitude. Moreover, intercropping and management practices influenced maize grain yield.
Conclusions. Intercropping reduced the growth and yield performance of mungbean compared to monocropping that is attributed to the competition of resources between two crops. However, this interspecific competition has been mollified at lower altitudes when staggered sowing of mungbean intercropped with maize through alternative double row pattern was done. Consequently, in these conditions mungbean growth and yield was improved.
Keywords. Altitude, grain yield, intercropping, nitrogen dose, row pattern.

La croissance et le rendement de *Vigna radiata* (L.) R.Wilczek sont influencés par l'altitude, la dose d'azote, le schéma de plantation et la date de semis en culture pure et associée avec du maïs

Description du sujet. Le haricot mungo (*Vigna radiata* [L.] R.Wilczek) est largement cultivé dans l'Asie du Sud en tant que source de protéines, de minéraux, de vitamines et de constituants bioactifs bénéfiques pour l'alimentation humaine et la santé. Il est bien adapté à la culture intercalaire avec des céréales pour augmenter la fixation de l'azote atmosphérique et la productivité des sols en aliments et en énergie digestible.
Objectifs. Cet article évalue l'impact de l'altitude, la dose d'azote, le schéma de plantation et la durée de la culture intercalaire du haricot mungo avec le maïs.

Méthode. Des expériences de trois ans (2015, 2016, 2017) ont été menées pour évaluer les composantes de la croissance et du rendement du haricot mungo dans différentes conditions environnementales et de gestion, notamment le système de culture (date de semis et culture intercalaire), l'altitude (1 500, 1 800 et 2 200 m) et la dose d'azote (28, 56, 113 kg·ha^{-1}), le schéma de plantation (alterné à chaque rangée et à doubles rangées alternées) et la date de semis de la culture intercalaire avec le maïs (simultané et échelonné) dans un dispositif en blocs complets randomisés. Des parcelles de haricot mungo ont également été établies séparément à titre de comparaison. Les composantes de la croissance et du rendement, c'est-à-dire la hauteur de la plante, la surface foliaire par plante, le poids de mille grains, le rendement en grain, le rendement biologique et l'indice de récolte ont été mesurés.

Résultats. L'analyse des contrastes orthogonaux a montré une variation significative de la hauteur de la plante en fonction de l'année et de l'altitude, de la surface foliaire en fonction de la culture intercalaire, de l'année et de l'altitude, du poids de mille grains en fonction de la culture intercalaire, du mode de plantation et de la période de culture intercalaire avec le maïs, du rendement en grains en fonction de la culture intercalaire, de l'année, de l'altitude et du mode de plantation, le rendement biologique en fonction de l'année, de l'altitude et du schéma de plantation, et l'indice de récolte en fonction de l'année et de l'altitude.

Conclusions. La croissance et le rendement du haricot mungo ont été réduits en culture intercalaire par rapport à la monoculture avec le maïs en raison de la concurrence, mais cette compétition interspécifique a été réduite à basse altitude, une croissance et un rendement améliorés y ayant été observés lorsque la culture intercalaire était conduite avec le maïs, avec alternance de rangées doubles et un semis échelonné.

Mots-clés. Altitude, rendement en grains, culture intercalaire, dose d'azote, configuration en rangées.

1. INTRODUCTION

Human food demand will increase up to 98% due to boost in human population from 7,300 million to 9,700 million by 2050 (Elferink & Schierhorn, 2016). This necessitates to enhance crop productivity by either increasing land area for crop production or improving yield per unit area through better management practices. The crop yield can be enhanced either by horizontal or vertical expansions. Currently, the horizontal expansion is not possible due to human demand for commercial, industrial and shelter land, which means that one should focus on boosting production per unit area. Intercropping could serve this purpose by enhancing land use efficiency. Cereal-legume intercropping like maize-mungbean under limited N supply and variable climatic conditions can be a good choice to improve crop productivity per unit area. In case of main crop (maize) failure due to adverse climatic condition or crop specific pest attack, the intercrop (mungbean) can assist farmer in terms of food and income security (Rusinamhodzi et al., 2011). Being a short stature and life duration crop, mungbean is thought to be intercropped with cereals and fodder crops *i.e.*, maize or sorghum. However in such scenario, a severe competition for nutrients, water and solar radiation between crops is expected.

Mungbean (*Vigna radiata* [L.] R.Wilczek) is a vital summer legume in Pakistan. In Pakistan, it is cultivated on an area of 141,000 ha having mean annual production of about 93,000 tons (Pakistan Economic Survey, 2012). Nearly 90% production of this crop is from Asia and more than 50% production belongs to subcontinent of India (FAO, 2010). However, its yield per hectare in Pakistan is 30% lesser compared to other Asian countries (FAO, 2010). The major causes of this low yield in Pakistan include nutritional imbalance in soil, low soil fertility, sowing of low yielding varieties and its competition with other commercial crops for land, which led to broader gaps between demand and supply (Imran et al., 2015). Among the legumes, mungbean is considered as an excellent source of protein, carbohydrates, thiamin, magnesium and manganese due to its high nutrients value and digestible energy. Its seeds are considered as a substitute of animal protein and form a balanced diet when mixed with cereals (Mansoor, 2007). The above ground plant biomass is usually used as animal fodder. Besides, whole plant can be ploughed and buried as a green manure (Rahman et al., 2010). Mungbean like other legumes improves soil fertility by fixing atmospheric dinitrogen (N_2) through the process of symbiosis with bacteria (Ilyas et al., 2018).

Mungbean was originated and domesticated in 1,500 BC in subcontinent India and thereafter it was introduced to other parts of Asia, Africa, Australia, the Americas and the West Indies. Now it is spread throughout the tropics from sea level to an elevation of 1,850 m in mountainous regions of Himalayas (Lambrides & Godwin, 2006). Mungbean is a fast growing and a drought tolerant crop that requires less amount of water (600-1,000 mm rainfall/year) to complete its growth (Mogotsi, 2006). It is an annual, erect or semi-erect plant with plant height up to 1.25 m and well developed rooting system (Lambrides & Godwin, 2006; Mogotsi, 2006; FAO,

2010) that ensures its feasibility as intercrop with cereals. Seeds of mungbean serve as a major edible food component not only in Asia (Pakistan, India) but are also consumed in southern parts of USA and Europe. Being an invaluable protein source, mungbean seed is an excellent alternative for humans where availability of meat is scarce, costly or greater population is vegetarian (AVRDC, 2012). Furthermore, its immature green pods and leaves are consumable as a vegetable (Mogotsi, 2006).

Pakistan is listed among the top ten countries most vulnerable to climate change extremes. Due to climatic changes, weather patterns vary on monthly and yearly basis and exert significant influence on growth and yield attributes of crops (Singh et al., 2014). Climatic variations are a combination of altitudinal and spatial variations which influence crop growth, development and yield in many different ways through regulating growth rates and reproductive capacity. Variation in altitude in mountainous areas lead to changes in temperature, humidity, heat and illumination that affect plant growth and development. Variations of environmental factors along the altitude are 100 times faster compared to those along the latitude (He et al., 2013; Horuz et al., 2014). A special feature of such changes is the lowest temperature below which crop growth is impossible due to opposing environmental conditions (Arshad et al., 2018). Increasing plant biodiversity through multiple cropping (intercropping) might create favorable microclimate and ecology for growth and yield of plants and ultimately sustainable land productivity (Li et al., 2009). Diverse species grown in proximity usually face interspecific competition and adverse repercussions if resources *i.e.*, water, nutrients and radiation are limited.

Nitrogen fertilizer, being the primary source of plant nutrition, is among the seventeen elements needed for plant growth and development. In plants, nitrogen is associated with chlorophyll where process of photosynthesis takes place. Moreover, nitrogen is important in all phases of plant growth. Hence, ensuring its availability to plant in proper quantity is required to optimize yield (Fan et al., 2019). Growth conditions adjustment – row arrangement and time of sowing – can help slacken interspecific competition and increase productivity. Therefore, this research was conducted to assess growth and yield performance of mungbean established as monocropping and intercropping with maize using three levels of nitrogen, two types of row patterns and two types of time of intercropping at three different elevation sites during three consecutive years. Moreover, the grain yield performance of maize was also assessed to observe the influence of intercropping with mungbean.

2. METHODOLOGY

2.1. Study site and climatic conditions

Research experiments were conducted during summer seasons of 2015, 2016 and 2017 at farmer's fields of Gilgit, Ghizer and Nagar districts in Gilgit-Baltistan region of Pakistan having altitudes of 1,500; 1,800 and 2,200 m from Mean Sea Level, respectively (**Figure 1**). The study area is characterized with temperate climatic conditions with annual rainfall less than 154 mm (**Figure 2**).

2.2. Experimental layout and treatments

At each experimental site, monocropping and intercropping of both maize and mungbean were established in a factorial combination using Randomized Complete Block Design with three replicates. At each location, during 1st year (2015) effect of three N levels (28, 56, 113 kg $N \cdot ha^{-1}$), 2nd year (2016) two planting patterns (alternate single row and alternate double row) while in 3rd year (2017) two sowing times (simultaneous and staggered) on mungbean growth (plant height, leaf area per plant, thousands grain weight, grain yield, biological yield and harvest index) under sole and intercropped with maize were studied. Grain yield of maize was also studied under sole and intercropping situations. Alternate single row pattern means one row of maize followed by one row of mungbean spaced 25 cm apart, while alternate double row pattern means two rows of maize spaced 25 cm apart followed by two rows of mungbean spaced 25 cm apart (**Figures 3-5**). In simultaneous seeding, both maize and legume were established at the same time, whereas maize was seeded fifteen days after seeding the legume in staggered seeding plots.

During 1st year of experimentation, nitrogen was applied in splits through urea whereas recommended doses of both phosphorus and potassium were applied entirely as basal dose at the time of sowing through triple superphosphate and potassium sulfate, respectively. For simultaneous sowing, dose of N was divided into two splits, 50% at seeding and remainder 50% at booting stage of maize. In case of staggered seeding, N was applied in three splits, *i.e.* 25% at mungbean sowing, 25% at maize sowing and the remainder 50% at booting stage of maize. For sole crops of mungbean, N, P and K were applied at the rate of 30 $kg \cdot ha^{-1}$ each at the time of sowing.

2.3. Experimental management

Before sowing, land was ploughed and leveled using tractor and implements and recommended varieties of mungbean (NM–2006) and maize (Azam) were

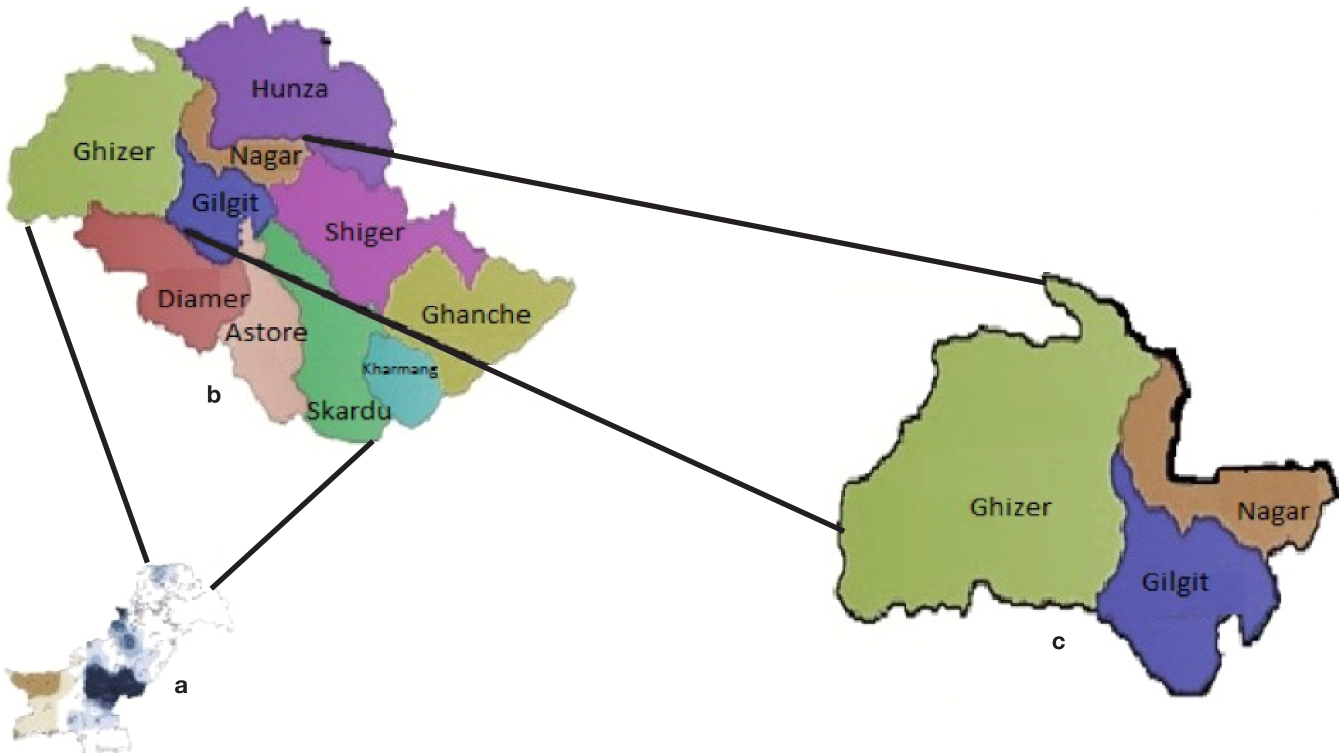

Figure 1. Maps for Pakistan (**a**), Gilgit-Baltistan (**b**) and study area (**c**) — *Carte du Pakistan (**a**), de Gilgit-Baltistan (**b**) et du site d'étude (**c**).*

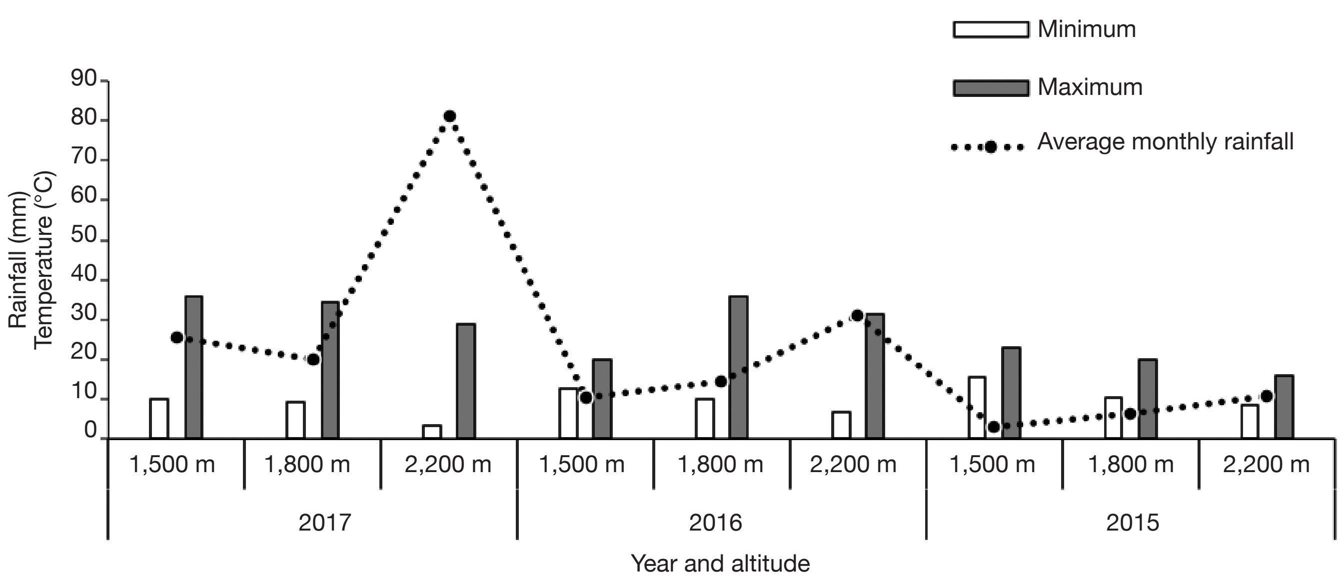

Figure 2. Mean monthly rainfall (lines) and ambient temperature (°C) depending on years and altitudes for the study area — *Pluies mensuelles moyennes (lignes) et température ambiante (°C) en fonction des années et altitudes pour la zone d'étude*.

cultivated as per treatments. In all experiments, plot size was maintained as 6 m × 4 m. Plots within each replication were separated by leaving one-meter vacant area in between while replications were separated by two-meter vacant area. Planting density of mungbean and maize was kept at 2×10^5 and 1×10^5 plants·

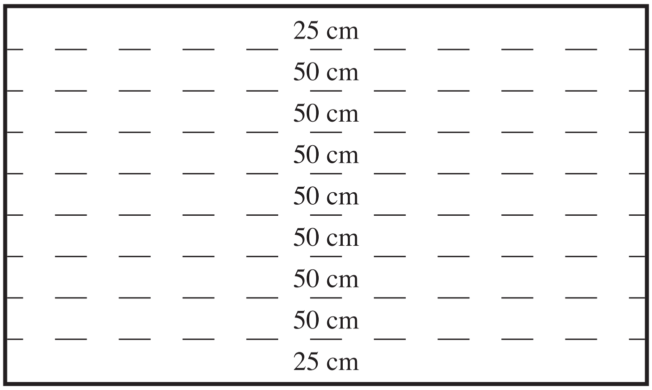

Figure 3. Row arrangement for monocropping system — *Disposition des rangées en monoculture*.

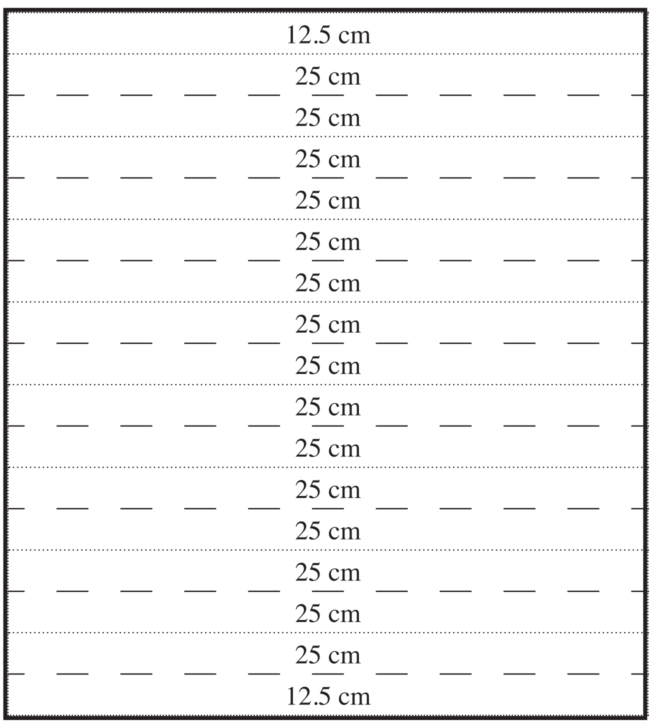

Figure 4. Row arrangement for alternate single row pattern in intercropping (…. for legume and - - - for maize) — *Disposition des rangées pour le modèle à rangée simple alternée en interculture (.... pour les légumineuses et - - - pour le maïs)*.

ha^{-1}, respectively. Intra plant spacing was 10 cm for mungbean and 20 cm for maize. Experiments were irrigated four times during the growing season with 14 days' interval after germination. All the plant protection measures were done according to the recommendations *i.e*. weeds were manually uprooted from the experimental area. To control insect pests, Carbofuran granules (2%) were used at the rate of 50 kg·ha^{-1}. The experimental design is summarized in **figure 6**.

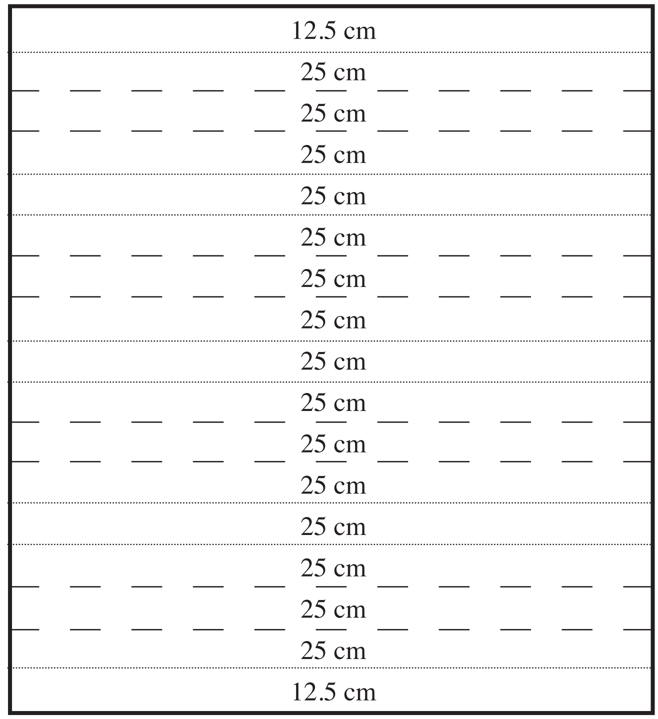

Figure 5. Row arrangement for intercropping (…. for legume and ----- for maize) — *Disposition des rangées pour l'interculture (.... pour les légumineuses et - - - pour le maïs)*.

2.4. Plant sampling and measurements

At flowering stage of mungbean, five plants were harvested randomly from each plot. Plant height (PH) of harvested plants was measured through meter rod and average plant height was calculated. Leaves of the plants were separated and average leaf area (LA) per plant was computed using disc method. At pod maturity stage, again five plants were sampled from each plot and pods and stover portions were separated. Pods were threshed and the collected grains were dried at 70 °C till 9% moisture content. Stover was weighed using digital balance. Further, thousand grain weight (TGW) and yield per hectare for grain and stover (biological) were calculated. Harvest index (HI) was computed by dividing grain yield with biological yield. For grain yield of maize, an area of 1 m^2 from each plot was harvested at its maturity stage and panicles were separated. Panicles of maize were threshed and the grains were dried at 70 °C till 12% moisture content and weighed, and grain yield of maize was expressed per hectare basis.

2.5. Statistical analysis

Growth and yield measurements (data) of mungbean and maize were statistically analyzed through Orthogonal Contrast Procedure using SAS program (Version 9.0) to compare means and levels of difference among means. The relationships between different growth and

Figure 6. Treatments and experimental layout example for one site and year — *Exemple de traitements et de dispositif expérimental pour un site et une année*.

Treatments						
Altitude	**Legume type**	**Nitrogen dose for intercropping treatments**	**Monocropping**	**Plot size**	**Spacing between plots**	**Spacing between replications**
1,500 m (A_1)	Mungbean (L1)	28 kg·ha^{-1} (N_1)	Maize (M)	4 m × 6 m	0.5 m	1.0 m
1,800 m (A_2)		56 kg·ha^{-1} (N_2)	Mungbean (L_1)			
2,200 m (A_3)		113 kg·ha^{-1} (N_3)				

$A_1L_1N_2$	$A_1L_1N_1$	$A_1L_1N_3$	M	L_1
1.0 m spacing				
$A_1L_1N_1$	L_1	$A_1L_1N_2$	M	$A_1L_1N_3$
1.0 m spacing				
$A_1L_1N_3$	M	L_1	$A_1L_1N_2$	$A_1L_1N_1$

yield parameters of mungbean were assessed using Pearson correlation analysis.

3. RESULTS

3.1. Growth and yield performance of mungbean

Mean plant height of mungbean was 37.48 cm in all experiments. However, it varied significantly due to altitude, cropping system, row pattern and years ($p \leq 0.05$; **Table 1**). Mungbean height was higher under sole cropping system than its intercropping with maize (**Figure 7a**). The plant height was greater in 2017 while significantly reduced in 2015 and 2016 ($p \leq 0.05$; **Figure 7b**). This is attributed to favorable climatic conditions during 2017 as compared to years 2016 and 2015. Plant gained more height at lower altitudes of 1,500 and 1,800 m than of 2,200 m (**Figure 7c**). In intercropping with maize, alternate double row pattern significantly and positively supported mungbean height compared to alternate single row pattern ($p \leq 0.05$; **Figure 7d**). However, nitrogen level and sowing time of intercropping with maize did not significantly affect mungbean plant height ($p > 0.05$).

Mean leaf area (LA) of mungbean was 141.1 cm^2·plant^{-1}. Year, altitude and plant row pattern influenced significantly leaf area of mungbean (**Table 1**). The mungbean LA was significantly increased in 2017 compared to 2016 and 2015 (**Figure 8a**). Mungbean cultivated on the altitude of 1,500 m produced the highest LA and significant reduction was observed at altitudes of 1,800 and 2,200 m ($p \leq 0.05$; **Figure 8b**). Mungbean intercropped with maize in alternate double row pattern gained more LA compared to alternate single row pattern ($p \leq 0.05$; **Figure 8c**).

Mean mungbean thousand grain weight (TGW) was 37.33 g in all experiments. The TGW was significantly affected by cropping system, year and altitude (**Table 1**). The TGW was greater in monocropping compared to its intercropping with maize ($p \leq 0.05$; **Figure 9a**). The TGW was higher in year 2017 than 2016 and 2015 (**Figure 9b**). The TGW was successively reduced as altitude increased from 1,500 m to 2,200 m ($p \leq 0.05$; **Figure 9c**). Cropping system, year, altitude and row pattern significantly influenced grain yield of mungbean (**Table 1**). Sole cropping of mungbean increased grain yield compared to its intercropping with maize ($p \leq 0.05$; **Figure 10a**). In year 2017, grain yield was the highest but reduced significantly in year 2016 and 2015 ($p \leq 0.05$; **Figure 10b**). At altitudes of 1,500 and 1,800 m, grain yield was higher compared to altitude of 2,200 m (**Figure 10c**). In intercropping systems, grain yield of mungbean was increased due to alternate double row pattern compared to alternate single row pattern ($p \leq 0.05$; **Figure 10d**).

Mean biological yield (BY) of mungbean was 9.13 t·ha^{-1}. The BY varied significantly due to year, altitude and row pattern (**Table 1**). In years 2017 and 2016, BY was significantly greater compared to

Table 1. Comparison of plant height, leaf area, thousand grain weight, grain yield, biological yield, and harvest index between cropping systems, years, altitudes, nitrogen levels, planting pattern and time of sowing using Orthogonal Contrasts — *Comparaison de la hauteur du plant, de la surface foliaire, du poids de 1 000 grains, du rendement en grain, du rendement biologique et de l'indice de récolte avec les systèmes de culture, les années, les altitudes, les niveaux d'azote, le dispositif de plantation et le temps de semis en utilisant l'analyse des contrastes orthogonaux.*

Source of variation contrast	**df**	**Mean square**					
		Plant height	**Leaf area**	**Thousand grain weight**	**Grain yield**	**Biological yield**	**Harvest index**
Cropping system							
Sole *vs* Inter	1	665.69**	20,749.15***	611.06***	91.89***	158.71***	0.00^{ns}
Error	86	98.17	925.74	17.17	1.59	2.52	0.01
CV, %	26.43	21.55	11.05	21.45	17.39	15.71	
Year							
2015 *vs* 2016	1	1,104.48***	7,649.93***	83.27*	12.70**	18.39*	0.50^{ns}
2015 *vs* 2017	1	5,546.82***	33,798.42***	477.50***	60.45***	0.23^{ns}	0.64^{ns}
2016 *vs* 2017	1	1,488.37***	8,127.89***	141.71***	15.52***	19.94*	0.00^{ns}
Error	85	41.87	782.03	18.94	1.97	4.12	0.00
CV, %	17.26	19.81	11.60	23.92	22.23	5.02	
Altitude (m)							
1500 *vs* 1800	1	155.81^{ns}	4,540.70*	48.79^{ns}	7.21^{ns}	11.67^{ns}	0.00^{ns}
1500 *vs* 2200	1	979.53***	13,942.77***	94.22*	24.23***	49.59^{ns}	0.00^{ns}
1800 *vs* 2200	1	354.00*	2,569.95^{ns}	7.40^{ns}	4.99^{ns}	13.14^{ns}	0.00^{ns}
Error	85	95.47	1,015.62	23.38	2.40	3.84	0.01
CV, %	26.06	22.58	12.89	26.37	21.44	15.82	
Nitrogen level ($kg \cdot ha^{-1}$)							
28 *vs* 56	1	0.05^{ns}	1.35^{ns}	0.66^{ns}	0.00^{ns}	0.00^{ns}	0.00^{ns}
28 *vs* 113	1	6.02^{ns}	12.92^{ns}	0.04^{ns}	0.05^{ns}	0.00^{ns}	0.00^{ns}
56 *vs* 113	1	7.16^{ns}	5.90^{ns}	0.36^{ns}	0.07^{ns}	0.00^{ns}	0.00^{ns}
Error	80	51.64	644.89	17.34	1.48	1.82	0.00
CV, %	19.17	17.99	11.10	20.70	14.79	9.45	
Planting pattern							
ASR *vs* ADR	1	222.04*	13,223.71***	56.60^{ns}	6.03*	14.45***	0.00^{ns}
Error	80	51.64	644.89	17.34	1.48	1.82	0.00
CV, %	19.17	17.99	11.10	20.70	14.79	9.45	
Time of sowing							
Simultaneous *vs* staggered	1	31.09^{ns}	2,134.65^{ns}	4.99^{ns}	0.32^{ns}	0.33^{ns}	0.00^{ns}
Error	80	51.64	644.89	17.34	1.48	1.82	0.00
CV, %	19.17	17.99	11.10	20.70	14.79	9.45	

*, **, ***: level of significance at $p = 0.05$, 0.01 and 0.001, respectively — *niveau de signification à* p *= 0,05; 0,01 et 0,001, respectivement.*

2015 ($p \leq 0.05$; **Figure 11a**). Altitudes of 1,500 m and 1,800 m produced higher BY compared to an altitude of 2,200 m (**Figure 11b**). In intercropping with maize, BY of mungbean was improved in alternate double row pattern compared to alternate single row pattern ($p \leq 0.05$; **Figure 11c**). Mean harvest index (HI) of mungbean was 0.64 in all the experiments. Besides, it was significantly influenced by year (**Table 1**). In year 2017, HI was the highest but significantly reduced in 2016 and 2015 ($p \leq 0.05$; **Figure 11d**).

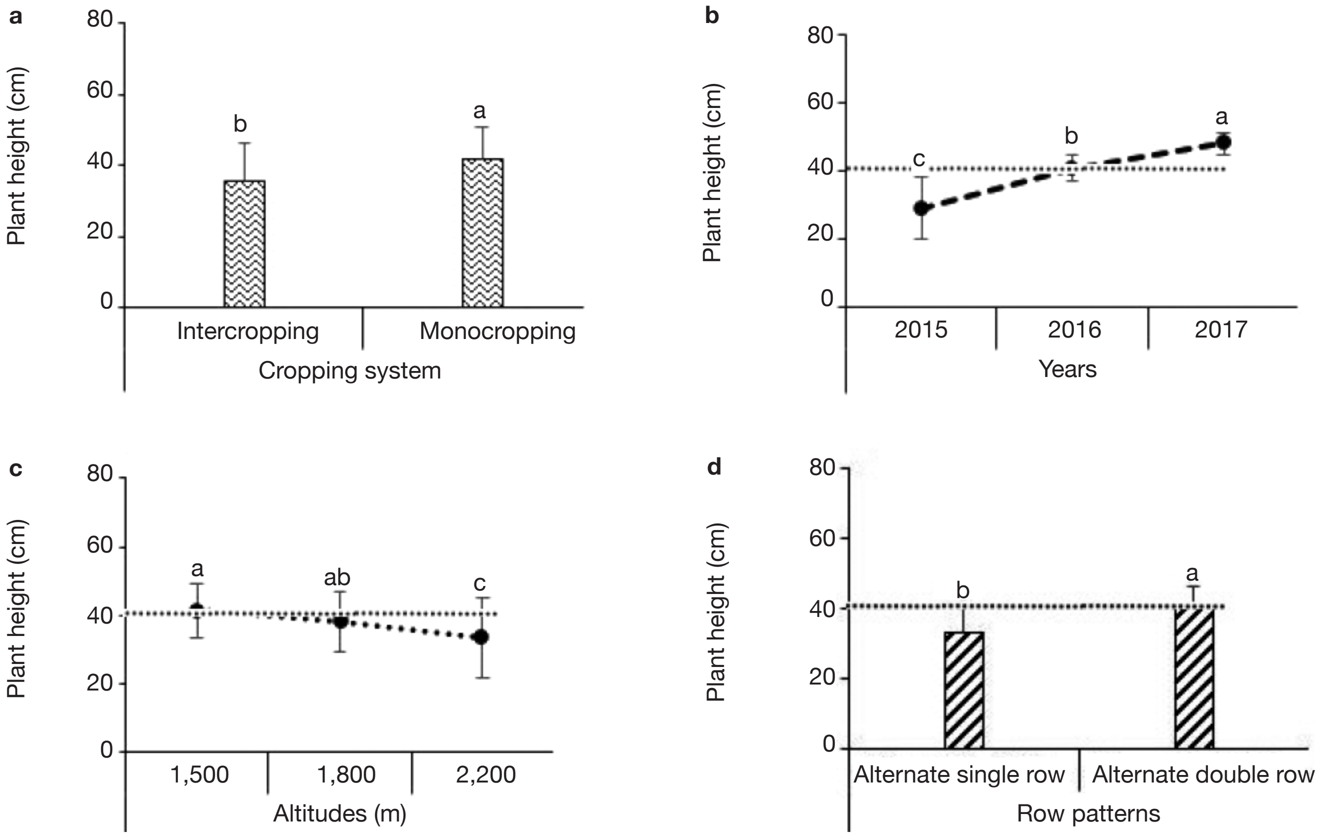

Figure 7. Variation in mungbean plant height due to cropping systems (**a**), years (**b**), altitudes (**c**) and row patterns (**d**) — *Variation de la hauteur du plant de haricot mungo en fonction des systèmes de culture (**a**), des années (**b**), des altitudes (**c**) et selon le semis en simple ou double rangée (**d**).*

Different small letters show significant differences among treatments at 5% probability level — *les différentes minuscules montrent des différences significatives entre les traitements à un niveau de probabilité de 5 %*; dotted error bars show standard error of the mean (n = 3) — *les barres d'erreur pointillées montrent l'écart-type de la moyenne (n = 3)*; lines on figures b, c and d represented plant height of sole mungbean crop — *les lignes sur les figures b, c et d représentent la hauteur du plant en monoculture de haricot mungo*.

3.2. Relationships between growth and yield parameters of mungbean

Relationships between growth and yield parameters of mungbean are presented in **Table 2**. Most of the parameters were strongly associated with each other except relationship between biological yield and harvest index (**Table 2**). A clear positive relation ($p > 0.05$) was found between mungbean leaf area (LA) and plant height due to more number of leaves on taller plants which consequently improved LA, hence contributed positively to grain yields through high net assimilation rates. Positive correlation between plant growth parameters and yield components of crops was also reported by Workayehu (2000), Jamali & Ali (2008) and Rafiq et al. (2010).

3.3. Grain yield performance of maize

Maize intercropped with mungbean was influenced due to different management systems. Compared to its monocropping, grain yield of maize did not decrease significantly during 2015 and 2016 years (**Figures 12a** and **12b**) but significantly decreased in 2017 (**Figure 12c**). In intercropping system, maize grain yield varied also significantly due to elevation (**Figures 12d**, **12e**, **12f**) N level (**Figure 12g**), row pattern (**Figure 12h**) and time of sowing (**Figure 12i**). Lower elevation (1,500 m), higher N level (113 kg·ha^{-1}), alternate single row pattern and staggered sowing yielded the highest.

4. DISCUSSION

Cereal-legume intercropping is an advantageous practice as it improves agroecology, plant diversity and stability of fields while reducing crop N fertilizer demand. However, owing to complications and bottlenecks of management, research for its adoption in production systems has been traditionally ignored especially in temperate climatic conditions (Peksen

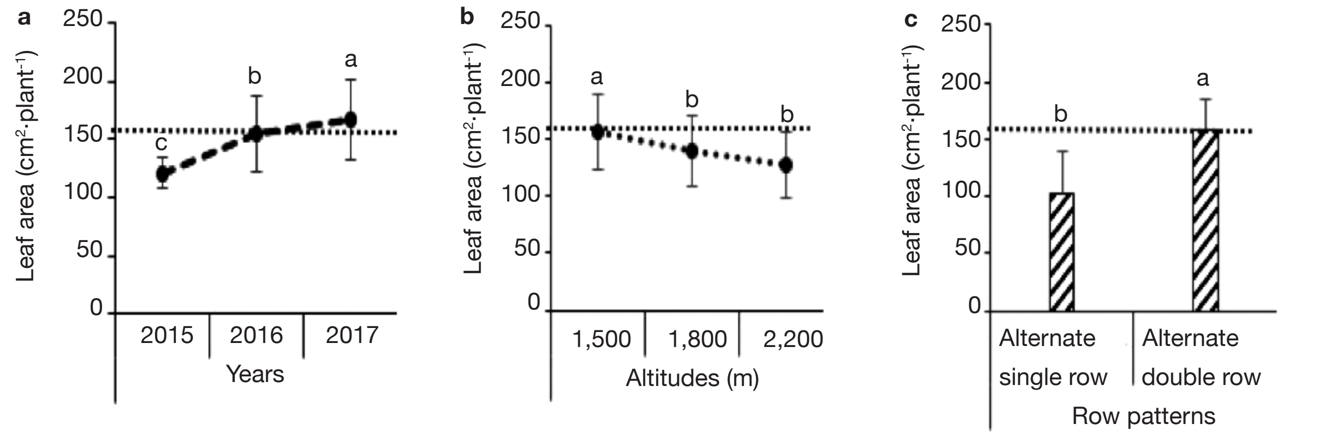

Figure 8. Variation in mungbean leaf area due to years (**a**), altitudes (**b**) and row patterns (**c**) — *Variation de la surface foliaire du haricot mungo en fonction des années (**a**), des altitudes (**b**) et selon le semis en simple ou double rangée (**c**).*

Small letters, error bars — *minuscules, barres d'erreur*: see **figure 7** — *voir **figure** 7*; dotted lines represented leaf area of sole mungbean crop — *les lignes pointillées représentent la surface foliaire du haricot mungo cultivé seul.*

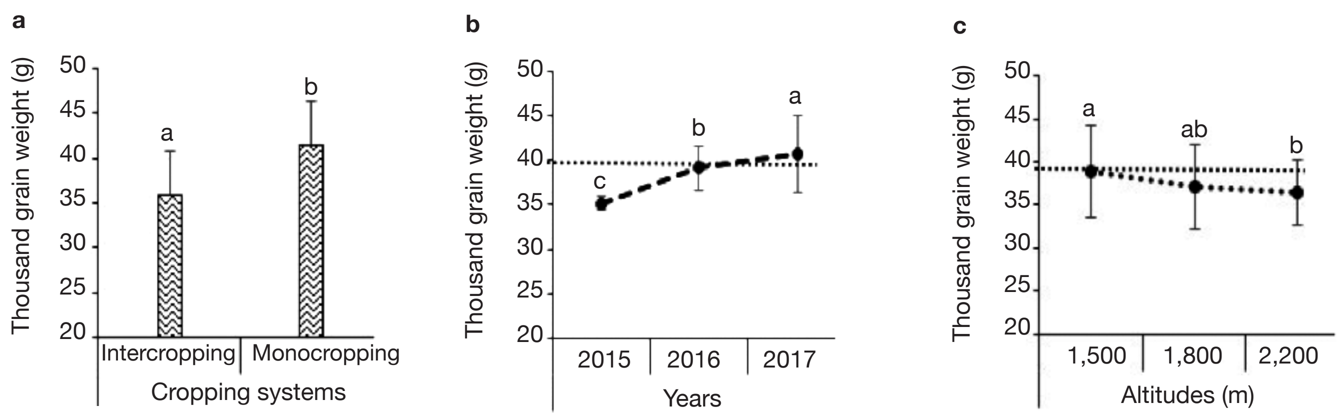

Figure 9. Variation in mungbean thousand grain weight due to cropping systems (**a**), years (***b***) and altitudes (**c**) — *Variation du poids de 1 000 grains de haricots mungo en fonction des sytèmes de culture (**a**), des années (**b**) et des altitudes (**c**).*

Small letters, error bars — *minuscules, barres d'erreur*: see **figure 7** — *voir **figure** 7*; dotted lines represent thousand grain weight of sole mungbean crop — *les lignes pointillées représentent le poids de 1 000 grains du haricot mungo cultivé seul.*

& Gulumser, 2013). Mungbean-maize intercropping adversely affects mungbean growth and grain yield due to dominance of adjacent maize and competition between both crops for resources *i.e.*, solar radiation, nutrients and water. Declines of growth and yield of mungbean have also been observed by Khan & Khaliq (2004) and Arshad & Ranamukhaarachchi (2012) after its intercropping with cereals. However, the intercropping competition can be decreased through better agronomic management practices as well as spatial and temporal adjustment of complementarity of intercrops.

The altitude of land influences growth and development of plants mainly through temperature effect (Xu et al., 2014). According to Kumar & O'Donnell (2009), temperature declines by 1 °C with every 100 m escalation of altitude. The association of altitudinal factors to temperature is similar to the relationship of distance from equator to poles of the Earth. Impact of altitudinal variations on plants physiological processes, especially leaf gas exchange, was reported by Sakata & Yokoi (2002). These variations might have influence on plant growth, yield parameters being governed by environmental factors such as air temperature, humidity, leaf gas exchange and type of solar radiation received and intercepted. The amount of solar radiation harvested by plant is directly associated with leaf area, which regulates growth rates, biological productivity and also economic returns of the crop. Moreover, leaf area serves as indicator for the

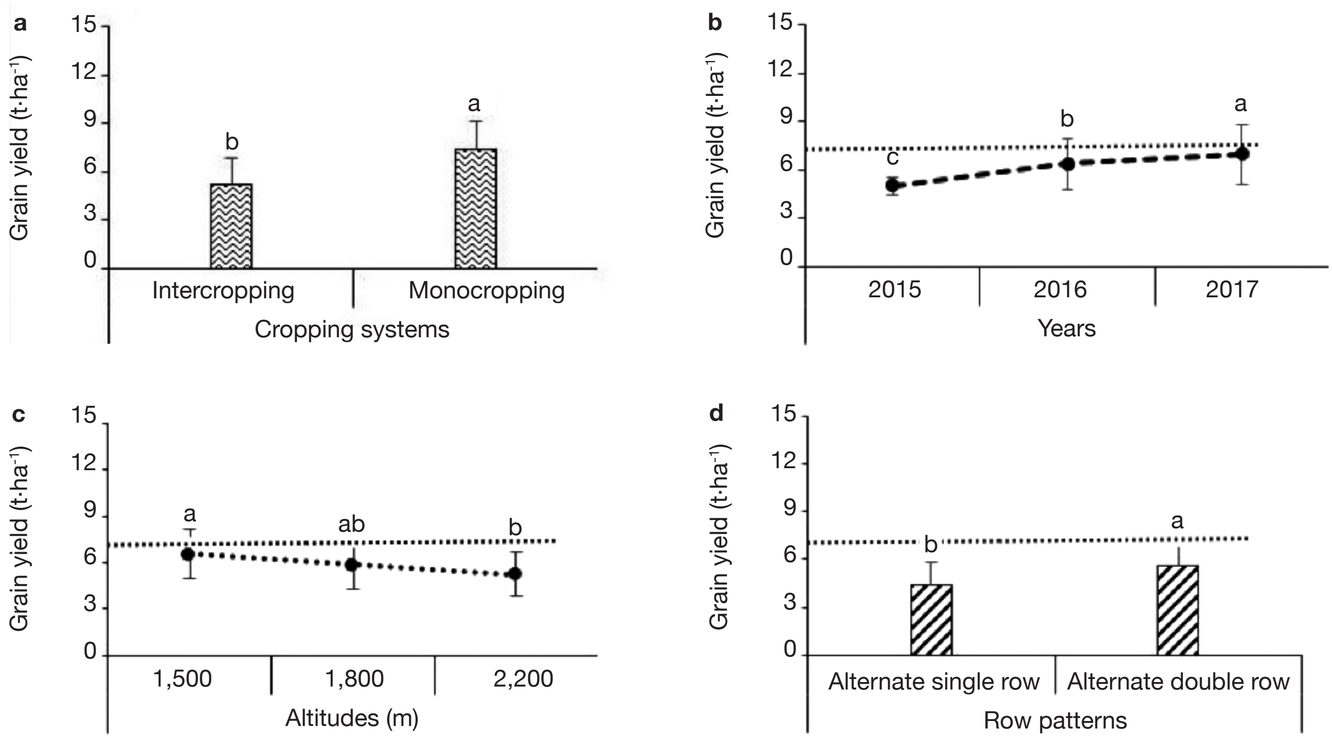

Figure 10. Variation in mungbean grain yield due to cropping systems (**a**), years (**b**), altitudes (**c**) and row patterns (**d**) — *Variation du rendenemt de grain dans le haricot mungo en fonction des systèmes de culture (**a**), des années (**b**), des altitudes (**c**) et des modèles de rangée (**d**).*

Small letters, error bars — *minuscules, barres d'erreur*: see **figure 7** — *voir **figure 7***; dotted lines represent grain yield of sole mungbean crop — *les lignes pointillées représentent le rendement du haricot mungo cultivé seul.*

status of nutritional, biotic and abiotic stresses on the plant (Vile et al., 2005).

A positive relation has been reported between altitude and intensity of shortwave radiation while a negative relation exists between altitude and ambient air temperatures (Sola et al., 2008). At lower altitudes, daytime light intensity is at par with photosynthetic saturation of C_3 plants like mungbean. Additionally, synchronization of favorable temperature with plant growth might enhance crop yield at such locations. These logics are in congruence with our study where we observed improvement in growth and productivity of mungbean at lower altitude due to varied climatic conditions.

Nitrogen is an essential primary plant nutrient required in large quantity. Its deficiency leads to significant reduction in plant growth and yield components (Gojon, 2017). Smart N management practices are required for better crop growth, development and yield. Application of mineral N in cereal-legume intercropping system is a major contributor to final production of cereals where legumes might stabilize N level of the soil and minimally dependent on external N sources (Fan et al., 2019). Therefore, little or no influence of applied N levels rates was noticed on mungbean in current study due to capacity of N fixing potential of mungbean crop.

Planting pattern in cereal-legume intercropping determines proximity of canopies and roots that subsequently govern resource, capture ability and degree of competency for nutrients, water and solar radiation. Aboveground competition is further intensified and aggravated in intercropping of taller and dwarf plants like maize and mungbean due to interference for solar radiation. Under alternate single row cropping pattern, tall plants have shading effect on dwarf plants under their canopy. Stripping cropping like alternate double row pattern of mungbean and maize promotes better penetration of solar radiation for faster photosynthetic rate hence better crop productivity of dwarf crop, *i.e.* mungbean. This spatial separation of canopy and root zones might lead to mollify competition for aforementioned resources subsequently enhanced growth and development of mungbean. Similar to row pattern, adjustment of sowing time in cereal-legume intercropping significantly reduces interspecific competition. It might separate the most competing growth stages of maize and mungbean which also help in minimizing competition for resources. Consequently, staggered sowing (different

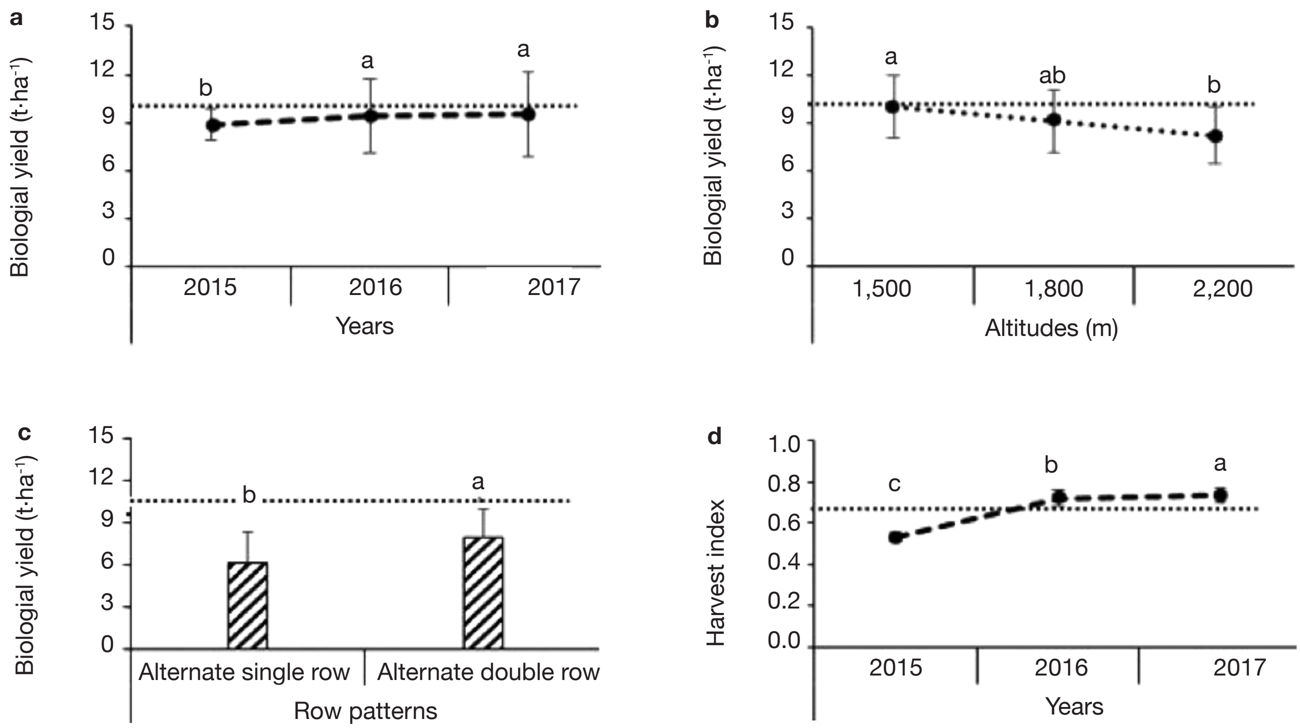

Figure 11. Variation in mungbean biological yield due to years (**a**), altitudes (**b**) and row patterns (**c**) and harvest index in different years (**d**) — *Variation dans le rendement biologique du haricot mungo en fonction des années (**a**), des altitudes (**b**) et des modèles de rangée (**c**) et l'index de récolte selon différentes années (**d**).*

Different small letters show significant differences among treatments at 5% probability level — *les différentes minuscules montrent des différences significatives entre les traitements à un niveau de probabilité de 5 %*; error bars show standard error of the mean (n = 3) — *les barres d'erreur montrent l'écart-type de la moyenne (n = 3)*; dotted lines on figures a, b and c represent biological yield, while on figure d, dotted line represents the harvest index of sole mungbean crop — *les lignes pointillées sur les figures a, b et c représentent le rendement biologique, tandis que sur la figure d, la ligne pointillée représente l'index de récolte du haricot mungo cultivé seul.*

Table 2. Inter-relationship among growth and yield parameters of mungbean — *Interrelation entre la croissance et les paramètres de rendement du haricot mungo.*

Parameter	Plant height	Leaf area	Thousand grain weight	Grain yield	Biological yield
Plant height	1.00				
Leaf area	0.80***	1.00			
Thousand grain weight	0.56***	0.83***	1.00		
Grain yield	0.71***	0.92***	0.89***	1.00	
Biological yield	0.37***	0.70***	0.73***	0.82***	1.00
Harvest index	0.68***	0.48***	0.36***	0.43***	-0.15^{ns}

***: significant correlation — *corrélation significative*; ns : not significant correlation — *corrélation non significative*.

seeding times) improved mungbean growth and its yield. Sowing of mungbean fifteen days earlier than maize yielded at par with its monocropping system. It might be due to reduced competition of resources between two crops rather than simultaneous seeding of both crops. Benefits of staggered seeding over simultaneous seeding have also been highlighted in previous studies (Arshad & Ranamukhaarach, 2012; Hirpa, 2014; Choudhary & Choudhury, 2016). Plant growth parameters serve as good indicators of grain yield in different crops and have positive interrelationship (Karim & Fattah, 2007; Tesfaye et al., 2018). Correlation findings provide a good understanding of relationship of different growth parameters with grain yield and hence associations among various characters is helpful for breeders and yield predictors for the selection of suitable traits (Sokoto et al., 2012).

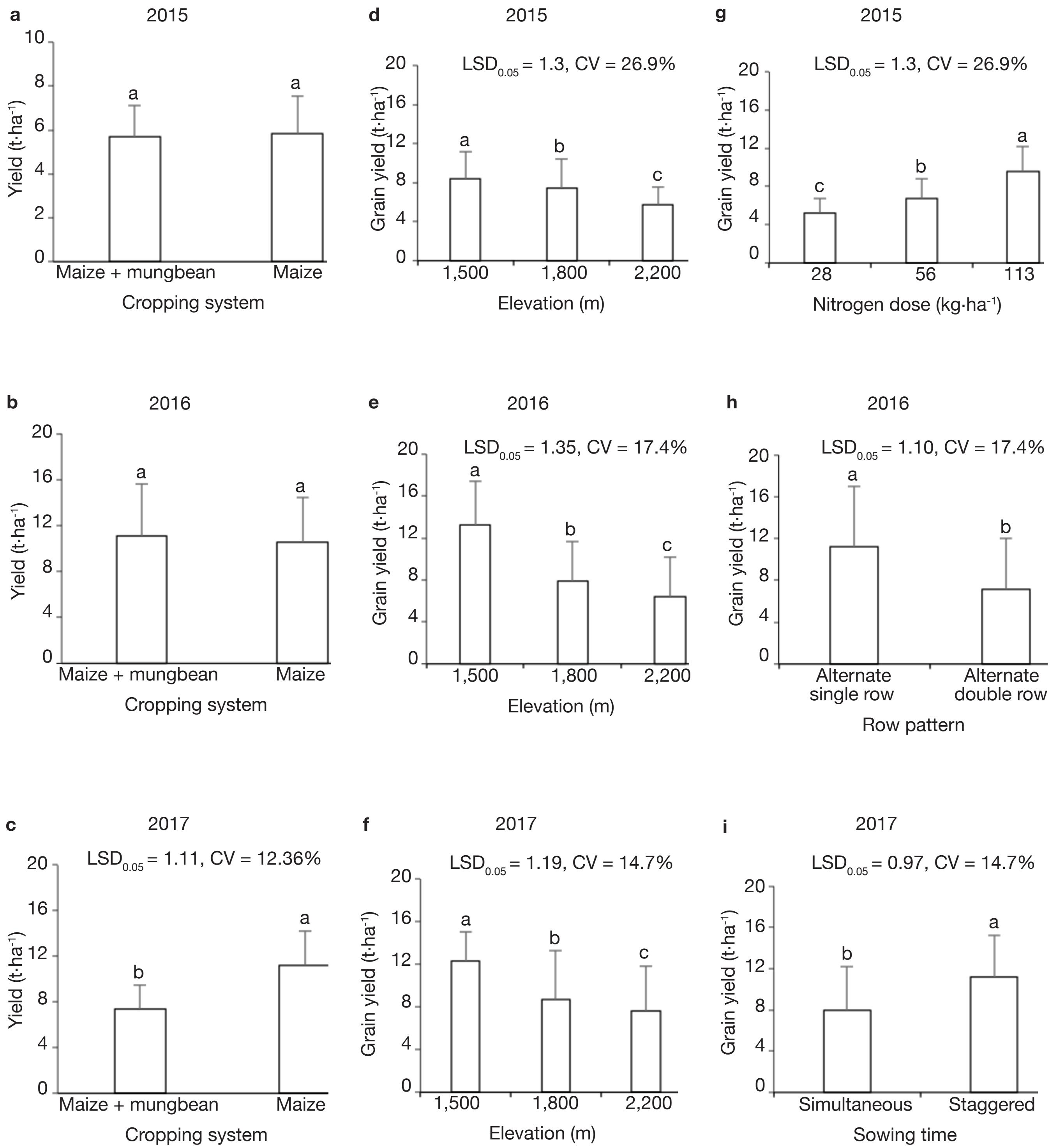

Figure 12. Grain yield performance of maize influenced by different management systems in year 2015 (**a, d, g**), 2016 (**b, e, h**) and 2017 (**c, f, i**) — *Performance du rendement en grain du maïs influencée par les différents systèmes de gestion en 2015 (**a, d, g**), 2016 (**b, e, h**) et 2017 (**c, f, i**).*

5. CONCLUSIONS

Research results indicated that mungbean growth and yield attributes varied significantly among different years and altitudes. Intercropping mungbean with maize reduced its growth and yield attributes as compared to its monocropping mainly due to competition for resources like solar radiation, nutrients and water. However, this interspecific competition was successfully mediated through proper adjustment of row patterns and time of seeding. Mungbean established with alternate double row pattern and seeded fifteen days prior to maize sowing in intercropping plots yielded at par with its monocropping system. Moreover, positive associations were observed among various growth and yield components of mungbean. It was concluded that productivity of maize-mungbean intercropping systems can be enhanced by strip cropping under staggered sowing at low altitudes.

Bibliography

Arshad M. & Ranamukhaarachchi S.L., 2012. Effects of legume type, planting pattern and time of establishment on growth and yield of sweet sorghum-legume intercropping. *Austr. J. Crop Sci.*, **6**, 1265-1274.

Arshad M. et al., 2018. Morpho-nutritional response of lettuce (*Lactuca sativa* L.) to organic waste extracts grown under hydroponic condition. *Appl. Ecol. Environ. Res.*, **16**, 3637-3648, doi.org/10.15666/aeer/1603_36373648

AVRDC (Asian Vegetable Research and Development Centre), 2012. *Mungbean AVDRC Progress Report 2012*. Shanhua, Taiwain: AVRDC.

Choudhary V.K. & Choudhury B.U., 2016. A staggered maize–legume intercrop arrangement influences yield, weed smothering and nutrient balance in the eastern Himalayan region of India. *Exp. Agric.*, **54**, 181-200, doi.org/10.1017/s0014479716000144

Elferink M. & Schierhorn F., 2016. *Global demand for food is rising. Can we meet it? Harvard Bus. Rev.*, www.hbr.org/2016/04/global-demand-for-food-is-rising-can-we-meet-it/, (11/01/2018).

Fan Z. et al., 2019. Synchrony of nitrogen supply and crop demand are driven *via* high maize density in maize/pea strip intercropping. *Sci. Rep.*, **9**, 10954, doi.org/10.1038/s41598-019-47554-1.

FAO, 2010. *Grassland index. A searchable catalogue of grass and forage legumes*. Roma: FAO.

Gojon A., 2017. Nitrogen nutrition in plants: rapid progress and new challenges. *J. Exp. Bot.*, **68**, 2457-2462, doi.org/10.1093/jxb/erx171

He Y.H. et al., 2013. Altitudinal pattern of plant species diversity in the Wulu Mountain Nature Reserve, Shanxi, China. *Acta Ecol. Sin.*, **33**, 2452-2462, doi.org/10.5846/stxb201208181163

Hirpa T., 2014. Response of maize crop to spatial arrangement and staggered inter seeding of haricot bean. *Int. J. Environ.*, **3**, 126-138, doi.org/10.3126/ije.v3i3.11072

Horuz A. et al., 2014. Nutrient concentrations and nutrient ratios of *Rhododendron ponticum* litter along an elevational gradient. *Ekoloji*, **23**, 1-7, doi.org/10.5053/ekoloji.2014.911

Ilyas N. et al., 2018. Contribution of nitrogen fixed by mung bean to the following wheat crop. *Commun. Soil Sci. Plant Anal.*, **49**, 148-158, doi.org/10.1080/00103624.2017.1421215

Imran K.A.A., Ahmad F. & Ullah I., 2015. Influence of hydrated calcium sulphate ($CaSO4.2H_2O$) and nitrogen levels on water infiltration rate and maize varieties productivity in rainfed area of Swat, Pakistan. *Chem. Mater. Res.*, **7**, 15-20

Jamali K.D. & Ali S.A., 2008. Yield and yield components with relation to plant height in semi-dwarf wheat. *Pak. J. Bot.*, **40**, 1805-1808.

Karim M.F. & Fattah Q.A., 2007. Growth analysis of chickpea cv. Bari Chhola-6 as affected by folar sprey of growth regulators. *Bangladesh J. Bot.*, **36**, 105-110, doi.org/10.3329/bjb.v36i2.1497

Khan M.B. & Khaliq A., 2004. Production of soybean (*Glycine max* L.) as cotton based intercrop. *J. Res. Sci.*, **15**, 79-84.

Khan M.B. & Khaliq A., 2004. Study of mungbean intercropping in cotton planted with different techniques. *J. Res. Sci.*, **15**, 23-31.

Kumar A. & O'Donnell S., 2009. Elevation and forest clearing effects on foraging differ between surface– and subterranean – foraging army ants (Formicidae: Ecitoninae). *J. An. Ecol.*, **78**, 91-97, doi.org/10.1111/j.1365-2656.2008.01483.x

Lambrides C.J. & Godwin I.D., 2006. Mungbean. *In*: Chittarajan K. *Genome mapping and molecular breeding in plants*. Vol. 3. Berlin/Heidelberg, Germany: Springer, 69-90.

Li C. et al., 2009. Crop diversity for yield increase. *PLoS ONE*, **4**, e8049, doi.org/10.1371/journal.pone.0008049

Mansoor M., 2007. *Evaluation of various agronomic management practices for increased productivity of mungbean (*Vigna radiata *L. Wilszek)*. Ph.D thesis: Gomal University, D. I. Khan (Pakistan).

Mogotsi K.K., 2006. *Vigna radiata* (L.) R.Wilczek. *In*: Brink M. & Belay G., eds. *PROTA 1: Cereals and pulses/Céréales et légumes secs*. [CD-Rom]. Wageningen, The Netherlands: PROTA.

Pakistan Economic Survey. 2012. *Agriculture in survey report 2012*. Islamabad: Ministry of Finance, 17-32.

Peksen E. & Gulumser A., 2013. Intercropping efficiency and yields of intercropped maize (*Zea mays* L.) and dwarf bean (*Phaseolus vulgaris* L.) affected by planting arrangements, planting rates and relative time of sowing. *Int. J. Curr. Microbiol. Appl. Sci.*, **2**, 290-299.

Rafiq M.A., Ali A., Malik M.A. & Hussain M., 2010. Effect of fertilizer levels and plant densities on yield and protein contents of autumn planted maize. *Pak. J. Agric. Sci.*, **47**, 201-208.

Rahman M.S., Haque M.F., Ahasan M.S. & Song H.J., 2010. Indirect enzyme linked immunesorvent assay for the diagnosis of *Brucellosis* in cattle. *Korean J. Vet. Serv.*, **32**, 113-119.

Rusinamhodzi L. et al., 2011. A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. *Agron. Sustainable Dev.*, **31**, 657-673, doi.org/ 10.1007/s13593-011-0040-2.

Sakata T. & Yokoi Y., 2002. Analysis of the O_2 dependency in leaf-level photosynthesis of two *Reynoutria japonica* populations growing at different altitudes. *Plant Cell Environ.*, **25**, 65-74, doi.org/10.1046/j.0016-8025.2001.00809.x

Singh D., Tsiang M., Rajaratnam B. & Diffenbaugh N.S., 2014. Observed changes in extreme wet and dry spells during the South Asian summer monsoon season. *Nat. Climate Change*, **4**, 456-461, doi.org/10.1038/nclimate2208

Sokoto M.B., Abubakar I.U. & Dikko A.U., 2012. Correlation analysis of some growth, yield, yield components and grain quality of wheat (*Triticum aestivum* L.). *Niger. J. Basic Appl. Sci.*, **20**, 349-356.

Sola Y. et al., 2008. Altitude effect in UV radiation during the evaluation of the effects of elevation and aerosols on the ultraviolet radiation 2002 (VELETA-2002) field campaign. *J. Geophys. Res.*, **113**, D23, doi.org/10.1029/2007jd009742

Tesfaye M., Belew D., Dessalegn Y. & Shumye G., 2018. Effect of planting time on growth, yield components, seed yield and quality of onion (*Allium cepa* L.) at Tehuledere district, northeastern Ethiopia. *Agric. Food Secur.*, **7**, 28, doi.org/10.1186/s40066-018-0178-0

Vile D. et al., 2005. Specific leaf area and dry matter content estimate thickness in laminar leaves. *Ann. Bot.*, **96**, 1129-1136, doi.org/10.1093/aob/mci264

Workayehu T., 2000. Effect of nitrogen fertiliser rates and plant density on grain yield of maize. *Afr. Crop Sci. J.*, **8**, 273-282, doi.org/10.4314/acsj.v8i3.27692

Xu P. et al., 2014. Foliar responses of *Abies fargesii* Franch. to altitude in the Taibai mountain, China. *Pol. J. Ecol.*, **62**, 479-492, doi.org/10.3161/104.062.0309

(35 ref.)