

CLUSTER BEAN INTERCROPPING WITH OKRA AND CHILI: AGRONOMIC RESPONSES AND ECONOMIC PERFORMANCE UNDER ARID CONDITIONS

Wasim Abbas Shah¹, Lubaina Soni^{*2}

¹Department of Horticulture, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University (BZU), Multan, Pakistan

^{*2}Department of Architecture and Planning, Dawood University of Engineering and Technology (DUET), Karachi, Pakistan

^{*2}lubaina.adnan@duet.edu.pk

DOI: <https://doi.org/10.5281/zenodo.23158765>

Keywords

Agro-ecology, cluster bean (Cyamopsis tetragonoloba), companion intercropping, interspecific competition, marginal rate of return, smallholder farming, sustainable agriculture, arid climates.

Article History

Received: 02 February 2025

Accepted: 12 April 2025

Published: 25 April 2025

Copyright @Author

Corresponding Author: *

Lubaina Soni

Abstract

Smallholder agricultural systems across arid and semi-arid zones of the Global South face mounting systemic risks stemming from land fragmentation, climatic anomalies, groundwater depletion, and escalating costs of synthetic chemical inputs. In response to these vulnerabilities, intercropping drought-hardy legumes with high-value horticultural cash crops represents a vital agro-ecological mechanism to maximize land-use efficiency, conserve soil capital, and enhance farm enterprise resilience. This two-year field investigation (conducted during 2023 and 2024 at Multan, Pakistan) evaluated the agronomic performance, biological efficiencies, allometric growth parameters, and economic viability of cluster bean (*Cyamopsis tetragonoloba* L.) cultivated in sole stands and intercropped with two morphologically contrasting horticultural companion crops: okra (*Abelmoschus esculentus* L.) and chili (*Capsicum frutescens* L.). The experiment was arranged in a Randomized Complete Block Design (RCBD) with three replications across five distinct cropping treatments: sole cluster bean (T₁), sole okra (T₂), sole chili (T₃), cluster bean intercropped with okra (T₄), and cluster bean intercropped with chili (T₅). Interspecific competition for spatial and nutritional resources significantly altered vegetative and reproductive allometric. Cluster bean vegetative development was highest in sole stands 19.77 cm plant height at first picking, 79.57 cm final plant height), but experienced significant suppression when intercropped with okra 16.72 cm and 69.68 cm, respectively and chili 16.35 cm and 68.72 cm, respectively. Leaf count per cluster bean plant was significantly restricted by okra competition 5.53 relative to chili intercropping 6.32 and sole stands 6.23. For companion vegetables, sole okra produced significantly more pods per plant 12.40 than intercropped okra 11.17, though cumulative pod yield of 14.85 t ha⁻¹ vs. 13.57 t ha⁻¹ was statistically maintained. Conversely, chili displayed pronounced competitive sensitivity: fruit count per plant dropped from 44.65 to 36.22, fruit fresh weight declined from 62.46 g to 47.56 g, and cumulative cumulative fruit yield suffered a statistically significant reduction from 3.49 t ha⁻¹ in monoculture to 2.65 t ha⁻¹ in intercropping ($p = 0.0151$). Despite individual yield trade-offs, comprehensive partial budget analysis revealed substantial economic premiums for polyculture diversification. Intercropping

cluster bean with okra achieved the highest enterprise profitability, delivering a net financial return of PKR 573,450 ha⁻¹, a marginal net benefit of PKR 474,950 ha⁻¹, a marginal rate of return (MRR) of 1,922.87%. Cluster bean intercropped with chili also yielded positive financial margins (net benefit of PKR 204,500 ha⁻¹; MRR of 476.83%, outperforming sole cluster bean monoculture (PKR 98,500 ha⁻¹). These empirical findings demonstrate that integrating low-water, nitrogen-fixing legumes with heavy-feeder horticultural vegetables stabilizes agrarian income and provides an adaptable polyculture model for climate-vulnerable smallholder farms.

INTRODUCTION

1.1 Global South Agricultural Transitions and Resource Stressors

Agrarian systems throughout the Global South are undergoing severe structural crises driven by climate-induced thermal anomalies, erratic precipitation patterns, aquifer depletion, and the continuous subdivision of agricultural land holdings. In developing agrarian economies like Pakistan, where more than 63% of the rural populace depends directly or indirectly on agriculture for subsistence and livelihood security, rural vulnerability is acutely tied to smallholder land viability. Over 86% of operational farming holdings in the country are below 5 hectares in spatial extent. Demographic expansion at an annual growth rate exceeding 2% has intensified pressures on limited land banks, resulting in severe per-capita arable land contraction. Between 2000 and 2011, Pakistan's total cropped area expanded by a marginal 6.2% (rising from 22.04 million hectares to 23.40 million hectares), with most of the land allocated to staple food grains (60%) and cash crops (23%), while pulse legumes (7%) and horticultural vegetables (2%) were restricted to minor areas.

This systematic under-allocation of spatial resources to horticulture has generated widespread public health vulnerabilities. According to World Health Organization dietary standards, an adult human requires a minimum balanced daily vegetable and fruit consumption threshold of 450 g. In contrast, average consumption in Pakistan remains restricted to approximately 235 g day⁻¹, creating an annual national nutritional supply deficit exceeding 10 million metric tons of essential protective produce. Resolving this national shortfall under prevailing land tenure constraints requires cropping systems that

enhance biomass and nutritional yield per unit area without necessitating external land acquisition or accelerating environmental degradation.

1.2 The Agro-Ecological Imperative for Companion Intercropping

For decades, high-input agricultural intensification paradigms relied upon monoculture cropping regimes sustained by heavy applications of synthetic inorganic fertilizers, chemical pesticides, and energy-intensive machinery. While monocultures provided short-term yield gains, these practices caused profound ecological damage: groundwater contamination from nitrate leaching, degradation of native soil microbiomes, destruction of pollinator biodiversity, and heightened economic exposure to single-crop failure from pest outbreaks or climate shocks.

In contrast, intercropping is the simultaneous cultivation of two or more crop species on the same spatial parcel for all or part of their growth cycles. It constitutes an established, ecologically regenerative agro-technology. Intercropping mimics natural polycultures by introducing temporal and spatial diversity into farming systems. The fundamental biological advantage of intercropping rests on complementary resource use, niche differentiation, and the facilitation effect. Component crop species with distinct root architectures, canopy heights, photosynthetic light-saturation points, and phenological maturation timelines exploit ambient resources (solar radiation, soil moisture, and mineral nutrients) more efficiently than when cultivated in isolated monocultures. When interspecific competition is lower than intraspecific competition, overall polyculture productivity is enhanced.

1.3 Crop Characteristics and Ecophysiological Dynamics

Legume-based intercropping provides critical ecological services. Symbiotic associations between leguminous root systems and soil-borne Rhizobium bacteria facilitate biological nitrogen fixation (BNF), converting atmospheric dinitrogen (N₂) into bioavailable ammonium compounds. This biological input reduces dependence on synthetic nitrogenous fertilizers, lowers production costs, and improves long-term soil health.

- **Cluster Bean (*Cyamopsis tetragonoloba* L.):**

Known locally as guar, cluster bean is an annual warm-season diploid (2n = 14) legume well-adapted to arid and semi-arid conditions. It features a deep taproot system capable of extracting moisture from subsoil profiles, tolerates drought stress, and fixes between 30 and 70 kg N ha⁻¹. Beyond its agronomic hardiness, its seeds yield an endosperm hydrocolloid (guar gum) widely used in food science, textiles, cosmetics, and industrial manufacturing, making it an economically valuable cash crop for semi-arid smallholders.

- **Okra (*Abelmoschus esculentus* L.):** Belonging to the Malvaceae family (2n = 130), okra is an indeterminate, fast-growing summer vegetable cultivated for its immature fibrous green pods. It exhibits a broad, erect canopy, high nutrient uptake, and a sustained indeterminate flowering habit. These characteristics make it a heavy feeder that requires continuous soil fertility throughout its reproductive cycle.

- **Chili (*Capsicum frutescens* L.):** A member of the Solanaceae family, chili is a long-duration, high-value condiment and cash crop. It has a branching, semi-spreading canopy, a shallow root system, and high susceptibility to moisture stress and shading during floral initiation and fruit development.

1.4 Research Objectives and Scope

While legume-cereal intercropping (e.g., maize-cowpea, sorghum-pigeon pea) has received extensive scholarly attention, empirical field evaluations assessing legume-vegetable polycultures under arid conditions remain limited. Critical knowledge gaps persist regarding how cluster bean interacts with heavy-feeding malvaceous crops (okra) versus sensitive solanaceous crops (chili), and whether

companion cropping stabilizes whole-farm economic returns.

To address these questions, this two-year field study investigates:

1. The influence of intercropping on the allometric, vegetative, and reproductive development of cluster bean, okra, and chili.
2. Interspecific competition and yield trade-offs between component crop species.
3. The economic feasibility, marginal rates of return (MRR), and enterprise profitability of diversified polycultures compared to sole monocultures under arid field conditions.

MATERIALS AND METHODS

2.1 Study Site

The field trials were conducted at the Vegetable Research Area, Department of Horticulture, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan, Pakistan, across two consecutive experimental years (2023 and 2024 as reported for this manuscript). The experiment evaluated cluster bean intercropping with okra and chili.

2.2 Experimental Design and Cropping Treatments

The experiment was arranged in a Randomized Complete Block Design (RCBD) using a two-factorial arrangement with three biological replications, establishing a total of 15 experimental field plots.

The experimental treatments comprised five cropping configurations:

- Treatment 1 (T₁): Sole Cluster bean (*Cyamopsis tetragonoloba* cv. BR-99)
- Treatment 2 (T₂): Sole Okra (*Abelmoschus esculentus* cv. Sabz Pari)
- Treatment 3 (T₃): Sole Chili (*Capsicum frutescens* cv. Ghotki)
- Treatment 4 (T₄): Cluster bean intercropped with Okra
- Treatment 5 (T₅): Cluster bean intercropped with Chili

2.3 Agronomic Husbandry and Planting Architecture

The experimental area was prepared and laid out according to the randomized complete block design. Raised ridges were spaced 60 cm apart. Cluster bean and okra were direct seeded, while

one-month-old chili seedlings were transplanted on the same planting date in both experimental years.

Sowing operations were synchronized across both experimental years on February 22 (2023 and 2024). Cluster bean and okra were direct seeded on ridge shoulders. For chili, healthy 30-day-old nursery seedlings raised in nursery beds were manually transplanted into field plots on the same date. In monoculture treatments, intra-row spacing was maintained at 15 cm for cluster bean, 30 cm for okra, and 30 cm for chili. In intercropping treatments (T_4 and T_5), cluster bean was sown in alternating intra-row configurations between companion plants on the ridge shoulders.

Fertilizer was applied uniformly across treatments at 60 kg P_2O_5 ha⁻¹, 40 kg K_2O ha⁻¹ and 30 kg N ha⁻¹, with nitrogen applied in three split doses.

2.4 Data Collection and Analytical Sampling

Ten representative plants per plot were tagged to evaluate allometric, vegetative, and reproductive development across the growing season:

- **Vegetative and Physiological Traits:** Plant height (cm) and stem diameter (mm, measured via digital Vernier callipers) were recorded at first commercial picking and following the final harvest. Leaf count per plant was enumerated at first picking. Leaf chlorophyll concentrations were measured on fully expanded leaves using a calibrated SPAD-502 chlorophyll meter (Minolta Camera Co., Japan). Root length (cm) was measured after carefully excavating root zones at final harvest. Plant fresh biomass (g) was recorded immediately upon whole-plant destructive harvesting; dry biomass (g) was determined after oven-drying vegetative matter at 70°C for 72 hours until constant weight was achieved.

- **Reproductive Yield Components:** For cluster bean and okra, pods per plant, pod length (cm), pod diameter (mm), fresh pod

weight (g), and dry pod weight (g) were recorded at each harvest. For chili, fruits per plant, fruit length (cm), fruit diameter (mm), fresh fruit weight (g), and oven-dried fruit weight (g) were measured across successive harvests. Total cumulative yields across all pickings were converted to metric tons per hectare (t ha⁻¹).

2.5 Economic Feasibility and Partial Budgeting

Economic performance was evaluated using the CIMMYT (1988) partial enterprise budgeting methodology. Total variable costs of production (PKR ha⁻¹) included direct agricultural inputs (seed, nursery raising, fertilizers, chemical sprays, irrigation water) and labour expenses (tillage, ridge construction, planting, weeding, and commercial picking operations) based on local farmgate market prices.

Gross revenue was calculated from the reported produce yields and market prices, and net benefit was obtained after deducting production costs. Marginal cost, marginal net benefit and marginal rate of return (MRR) were calculated following CIMMYT (1988).

To determine the relative financial attractiveness of switching between cropping systems, marginal cost (Delta C) and marginal net benefit (Delta B) were computed:

$$MRR (\%) = (\text{Marginal net benefit} / \text{Marginal cost}) \times 100.$$

2.6 Statistical Analysis

All data were subjected to two-way factorial Analysis of Variance (ANOVA) using the Statistix 8.1 software package (Analytical Software, Tallahassee, FL, USA). Cropping treatments served as the main factor and experimental years as the secondary factor. Where the F-test indicated statistical significance ($p \leq 0.05$), post-hoc mean separation was performed using Fisher's Protected Least Significant Difference (LSD) test at the 5% level of probability.

RESULTS

3.1 Allometric and Yield Responses of Cluster Bean

Table 1. Principal growth and yield responses of cluster bean under sole and intercropping treatments across 2023 and 2024.

Treatment / factor	Plant height at first picking (cm)	Leaves plant ⁻¹ at first picking	Pods plant ⁻¹	Final plant height (cm)	Pod yield (t ha ⁻¹)
T ₁ – Cluster bean alone	19.77 a	6.23 a	49.47 a	79.57 a	3.94 a
T ₂ – Cluster bean × okra	16.72 b	5.53 b	37.02 a	69.68 b	3.69 a
T ₃ – Cluster bean × chilies	16.35 b	6.32 a	45.53 a	68.72 b	3.36 a
Year 1 (2023)	13.68 b	5.09 b	33.16 b	—	3.57 a
Year 2 (2024)	21.55 a	6.97 a	54.86 a	—	3.76 a
Treatment p-value	0.0188 *	0.0453 *	0.0906 ns	0.0383 *	0.5367 ns
Year p-value	<0.001 **	<0.001 **	0.0015 **	<0.001 **	0.6587 ns

Treatment × Year p-value	0.2809 ns	0.0552 ns	0.0406 *	0.3727 ns	0.2253 ns
--------------------------	-----------	-----------	----------	-----------	-----------

* Significant at $p \leq 0.05$; ** significant at $p \leq 0.01$; ns = non-significant. Means sharing a letter within a factor are not significantly different by Fisher's LSD at 5%.

Cluster bean vegetative growth was affected by cropping system. Plant height at first picking was greater in sole stands (19.77 cm) than in cluster bean-okra (16.72 cm) or cluster bean-chili (16.35 cm) systems ($p = 0.0188$), and final plant height also differed among treatments ($p = 0.0383$). Year effects were significant for plant height at first picking, with 21.55 cm in 2024 compared with 13.68 cm in 2023 ($p < 0.001$).

- Leaf production at first picking also differed among treatments ($p = 0.0453$). Cluster bean-okra produced 5.53 leaves plant⁻¹, compared with 6.23 and 6.32 leaves plant⁻¹ in sole cluster bean and cluster bean-chili, respectively. Leaf number was higher in 2024 than 2023 (6.97 vs. 5.09 leaves plant⁻¹; $p < 0.001$).

- The main treatment effect on pods plant⁻¹ was not significant ($p = 0.0906$), but the treatment × year interaction was significant ($p = 0.0406$). In 2024, sole cluster bean produced 66.33 pods

plant⁻¹ and cluster bean-chili 56.00 pods plant⁻¹, whereas all treatment combinations in 2023 were lower (31.80–35.07 pods plant⁻¹). Thus, reproductive response varied with season rather than showing a uniform treatment effect.

-

- Other measured traits, including stem diameter, SPAD chlorophyll, root length, and biomass, did not differ significantly among cluster bean treatments ($p > 0.05$), indicating that treatment effects were concentrated mainly in plant stature and early leaf production rather than across all measured traits.

- Despite these vegetative differences, cumulative cluster bean pod yield did not differ significantly among systems ($p = 0.5367$) or between years ($p = 0.6587$). Mean yields were 3.94 t ha⁻¹ in sole stands, 3.69 t ha⁻¹ with okra, and 3.36 t ha⁻¹ with chili.

3.2 Performance and Physiological Responses of Okra (*Abelmoschus esculentus*)

Table 2. Principal growth, pod-production and yield responses of okra under sole and cluster bean intercropping across 2023 and 2024.

Treatment / factor	Plant height at first picking (cm)	Pods plant ⁻¹	Fresh pod weight plant ⁻¹ (g)	Dry pod weight plant ⁻¹ (g)	Pod yield (t ha ⁻¹)
T ₁ – Okra alone	28.31 a	12.40 a	267.29 a	35.34 a	14.85 a
T ₂ – Okra × cluster bean	32.22 a	11.17 b	244.22 a	31.48 a	13.57 a
Year 1 (2023)	28.04 a	12.10 a	—	—	—
Year 2 (2024)	32.49 a	11.47 a	—	—	—
Treatment p-value	0.1033 ns	0.0273 *	0.0734 ns	0.1978 ns	0.0730 ns
Year p-value	0.0713 ns	0.1870 ns	—	—	ns
Treatment × Year p-value	0.7177 ns	0.4217 ns	—	—	ns

* Significant at $p \leq 0.05$; ns = non-significant. Dashes indicate values not retained in the consolidated table because the corresponding year-specific estimates were not required for the principal comparison.

- Okra pod number was the only principal reproductive component showing a significant treatment effect. Sole okra produced 12.40 pods plant⁻¹ compared with 11.17 pods plant⁻¹ under cluster bean intercropping ($p = 0.0273$). Neither year nor the treatment × year interaction was significant.
- Plant height at first picking did not differ significantly between sole and intercropped okra (28.31 vs. 32.22 cm; $p = 0.1033$). The measured stem diameter, SPAD chlorophyll and leaf number likewise showed no significant treatment effects.

- Pod length, pod diameter, fresh pod weight and dry pod weight were not significantly affected by the cropping system. A treatment × year interaction was reported for fresh vegetative biomass ($p = 0.0052$), indicating that biomass response varied with both cropping treatment and year rather than following a consistent intercropping effect.

- Cumulative okra pod yield was also statistically unchanged by intercropping ($p = 0.0730$), with 14.85 t ha⁻¹ in sole stands and 13.57 t ha⁻¹ when intercropped with cluster bean.

3.3 Performance and Sensitivity Responses of Chili (*Capsicum frutescens*)

Table 3. Principal growth, fruit-production and yield responses of chili under sole and cluster bean intercropping across 2023 and 2024.

Treatment / factor	Plant height at first picking (cm)	Fruits plant ⁻¹	Fresh fruit weight plant ⁻¹ (g)	Dry fruit weight plant ⁻¹ (g)	Fruit yield (t ha ⁻¹)
T ₁ – Chilies alone	25.45 a	44.65 a	62.46 a	10.27 a	3.49 a
T ₂ – Chilies × cluster bean	25.40 a	36.22 b	47.56 b	7.98 a	2.65 b
Year 1 (2023)	—	34.68 b	47.96 b	—	2.67 b
Year 2 (2024)	—	46.18 a	62.05 a	—	3.46 a
Treatment p-value	0.9866 ns	0.0076 **	0.0133 *	0.0562 ns	0.0151 *
Year p-value	0.4474 ns	0.0017 **	0.0168 *	0.4349 ns	0.0188 *
Treatment × Year p-value	—	ns	ns	ns	0.4653 ns

* Significant at $p \leq 0.05$; ** significant at $p \leq 0.01$; ns = non-significant. Dashes indicate values not retained in the consolidated table where year-specific estimates were not required for the principal comparison.

* Significant at $p \leq 0.05$; ** Highly significant at $p \leq 0.01$; ns = non-significant.

- Chili showed a clearer treatment response than okra. Fruit number declined from 44.65 fruits plant⁻¹ in sole chili to 36.22 fruits plant⁻¹ under intercropping ($p = 0.0076$), while fresh fruit weight declined from 62.46 to 47.56 g plant⁻¹ ($p = 0.0133$). Both variables were also higher in 2024 than 2023.
- Cumulative chili fruit yield was significantly lower under intercropping ($p = 0.0151$), declining from 3.49 t ha⁻¹ in sole chili to 2.65 t

- ha⁻¹ with cluster bean, a reduction of approximately 24%. Year also affected yield ($p = 0.0188$), while the treatment $\times$ year interaction was not significant.
- In contrast, plant height and the other measured vegetative traits of chili did not show significant treatment differences ($p > 0.05$). The stronger treatment effects were therefore expressed primarily in reproductive traits and total fruit yield.

3.4 Economic Analysis

Table 4. Partial-budget economic analysis of cluster bean sole and intercropping systems.

Cropping system	Total cost (PKR ha ⁻¹)	Net benefit (PKR ha ⁻¹)	Marginal cost (PKR ha ⁻¹)	Marginal net benefit (PKR ha ⁻¹)	MRR (%)
Cluster bean alone	60,558	98,500	—	—	—
Cluster bean $\times$ okra	85,258	573,450	24,700	474,950	1,922.87
Cluster bean $\times$ chilies	82,788	204,500	22,230	106,000	476.83

All values are based on the reported enterprise-budget calculations. The original thesis column labelled “Benefit cost ratio” contains non-conventional entries and is not reproduced as a BCR in this manuscript.

DISCUSSION

4.1 Differential effects of intercropping on cluster bean

The results indicate that cluster bean responded to intercropping mainly through changes in vegetative development rather than a statistically detectable change in cumulative pod yield. Plant height at first picking and final plant height were lower in both intercrop combinations than in sole cluster bean, and leaf number at first picking was particularly reduced when cluster bean was paired with okra. These responses are consistent with the general expectation that plants sharing soil volume and canopy space may experience competition for light, water and nutrients. Earlier intercropping studies have likewise reported reductions in growth or yield of legumes when paired with competitive companion crops (Hussain, 2003; Alhaji, 2008).

Because the present experiment did not directly measure light interception, soil moisture depletion, root competition or nutrient uptake, these processes should be regarded as plausible explanations rather than demonstrated mechanisms.

The absence of a significant treatment effect on cumulative cluster bean pod yield is important. Although vegetative growth was reduced, mean pod yield remained statistically similar across sole cluster bean (3.94 t ha⁻¹), cluster bean-okra (3.69 t ha⁻¹), and cluster bean-chili (3.36 t ha⁻¹). This indicates that the measured reductions in stature did not necessarily translate into proportional yield losses under the conditions of the experiment. The significant treatment $\times$ year interaction for pod number further shows that reproductive responses were season dependent. Such variation cautions against interpreting a single growth trait as a direct proxy for final yield performance.

4.2 Contrasting responses of okra and chili

The companion crops differed clearly in their response to cluster bean. Okra showed a modest

reduction in pods per plant, from 12.40 in sole cropping to 11.17 under intercropping, but this difference did not translate into a statistically significant reduction in cumulative pod yield (14.85 versus 13.57 t ha⁻¹; $p = 0.0730$). Other measured traits, including plant height, pod weight and the reported physiological variables, were also largely unchanged. Taken together, these results indicate that okra maintained relatively stable yield performance in the tested cluster bean-okra configuration.

Chili was more sensitive. Intercropping reduced fruits per plant from 44.65 to 36.22, fresh fruit weight from 62.46 to 47.56 g plant⁻¹, and cumulative fruit yield from 3.49 to 2.65 t ha⁻¹. The significant treatment effects were concentrated largely in reproductive attributes, while plant height and other vegetative measurements were not significantly different. The pattern is compatible with greater competition during flowering and fruit development, although the experiment did not measure canopy light interception, photosynthetic rate, flower abortion or soil-water status and therefore cannot establish the precise mechanism. Previous studies of vegetable intercropping have also reported crop-specific responses to companion species, emphasizing that compatibility depends on the crop combination and spatial arrangement (Sing, 1993; Ofosu-Anim & Limbani, 2007).

4.3 Seasonal effects and interpretation of variability

Year effects were evident for several traits, particularly cluster bean early growth and pod number and chili fruit number, fresh fruit weight and total yield. For chili, fruit yield increased from 2.67 t ha⁻¹ in 2023 to 3.46 t ha⁻¹ in 2024, while the treatment × year interaction was not significant. For cluster bean, plant height and leaf number were also greater in 2024, and the significant treatment × year interaction for pod number indicates that treatment responses were not identical between years. These patterns demonstrate seasonal variability in crop performance. Because the study did not quantify the specific environmental variables responsible, the year effect should be interpreted as evidence of

seasonal variation rather than attributed to a particular climatic driver.

4.4 Economic implications of the cropping systems

The economic analysis provides a different perspective from the individual-crop yield results. Intercropping increased total production costs relative to sole cluster bean, from PKR 60,558 ha⁻¹ to PKR 85,258 ha⁻¹ for cluster bean-okra and PKR 82,788 ha⁻¹ for cluster bean-chili. However, the additional costs were accompanied by higher net benefits. The cluster bean-okra system generated a net benefit of PKR 573,450 ha⁻¹, compared with PKR 204,500 ha⁻¹ for cluster bean-chili and PKR 98,500 ha⁻¹ for sole cluster bean. The corresponding marginal rates of return were 1,922.87% and 476.83% for cluster bean-okra and cluster bean-chili, respectively, relative to the sole-cluster-bean baseline.

These economic results should be interpreted within the assumptions of the partial-budget analysis. The higher return from cluster bean-okra reflects the combined value of the two harvested crops and the reported production costs; it does not mean that every component crop individually yielded more under intercropping. In particular, chili yield declined significantly under intercropping, whereas the okra yield difference was not statistically significant. The reported marginal returns are specific to the production costs and produce prices used in the study and should not be generalized across locations or market periods without updated economic data.

4.5 Agronomic interpretation and research implications

Overall, the experiment demonstrates crop-specific compatibility rather than a universal benefit of cluster bean intercropping. Cluster bean retained statistically similar pod yield across systems, okra maintained cumulative yield despite a lower pod count per plant, and chili experienced measurable reproductive and yield penalties. The economic analysis nevertheless showed positive marginal returns for both intercrop configurations examined. Future trials should focus on spatial arrangement, relative plant density and planting-time differences,

particularly for cluster bean–chili systems, while retaining cluster bean–okra as a candidate configuration for further multi-season evaluation. Additional measurements of light interception, soil moisture, nutrient uptake and standard intercropping indices such as land equivalent ratio would help determine the mechanisms and biological efficiency of these combinations more rigorously.

CONCLUSIONS AND RESEARCH IMPLICATIONS

This two-year field study showed that the effects of cluster bean intercropping were crop specific. Cluster bean experienced reductions in several vegetative traits under intercropping, but cumulative pod yield was not significantly different among cropping systems. Okra showed a significant reduction in pods per plant but no significant reduction in cumulative pod yield. Chili, in contrast, showed significant reductions in fruit number, fresh fruit weight and total fruit yield under intercropping.

The economic analysis showed positive marginal returns for both intercropping configurations relative to sole cluster bean, with the reported net benefit and MRR being higher for cluster bean–okra than for cluster bean–chili. These economic results reflect the combined output of the component crops, and the costs and prices used in the analysis and should therefore be interpreted as system-specific rather than universally transferable.

The findings support further evaluation of cluster bean–okra as a potentially compatible vegetable intercrop under comparable conditions. For cluster bean–chili, future experiments should test wider spacing, altered row arrangements and/or staggered planting dates to reduce possible competition. Multi-location and multi-season trials, together with direct measurements of resource capture and standard intercropping-efficiency indices, are needed before broader agronomic recommendations are made.

REFERENCES

- Abbo, S., Yadun, S. L., & Gopher, A. (2010). Agricultural origins: Centers and noncenters; A near eastern reappraisal. *Critical Reviews in Plant Sciences*, 29(5), 317–328.
- Abd-El-Kader, A. A., Shaaban, S. M., & Abd-El-Fattah, M. S. (2010). Effect of irrigation levels and organic compost on okra plants (*Abelmoschus esculentus* L.) grown in sandy calcareous soil. *Agriculture and Biology Journal of North America*, 1(3), 225–231.
- Abid, M., Malik, S. A., Bilal, K., & Wajid, R. A. (2002). Response of okra (*Abelmoschus esculentus* L.) to EC and SAR of irrigation water. *International Journal of Agriculture and Biology*, 4(3), 311–314.
- Adeniji, O. T., & Peter, J. M. (2005). Stepwise regression analysis of pod and seed yield characters in segregating F2 population of West African okra (*Abelmoschus caillei*). *Proceedings of the 30th Conference, Genetics Society of Nigeria*, 250–258.
- Adeniyi, O. R. (2011). Economic aspects of intercropping systems of vegetables (okra, tomato and cowpea). *African Journal of Plant Sciences*, 5(11), 648–655.
- Adetuyi, F. O., Osagie, A. U., & Adekunle, A. T. (2008). Effect of postharvest storage techniques on the nutritional properties of Benin indigenous okra *Abelmoschus esculentus* (L.) Moench. *Pakistan Journal of Nutrition*, 7(5), 652–657.
- Adu-Gyamfi, J. J., Myaka, F. A., Sakala, W. D., Odgaard, R., Vesterager, J. M., & Jensen, H. H. (2007). Biological nitrogen fixation and nitrogen and phosphorus budgets in farmer-managed intercrops of maize-pigeonpea in semiarid southern and eastern Africa. *Plant and Soil*, 295(1–2), 127–136.
- Aladele, S. E., Ariyo, O. J., & Lapena, R. (2008). Genetic relationship among West African okra (*Abelmoschus caillei*) and Asian genotypes (*Abelmoschus esculentus*) using RAPD. *African Journal of Biotechnology*, 7(10), 1426–1431.

- Alhaji, I. H. (2008). Yield performance of some cowpea varieties under sole cropping and intercropping with maize at Bauchi, Nigeria. *African Research Review*, 2(3), 278-291.
- Altieri, M. A. (1999). The ecological role of biodiversity in agroecosystems. *Agriculture, Ecosystems & Environment*, 74(1-3), 19-31.
- Altieri, M. A., Letourneau, D. K., & Davis, J. R. (1983). Developing sustainable agroecosystems. *BioScience*, 33(1), 45-49.
- Anonymous. (2011). *Agricultural Statistics of Pakistan 2010-2011*. Ministry of National Food Security and Research, Economic Wing, Government of Pakistan, Islamabad.
- Anonymous. (2014). *FAO Statistical Database (FAOSTAT)*. Food and Agriculture Organization of the United Nations, Rome, Italy.
- Arapitsas, P. (2008). Identification and quantification of polyphenolic compounds from okra seeds and skins. *Food Chemistry*, 110(4), 1041-1045.
- Baloch, A. F. (1994). Vegetable crops. In M. N. Malik (Ed.), *Horticulture* (pp. 510-530). National Book Foundation, Islamabad, Pakistan.
- Benjawan, C., Chutichudet, P., & Kaewsit, S. (2007). Effect of green manures on growth, yield and quality of green okra (*Abelmoschus esculentus* L.) Harlium cultivar. *Pakistan Journal of Biological Sciences*, 10(7), 1028-1035.
- Berke, T. G. (2000). Hybrid seed production in Capsicum. In A. S. Basra (Ed.), *Hybrid Seed Production in Vegetables: Rationale and Methods in Selected Species* (pp. 49-67). Food Products Press, New York.
- Bhatt, M., & Rao, S. (2005). Influence of pod load on response of okra to water stress. *Indian Journal of Plant Physiology*, 10(1), 54-59.
- Bhatti, M. B., & Sial, M. B. (1971). Guar: Its utility in food and non-food industries. *Pakistan Journal of Scientific and Industrial Research*, 14, 12-17.
- Caetano, L. C. S., Ferreira, J. M., & Araújo, M. L. (1999). Productivity of carrot and lettuce in an intercropping system. *Horticultura Brasileira*, 17(2), 143-146.
- Choudhary, B. S., & Singh, V. P. (1986). Extent of outcrossing in guar (*Cyamopsis tetragonoloba* (L.) Taub.). *Genetica Agraria*, 40, 59-62.
- CIMMYT. (1988). *From Agronomic Data to Farmer Recommendations: An Economic Training Manual*. International Maize and Wheat Improvement Center, Mexico, D.F.
- Clawson, D. L. (1985). Harvest security and intraspecific diversity in traditional tropical agriculture. *Economic Botany*, 39(1), 56-67.
- Doijode, S. D. (2001). *Seed Storage of Horticultural Crops*. Food Products Press, Haworth Press, New York.
- Dunn, F., Williams, J., Verberg, K., & Keating, B. A. (1999). Can agricultural catchment emulate natural ecosystems in recharge control in southeastern Australia? *Agroforestry Systems*, 45(1-3), 343-364.
- Egbe, O. M., & Bar, A. M. N. (2010). Pigeonpea/sorghum intercropping in southern guinea savanna: Effects of planting density of pigeonpea. *Nature and Science*, 8(11), 156-167.
- Einhellig, F. A., & Leather, G. R. (1988). Potentials for exploiting allelopathy to enhance crop production. *Journal of Chemical Ecology*, 14(10), 1829-1844.
- El-Swaify, S. A., Lo, A., Joy, R., Shinshiro, L., & Yost, R. S. (1988). Achieving conservation effectiveness in the tropics using legume-intercrops. *Soil Technology*, 1(1), 1-12.
- Emuh, F. N., Ofuoku, A. E., & Oyefia, E. (2006). Effect of intercropping okra (*Abelmoschus esculentus*) with pumpkin (*Cucurbita maxima*) on some growth parameters and economic yield of maize (*Zea mays*) and maximization of land use in a fadama soil. *Research Journal of Biological Sciences*, 1(1-4), 50-54.

- Faroda, A. S., & Singh, R. (2003). Crop production strategies for arid legumes with remunerative efforts and cost. In A. Henry, D. Kumar, & N. B. Singh (Eds.), *Advances in Arid Legumes Research* (pp. 161-171). Scientific Publishers, Jodhpur, India.
- Fujita, K., Ofosu-Budu, K. G., & Ogata, S. (1992). Biological nitrogen fixation in mixed legume-cereal cropping systems. *Plant and Soil*, 141(1-2), 155-175.
- Fukai, S., & Trenbath, B. R. (1993). Processes determining intercrop productivity and yields of component crops. *Field Crops Research*, 34(3-4), 247-271.
- Fustec, J., Lesuffleur, F., Mahieu, S., & Cliquet, J. B. (2010). Nitrogen rhizodeposition of legumes: A review. *Agronomy for Sustainable Development*, 30(1), 57-66.
- Geno, L., & Geno, B. (2001). *Polyculture Production: Principles, Benefits and Risks of Multiple Cropping Systems*. Rural Industries Research and Development Corporation (RIRDC), Publication No. 01/034, Canberra, Australia.
- Ghanbari, A., Dahmardeh, M., Siahshar, B. A., & Ramroudi, M. (2010). Effect of maize (*Zea mays* L.) - cowpea (*Vigna unguiculata* L.) intercropping on light distribution, soil temperature and soil moisture in arid environment. *International Journal of Food, Agriculture and Environment*, 8(1), 102-108.
- Ghorab, A. H. E., Javed, Q., Anjum, F. M., Hamed, S. F., & Shaaban, H. A. (2013). Pakistani bell pepper (*Capsicum annuum* L.): Chemical compositions and its antioxidant activity. *International Journal of Food Properties*, 16(1), 18-32.
- Ghosh, P. K., Mohanty, M., Bandyopadhyay, K. K., Painuli, D. K., & Misra, A. K. (2006). Growth, competition, yield advantage and economics in soybean/pigeonpea intercropping system in semi-arid tropics of India. *Field Crops Research*, 96(1), 80-89.
- Gómez-Rodríguez, O., Zavaleta-Mejía, E., González-Hernández, V. A., Livera-Muñoz, M., & Cárdenas-Soriano, E. (2003). Allelopathic effect of marigold intercropped with tomato on *Alternaria solani* conidia germination. *Revista Mexicana de Fitopatología*, 21(3), 421-428.
- Guldan, S. J., Martin, C. A., & Falk, C. L. (1998). Interseeding snap pea into stands of chile pepper reduced yield of pea more than that of chile. *HortScience*, 33(4), 660-662.
- Horwith, B. (1985). A role for intercropping in modern agriculture. *BioScience*, 35(5), 286-291.
- Howard, L. R., Talcott, S. T., Brenes, C. H., & Villalon, B. (2000). Changes in phytochemical and antioxidant activity of selected pepper cultivars (*Capsicum* species) as influenced by maturity. *Journal of Agricultural and Food Chemistry*, 48(5), 1713-1720.
- Hussain, S. A. (2003). *Growth, Yield and Economic Impacts of Intercropping in Vegetables* (Doctoral dissertation). NWFP Agricultural University, Peshawar, Pakistan.
- Hymowitz, T., & Upadhyya, M. D. (1963). The chromosome number of *Cyamopsis serrata* Schinz. *Current Science*, 32, 427-428.
- Jackson, L. E., Pascual, U., & Hodgkin, T. (2007). Utilizing and conserving agrobiodiversity in agricultural landscapes. *Agriculture, Ecosystems & Environment*, 121(3), 196-210.
- Kandoria, J. L., Singh, G., & Singh, L. (1999). Effect of intercropping cauliflower with tomato on the incidence of diamondback moth. *Insect Environment*, 5(3), 137-138.
- Kashif, S. R., Yaseen, M., Arshad, M., & Ayub, M. (2008). Response of okra (*Abelmoschus esculentus* L.) to soil given encapsulated calcium carbide. *Pakistan Journal of Botany*, 40(1), 175-181.
- Keating, B. A., & Carberry, P. S. (1993). Resource capture and use in intercropping: Solar radiation. *Field Crops Research*, 34(3-4), 273-301.

- Khasmakhi, S. A., Sedaghatthoor, S., Mohammadi, J., & Olfati, J. A. (2009). Effect of plant density on bell pepper yield and quality. *International Journal of Vegetable Science*, 15(3), 264-271.
- Khatiwada, P. P. (2000). Intercropping cauliflower under maize: An approach to extend the cauliflower production season for subsistence farmers. *Kasetsart Journal of Natural Sciences*, 34, 72-80.
- Kumar, D., & Singh, N. B. (2002). Guar: An introduction. In D. Kumar & N. B. Singh (Eds.), *Guar in India* (pp. 1-10). Scientific Publishers, Jodhpur, India.
- Kumar, S., & Rai, M. (2005). Chili in India. *Chili Pepper Institute Newsletter*, 22, 1-3.
- Kumar, V., Yadav, B. D., & Yadav, J. S. (2003). Spatial-temporal management for grain production of cluster bean genotype HG 563 in light textured soil of Southern Haryana. *Proceedings of the National Symposium on Sustainability of Forages*, CCSHAU, Hisar, India, 77.
- Lamberts, M. (1980). Intercropping with Potatoes (Master's thesis). Cornell University, Ithaca, NY.
- Lamont, W. J. (1999). Okra: A versatile vegetable crop. *HortTechnology*, 9(2), 179-184.
- Lanini, W. T., Orloff, S. B., Vargas, R. N., & Orr, J. P. (1992). Using oats as companion crop in establishing alfalfa. *California Agriculture*, 46(4), 25-27.
- Leihner, D. E., Ruppenthal, M., Hilger, T. H., & Castillo, J. A. F. (1996). Soil conservation effectiveness and crop productivity of forage legume intercropping, contour grass barriers and contour ridging in cassava on Andean hillsides. *Experimental Agriculture*, 32(3), 327-338.
- Lengsfeld, C., Titgemeyer, F., Faller, G., & Hensel, A. (2004). Glycosylated compounds from okra inhibit adhesion of *Helicobacter pylori* to human gastric mucosa. *Journal of Agricultural and Food Chemistry*, 52(6), 1495-1503.
- Lichtfouse, E., Navarrete, M., Debaeke, P., Souchère, V., Alberola, C., & Ménéssieu, J. (2009). Agronomy for sustainable agriculture: A review. *Agronomy for Sustainable Development*, 29(1), 1-6.
- Liebman, M., & Dyck, E. (1993). Crop rotation and intercropping strategies for weed management. *Ecological Applications*, 3(1), 92-122.
- Lindemann, W. C., & Glover, C. R. (2003). Nitrogen Fixation by Legumes (Guide A-129). Cooperative Extension Service, New Mexico State University, Las Cruces, NM.
- Lithourgidis, A. S., Dordas, C. A., Damalas, C. A., & Vlachostergios, D. N. (2011). Annual intercrops: An alternative pathway for sustainable agriculture. *Australian Journal of Crop Science*, 5(4), 396-410.
- Malézieux, E., Crozat, Y., Dupraz, C., Laurans, M., Makowski, D., Ozier-Lafontaine, H., Rapidel, B., de Tourdonnet, S., & Valantin-Morison, M. (2009). Mixing plant species in cropping systems: Concepts, tools and models. A review. *Agronomy for Sustainable Development*, 29(1), 43-62.
- Mallanagouda, B., Sulikeri, G. S., Murthy, B. G., & Prathibha, N. C. (1995). Performance of chilli (*Capsicum annum*) under different intercropping systems and fertility levels. *Indian Journal of Agronomy*, 40(2), 277-279.
- Martin, F. W., Rhodes, A. M., Ortiz, M., & Diaz, F. (1981). Variation in okra. *Euphytica*, 30(3), 697-705.
- McGregor, S. E. (1976). Insect Pollination of Cultivated Crop Plants (Agriculture Handbook No. 496). Agricultural Research Service, USDA, Washington, D.C.
- Michel, V. V., Wang, J. F., Midmore, D. J., & Hartman, G. L. (1997). Effects of intercropping and soil amendment with urea and calcium oxide on the incidence of bacterial wilt of tomato and survival of soil-borne *Pseudomonas solanacearum* in Taiwan. *Plant Pathology*, 46(4), 600-610.
- Midmore, D. J. (1993). Agronomic modification of resource use and intercrop productivity. *Field Crops Research*, 34(3-4), 357-380.

- Mihailović, V., Erić, P., & Mikić, A. (2004). Growing peas and vetches for forage in Serbia and Montenegro. *Grassland Science in Europe*, 9, 457-459.
- Moekchantuk, T., & Kumar, P. (2004). Export Okra Production in Thailand. Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific, Bangkok, Thailand.
- Nadeem, M., Muhammad, F., Anjum, S., Khan, A. M. R., Saeed, M., & Riaz, A. (2011). Antioxidant potential of bell pepper (*Capsicum annuum* L.). *Pakistan Journal of Science*, 63(1), 45-51.
- Newman, E. I. (1988). Mycorrhizal links between plants: Their functioning and ecological significance. *Advances in Ecological Research*, 18, 243-270.
- Nielsen, H. H., Peoples, M. B., & Jensen, E. S. (2011). Faba bean in cropping systems. *Grain Legumes*, 56, 32-33.
- Nihoul, F. T., Struik, P. C., Vredenberg, W. J., Renkema, J. A., & Parlevliet, H. (1994). Implications of intercropping (sweet pepper-tomato) for the biological control of pests in glasshouses. In *Plant Production on the Threshold of a New Century* (pp. 205-211). Wageningen Agricultural University, Wageningen, The Netherlands.
- Njoroge, J. M., & Kimemia, J. K. (1995). Economic benefits of intercropping young Arabica and Robusta coffee with food crops in Kenya. *Outlook on Agriculture*, 24(1), 27-34.
- Oforu-Anim, J., & Limbani, N. V. (2007). Effect of intercropping on the growth and yield of cucumber (*Cucumis sativus* L.) and okra (*Abelmoschus esculentus* L.). *International Journal of Agriculture and Biology*, 9(4), 594-597.
- Onduru, D. D., & Du Preez, C. C. (2007). Ecological and agro-economic study of small farms in sub-Saharan Africa. *Agronomy for Sustainable Development*, 27(3), 197-208.
- Papanastasis, V. P., Arianoutsou, M., & Lyrantzis, G. (2004). Management of biotic resources in ancient Greece. *Proceedings of the 10th Mediterranean Ecosystems (MEDECOS) Conference*, Rhodes, Greece, 1-11.
- Patil, S., Kotikal, Y. K., Revanappa, S. T., & Patil, D. R. (1997). Effect of intercropping on the infestation of tomato fruit borer (*Helicoverpa armigera*). *Advances in Agricultural Research in India*, 8, 141-146.
- Payakhapaab, S., Boonyakiat, D., & Nikornpun, M. (2012). Genetic evaluation and physico-chemical properties of chillies (*Capsicum annuum* L.). *Journal of Agricultural Science*, 4(12), 253-260.
- Pérez-Gálvez, A., Martin, H. D., Sies, H., & Stahl, W. (2003). Incorporation of carotenoids from paprika oleoresin into human chylomicrons. *British Journal of Nutrition*, 89(6), 787-793.
- Pino, M., Domini, M. E., Terry, E., Bertoli, M., & Espinosa, R. (1994). Maize as a protective crop for tomato under conditions of environmental stress. *Cultivos Tropicales*, 15(2), 60-63.
- Plucknett, D. L., & Smith, N. J. H. (1986). Historical perspectives on multiple cropping. In C. A. Francis (Ed.), *Multiple Cropping Systems* (pp. 20-39). Macmillan Publishing Company, New York.
- Prasad, K. S., & Mohan, N. K. (1995). Intercropping of different vegetables and field species with brinjal. *Indian Journal of Agricultural Sciences*, 65(1), 39-41.
- Qasim, S. A., Anjum, M. A., Hussain, S., & Ahmad, S. (2013). Effect of pea intercropping on biological efficiencies and economics of some non-legume winter vegetables. *Pakistan Journal of Agricultural Sciences*, 50(3), 399-406.
- Rahman, M. M., Amano, T., & Shiraiwa, T. (2009). Nitrogen use efficiency and recovery from N fertilizer under rice-based cropping systems. *Australian Journal of Crop Science*, 3(6), 336-351.

- Rai, P. S., & Dharmatti, P. R. (2013). Genetic divergence studies in cluster bean (*Cyamopsis tetragonoloba*). *Global Journal of Science Frontier Research*, 13(1), 1-5.
- Raju, K. V., & Luckose, C. K. (1991). Trends in area, production and exports of chillies from India. *Agricultural Situation in India*, 45, 767-772.
- Rao, A. V. (1995). Biological nitrogen fixation in arid ecosystem. In R. K. Behl (Ed.), *Plant-Microbe Interactions in Sustainable Agriculture* (pp. 89-101). Bio-Science Publishers, Hisar, India.
- Rao, M. R. (1986). Cereals in multiple cropping systems. In C. A. Francis (Ed.), *Multiple Cropping Systems* (pp. 96-132). Macmillan Publishing Company, New York.
- Rubatzky, V. E., & Yamaguchi, M. (1997). *World Vegetables: Principles, Production, and Nutritive Values* (2nd ed.). Chapman & Hall, New York.
- Sabahelkheir, M. K., Abdalla, A. H., & Nourai, S. H. (2012). Quality assessment of guar gum (endosperm) of guar (*Cyamopsis tetragonoloba*). *International Research Journal of Biological Sciences*, 1(1), 67-70.
- Šarūnaitė, L., Deveikytė, I., Semaškienė, R., & Kadžiulienė, Z. (2009). The influence of grain legumes on spring wheat yield formation and phytosanitary state. *Agronomy Research*, 7(1), 465-470.
- Scherr, S. J., & McNeely, J. A. (2008). Biodiversity conservation and agricultural sustainability: Towards a new paradigm of 'ecoagriculture' landscapes. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1491), 477-494.
- Schippers, R. R. (2000). *African Indigenous Vegetables: An Overview of the Cultivated Species*. Natural Resources Institute, Chatham, UK.
- Shahid, M. A., Pervez, M. A., Balal, R. M., & Ahmad, R. (2011). Salt stress effects on some morphological and physiological characteristics of okra (*Abelmoschus esculentus* L.). *Soil & Environment*, 30(1), 66-73.
- Shinoj, P., & Mathur, V. C. (2006). Analysis of demand for major spices in India. *Agricultural Economics Research Review*, 19(2), 367-376.
- Sing, R. V. (1993). Production potential and economics of vegetables intercropped with rainfed okra. *Indian Journal of Horticulture*, 50(1), 73-76.
- Sivaraman, K., & Palaniappan, S. P. (1994). Turmeric-maize and onion intercropping systems on yield and land use efficiency. *Journal of Spices and Aromatic Crops*, 3(1), 19-27.
- Smith, M. E., & Francis, C. A. (1986). Breeding for multiple cropping systems. In C. A. Francis (Ed.), *Multiple Cropping Systems* (pp. 219-249). Macmillan Publishing Company, New York.
- Tefera, T., & Tana, T. (2002). Agronomic performance of sorghum and groundnut cultivars in sole and intercrop cultivation under semi-arid conditions. *Journal of Agronomy and Crop Science*, 188(4), 212-218.
- Thrupp, L. A. (2002). Linking agricultural biodiversity and food security: The valuable role of agrobiodiversity for sustainable agriculture. *International Affairs*, 76(2), 283-297.
- Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature*, 418(6898), 671-677.
- Tofinga, M. P., Paolini, R., & Snaydon, R. W. (1993). A study of root and shoot interactions between cereals and peas in mixtures. *The Journal of Agricultural Science*, 120(1), 13-24.
- Tom, C. T., & Asiegbo, J. E. (2002). Evaluation of short duration ICRISAT pigeonpea cultivars in mixtures with FARZ-7 maize under the derived savannah conditions of Nigeria. *International Journal of Agriculture and Rural Development*, 3, 138-143.
- Tsubo, M., Walker, S., & Mukhala, E. (2001). Comparisons of radiation use efficiency of mono-/inter-cropping systems with different row orientations. *Field Crops Research*, 71(1), 17-29.

- Van Etten, C. H., Miller, R. W., Wolff, I. A., & Jones, Q. (1961). Amino acid composition of twenty-seven selected seed meals. *Journal of Agricultural and Food Chemistry*, 9(1), 79-82.
- Vandermeer, J. H. (1989). *The Ecology of Intercropping*. Cambridge University Press, Cambridge, UK.
- Waddington, S. R., Mekuria, M., Siziba, S., & Karigwindi, J. (2007). Long-term yield sustainability and financial returns from grain legume-maize intercrops on a sandy soil in subhumid north-central Zimbabwe. *Experimental Agriculture*, 43(4), 489-503.
- Walsh, B. M., & Hoot, S. B. (2001). Phylogenetic relationships of Capsicum (Solanaceae) using DNA sequences from two noncoding regions: The chloroplast atpB-rbcL spacer region and nuclear waxy introns. *International Journal of Plant Sciences*, 162(6), 1409-1418.
- Whistler, R. L., & Hymowitz, T. (1979). *Guar: Agronomy, Production, Industrial Use, and Nutrition*. Purdue University Press, West Lafayette, IN.
- Whitehead, W. F., & Singh, B. P. (2000). Yield, time of maximum CO₂ exchange rate, and leaf-area index of 'Clemson Spineless' okra are affected by within-row spacing. *HortScience*, 35(5), 849-852.
- Wien, H. C., & Smithson, J. B. (1981). The evaluation of genotypes for intercropping. *Proceedings of the International Workshop on Intercropping*, ICRISAT, Hyderabad, India, 105-116.
- Willey, R. W. (1979). Intercropping: Its importance and research needs. Part 1. Competition and yield advantages. *Field Crop Abstracts*, 32, 1-10.
- Willey, R. W., & Rao, M. R. (1980). A competitive ratio for quantifying competition between intercrops. *Experimental Agriculture*, 16(2), 117-125.
- Yildirim, E., & Güvenç, I. (2005). Intercropping based on cauliflower: More productive, profitable and highly sustainable. *European Journal of Agronomy*, 22(1), 11-18.
- Yu, J. Q. (1999). Allelopathic suppression of *Pseudomonas solanacearum* infection of tomato in a tomato-Chinese chive intercropping system. *Journal of Chemical Ecology*, 25(11), 2409-2417.
- Zougmore, R., Kambou, F. N., Ouattara, K., & Guillobez, S. (2000). Sorghum-cowpea intercropping: An effective technique against runoff and soil erosion in the Sahel (Saria, Burkina Faso). *Arid Land Research and Management*, 14(4), 329-342.