Original Article

Growth analysis of intercropped Wheat, Chickpea and wild Mustard based on physical and thermal time scales

Aryan S. A. Dizayee*, Sami M. Maaroof

Department of Field Crops, College of Agriculture, Salahaddin University-Erbil, Kurdistan Region, Iraq.

Correspondence: Aryan S. A. Dizayee, Department of Field Crops, College of Agriculture, Salahaddin University-Erbil, Kurdistan Region, Iraq.

Email: aryan.ahmed @ su.edu.krd.

ABSTRACT

A field experiment was carried out on intercropping of wheat (*Triticum aestivum* L.), chickpea (*Cicer arietinum* L.), and wild mustard (*Sinapis arvensis* L.). Treatments from combinations of either single, double or triple (row: crop) proportions were arranged in the standard replacement series at Grdarasha experimental farm (36.2° N, 44.1° E, and elevation of 476 m) during the winter season of 2016-17. The aim of the present study was to evaluate some of the growth aspects of wheat (A) and chickpea (B) in the presence of wild mustard (C), which invades common weed in these areas. Wheat crop possessed the highest values of biological dry biomass (BIO), crop growth rate (CGR), and relative growth rate (RGR) whether measured on physical or thermal scales at the first three growth intervals, while mustard weed showed superiority in the same growth aspects at the last two growth stages of flowering and maturity. This could be the reason for the lower performance of the cultivated crops in the presence of the wild mustard.

Keywords: Intercropping, Growth indices, Row: crop ratio

Introduction

Wheat (*Triticum aestivum* L.) is the most important food crop in Kurdistan region which lays under semi-guaranteed rainfall. Chickpea (*Cicer arietinum* L.) is a staple crop pulse and is used throughout the world, particularly Asian countries. [1] Wheat and chickpea comprise respectively 50% and 20% of the total food production in the region. They consist of the first cereal and third pulse of the most edible crops that play a vital role in universal agricultural economy, [2] with average productivity of 2.109 t ha^{-1} and 0.9 t ha^{-1} respectively. [3] Wheat production reduced in Iraq by minus 14% during the period from 2013 to 2018. [4] Wild mustard (*Sinapis arvensis* L.) was recorded as early as 1748 in New York State (c.f. Mulligan and Bailey, 1975).[5] Mustard plants have the ability of dense invading due to the production of 2000 to 3500 viable soil embedded up to sixty years. [6]

The natural resources such as water, soil, air, temperature, and other environmental resources caused by humans, lead to differences in production (c.f. Rad *et al.*, 2018).[7] So, the studying of growth aspects of the interplant species supports the ecological management of the field crops. Growth analysis is one of the basic techniques used to determine growth aspects and represents the first step in primary production analysis, which is the most practical way to evaluate net photosynthetic production. [8] Hoffmann and Poorter (2002) mentioned that the most important growth aspect is the relative growth rate (RGR).[9] Crop dry matter production can be analyzed in terms of crop growth rate (CGR) and RGR, the two important growth indices used in growth analysis. [10] Growth indices based on the temperature, such as growing degree days (GDD), rather than elapsed time, allow for direct comparison among cultivars with different phonological and development techniques, and may otherwise be confused by temperature variations. [11] Davidson and Campbell (1984) found high mean values of initial RGR increasing up to near anthesis, then

Access this article online	
Website: www.japer.in	**E-ISSN:** 2249-3379

How to cite this article: Aryan S. A. Dizayee, Sami M. Maaroof. Growth analysis of intercropped Wheat, Chickpea and wild Mustard based on physical and thermal time scales. J Adv Pharm Edu Res 2019;9(2):108-114.
Source of Support: Nil, Conflict of Interest: None declared.

decreasing with time up to zero, then negative values, during the first maturity stage. [12] Differences in RGR and CGR are rarely mentioned in growth studies. This fact was reported also by [13] who recorded differences in RGR and CGR affecting yield and yield improvement.

Many researchers regarded that plant biological processes are differed due to/or associated with masked role of temperature in physiological processes rather than time, and this principle was recorded by Remur since 1735.[11] Consequently, wheat and chickpea productions vary in the area including the current research, following the fluctuations in both the amount and distribution of rainfall. The scarcity of rainfall in the small parcels pushes the farmers toward intercropping choice. Intercropping is an old practice, placed on the fringes of modern agriculture dominated by large tracts of mono-cultural crops, consuming resources and high yield crops. [14, 15] The practice of growing of two or more dissimilar crop species or varieties in distinct row combinations simultaneously on the same field practicing is some kind of intercropping as described by [16]. Many researchers mentioned the importance of this process. [16-20] Intercropping plays a major role in expanding biodiversity and maintenance of ecological balance in agriculture ecosystem. [21]

The current research was carried out to study the beneficial gains from the wheat-based intercropping system including chickpea in the presence of natural wild mustard, over a variable row arrangement. The wheat was taken as a base crop and modified growth degree days or the unit scale (phyllocrone), besides elapsed time were employed to analyze the growth, aiming to find out the appropriate treatment with compatible row ratio.

Materials and Methods

A field study was carried out in Grdarasha, the experimental farm of college of Agriculture-University of Salahaddin–Erbil, on geographical location (36.2° N, 44.1° E and elevation 470 m above the mean sea level), to study some of the growth aspects from intercropping wheat, chickpea, and wild mustard in single, double, and triple (row: crop) arrangement in a standard replacement series maintaining total number of 6 rows with varying ratios of species components, so that seven (row: species) consortia were formed the basic combinations of 21 plots repeated in 3 replications to form 63 units with an area of (2×2.40 m) including 20 cm departed sowing lines in randomized complete block design (RCBD). Each treatment was duplicated to avoid any probable risk. Data related to growth measurements and their estimated indices as biological dry biomass, crop growth rates, and relative growth rates based on physical (days) and thermal (phyllocrone) time scales were recorded and analyzed. Field practicing related to land preparing and cropping densities were achieved upon local agricultural recommended criteria. Mustard plant population was resembled from its natural local invasion density. The soil of the experiment was silty clay with composition of sand (11.22%), silt (47.28%), and clay (41.75%) with pH of 7.82, EC of 0.2, 0.6% OM, 0.22% total nitrogen, as well as available P and K of 3.73 and 100 respectively. The climatic data during the experiments are presented in Table 2. Plant sampling achieved at emergence and physiological maturity including three regular samplings at each 20 days interval from emergence up to harvesting to measure the total biomass accumulation then estimating crop growth and relative growth rates based on time intervals scaled by days after establishment and modified growth degree days (phyllochron). Seeding was done on Nov. 26th 2016, while harvesting was executed manually at different dates (May 16th, 17th, and 18th 2017) for wild mustard, chickpea, and wheat respectively according to their seed dryness.

Physiological study

Random samples were taken from the inner lines of each plot along the total of one meter for each species every 20 days from plant establishment (DAS). The samples were dried at 72 ℃ for 48 hours, and both CGR (g $m^{-2}d^{-1}$) and RGR (mg $g^{-1}d^{-1}$) were determined from the standard formulae. [22]

Estimation of Growth Indices

The CGR is defined as the daily production of plant dry matter per land unit area, and the RGR is the daily accumulation of dry matter relative to the current plant dry weight. [23] Because of the differences in the pattern of growth and maturation among the three competitor species used in this study, and due to the direct effect of temperature rather than day lengths, GDD was also taken into account to determine both CGR and RGR. Growth analysis was done based on measuring various mean rate changes in plant weights obtained at each interval following Radford (1967).

1- Crop Growth Rate (CGR).

$$\text{CGR (g m}^{-2}\text{d}^{-1}) = \frac{w2 - w1}{t2 - t1}$$

W_2 and W_1 = Plant dry matter (g) at time $_2$ and time $_1$, respectively.

T_2 and T_1 = Physical times (days)

2- Relative Growth Rate (RGR)

$$\text{RGR (mg g}^{-1}\text{phyl}^{-1}) = \frac{(\log e\, w2 - \log e\, w1)}{(t2 - t1)}$$

ln = Natural logarithm (e = 2.718)

3- Growth Degree Days (GDD)

$$GDD = [(T_{max} - T_{min})/2] - T_b$$

Where BIO is biological weights (g) and a temperature index measured in GDD units and calculated by summing the following equation [11] for each day from the date of sowing to the date of each sampling. GDD is the growing degree day for 1th day; T_{max} is the maximum daily air temperature with an upper limit of 30 C°; T_{min} is the minimum daily air temperature with a lower limit of 0 ℃; Tb is set equal to 0 C°, i.e. the base temperature below which no growth occurs.[24]

GDD_2 and GDD_1 = Growth degree day at the beginning and end of each sampling interval (Phyllocron), respectively. Tuckey's 0.05 statistical analysis achieved on obtained data using SAS computer package. Tuckey's $_{HSD}$ test was adopted to obtain 5% level of significance.

Results and Discussion

Tables 3 and 4 show the BIO at plant growth establishment, and at 20, 40 and 60 days after establishment referred to as BIO_a, BIO_b, BIO_c, and BIO_d respectively in addition to the dry biomass at physiological maturity (BIO_e). Biological biomass reached its significantly ($P \leq 0.05$) highest values at growth intervals a, b and c for wheat, and intervals d and e for mustard plant. The superiority in biomass production followed by superiority in crop growth rate and relative growth rates based on time CGR and RGR, and thermal scales CGRf and RGRf (f after phyllocrone). Biomass mean values were 1.43, 4.12, and 14.57 g for wheat at the first three growth intervals a, b, and c respectively, while biomass mean values were 25.22 g and 31.24 g for the mustard plant at the two last growth intervals d and e, respectively. Chickpea was dominated by wheat and mustard plant in all the studied parameters. Superiority in crop growth rates and relative growth rates of wheat and mustard at the above-mentioned intervals related to each species and the significant lowest mean values of biomass of chickpea are the probable reasons for the higher and lower mean values of crop growth rates and relative growth rates of corresponding species. Crop growth rates as well as relative growth based on elapsed days behaved in direction to their corresponding rates based on thermal scale in superiority but had quite different mean values due to the variation of accumulated GDD (phyllochron) at the same growth period over the different season days. Wheat crop had crop growth rate of 0.033 g $m^{-2}d^{-1}$ and 0.522 g $m^{-2}d^{-1}$ or 0.413 g $m^{-2}phyl^{-1}$ then 3.898 g $m^{-2}phyl^{-1}$, during the first two intervals a and b, while the relative growth rate was 0.0059 mg $g^{-1}d^{-1}$ and 0.0737 mg $g^{-1}phyl^{-1}$ at RGR_a and $RGRf_a$ respectively. The external abnormal superiorities of CGR_c, $CGRf_d$, RGR_c, and $RGRf_d$ seem to be in the benefit of mustard plant at intervals c and a, which is normal indeed due to estimation of those indices from two successive weight values. Mustard plant was superior in both of crop growth rates and relative growth rates at the two last growth intervals c and d with mean values of 0.801 g $m^{-2}d^{-1}$ and 0.301 g $m^{-2}d^{-1}$ or 4.684 g $m^{-2}phyl^{-1}$ and 1.400 g $m^{-2}phyl^{-1}$ crop growth rates with 0.0220 mg $g^{-1}d^{-1}$, 0.0046 mg $g^{1}d^{-1}$ or 0.1284 mg $g^{-1}phyl^{-1}$ and 0.0214 mg $g^{-1}phyl^{-1}$ of relative growth rates based on both time scales, respectively.

Table (5) reveals that most of parameters possessed non-significant differences when measured from the intercrops, except the intercropping consortium 1A2B3C that obtained significant superiority in the biological weights of 20.85 g and 23.86 g at the last two growth intervals BIO_d and BIO_e, crop growth rates of 0.431 and 0.498 g $m^{-2}d^{-1}$ or 3.217 and 2.909 g m^{-2} $phyl^{-1}$ at growth intervals CGR_b, CGR_c, $CGRf_b$, and $CGRf_c$ for both time scales respectively. This might be having 50% of cropping rows of the superior species mustard plant, while the treatment combination of 3A2B1C revealed superiority in biological weight of 1.50 g at growth interval BIO_a. Table (6) didn't reveal any significant differences among three competitor species on RGR.

Tables 7 and 8 postulated significant differences at 5% probability among the different interactions between crops and intercropping consortia as the interaction between chickpea and the consortium wheat×1A2B3C produced the highest values of biological weights of 16.37 g at growth interval BIO_c. Besides, the highest mean values of 0.658 g $m^{-2}d^{-1}$ or 4.913 g $m^{-2}phyl^{-1}$ crop growth rates were observed at growth intervals CGR_b and $CGRf_b$ respectively. For wheat × 1A3B2C recorded highest mean value was 4.97 g and 0.578 g $m^{-2}phyl^{-1}$ at BIO_b and $CGRf_a$, while wheat×3A1B2C was superior at BIO_a (1.77 g). Interaction consortium of mustard×1A2B3C possessed the highest significant mean values of 0.858 and 0.358 $gm^{-2}d^{-1}$ or 5.019 and 1.667 g $m^{-2}phyl^{-1}$ at growth intervals CGR_c, CGR_d, $CGRf_c$, and $CGRf_d$, while RGR_d and $RGRf_d$ possessed 0.0053 mg $g^{-1}d^{-1}$ or 0.0245 mg $g^{-1}phyl^{-1}$ for both time scales, respectively. Interaction of mustard×1A3B2C postulated 27.30 g and 34.19 g at last two growth intervals BIO_e and BIO_d, while mustard×2A1B3C interaction had higher values of 0.0102 and 0.0240 mg $g^{-1}d^{-1}$ or 0.1047 mg $g^{-1}phyl^{-1}$ and 0.1403 mg $g^{-1}phyl^{-1}$ at growth intervals RGR_a, RGR_c, $RGRf_a$, and $RGRf_c$, respectively. Comparison between CGR and RGR was measured on the bases of time (days) and thermal time (phyllochron), as phyllochron refers to 100 ℃ of accumulated temperature, the standard amount of temperature required to produce one wheat leaf or GDD.

Conclusions

To summarize the overall results of this study, it was conducted in general that the wild mustard negatively acts as a competitor to the principle crops according to wheat and chickpea.

Acknowledgments

We appreciate the assistance of the Field Crops Department, College of Agriculture, and University of Salahaddin-Erbil for their help and conducting these experiments.

References

1. Sumbul, A., Rizvi, R., Salah, M., Tiyagi, S.A., Ansari, R.A. and Mahmood, I. Role of Different Sawdusts and Bioinoculant in the Management of Root-Knot Nematode Infesting Chickpea. Asian Journal of Crop Science. 2015; 7(3), p.197-206.
2. FAO. Production Year Book, 2002. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 2003; http://apps.fao.org.
3. Al-Qaesi, H.A.H. and Salih, A.A. The Analysis of the Main Statistical Indicators Which Characterize the Agriculture's Evolution in the Vegetal Sector of the Republic of Iraq. Scientific Papers Series-Management,

Economic Engineering in Agriculture and Rural Development. 2018; 18(1), pp.45-51.
4. FAO. Giews country brief of Iraq. 2018.
5. Mulligan, G.A. and Bailey, L.G. The Biology of Canadian Weeds. 8. *Sinapis arvensis* L. Canadian Journal of Plant Science. 1975; 55(1), pp. 171-183.
6. Warwick, S.I., Beckie, H.J., Thomas, A.G. and McDonald, T. The biology of Canadian Weeds. 8. *Sinapis arvensis* L. (updated). Canadian Journal of Plant Science. 2000; 80(4), pp. 939-961.
7. Rad, M.H., Ebrahimi, M. and Shirmohammadi, E. Land Use Change Effects on Plant and Soil Properties in a Mountainous Region of Iran. Journal of Environmental Science and Management. 2018; 21(2), pp.47-56.
8. Nogueira, S.S.S., Nagai, V., Braga, N.R., Novo, M. and Camargo, M.B.P. Growth analysis of chickpea (*Cicer arietinum* L.). Scientia Agricola. 1994; 51(3), pp. 430-435.
9. Hoffmann, W.A. and Poorter, H. Avoiding bias in calculations of relative growth rate. Annals of botany. 2002; 90(1), pp. 37-42.
10. Watson, D. J. The physiological basis of variation in yield. Advances in Agronomy. 1952; 4, pp. 101-45.
11. Russelle, M.P., Wilhelm, W.W., Olson, R.A. and Power, J.F. Growth Analysis Based on Degree Days. Crop science. 1984; 24(1), pp. 28-32.
12. Davidson, H. R., and Campbell, C. A. Growth rates, harvest index and moisture use of Manitou spring wheat as influenced by nitrogen, temperature and moisture. Canadian Journal of Plant Science. 1984; 64, pp. 825-839.
13. Siddique, K. H. M., Belford, R. K., Perry, M. W., and Tennant, D. Growth, Development and Light Interception of Old and Modern Wheat Cultivars in a Mediterranean Type Environment. Australian Journal of Agricultural Research. 1989; 40, pp. 473-87.
14. Zhang, F., Shen, J., Zhang, J., Zuo, Y., Li, L. and Chen, X. Rhizosphere Processes and Management for Improving Nutrient Use Efficiency and Crop Productivity: Implications for China. Advances in Agronomy. 2010; 107, pp. 1-32.
15. Li L, Zhang, L.Z and Zhang, F.Z. Crop mixtures and the mechanisms of overyielding. In: Levin SA, ed. Encyclopedia of biodiversity, Waltham, MA, USA 2nd ed, Vol, 2. Academic Press. 2013; pp. 382–395.
16. Katyayan, A. Fundamentals of Agriculture, Kushal Publications & Distributors, Varanasi, Uttar Pradesh. 2005; pp. 10-11.
17. Ahlgren, H.L. and Aamodt, O.S. Harmful Root Interactions as a Possible Explanation for Effects Noted between Various Species of Grasses and Legumes. Agronomy Journal. 1939; 31(11), pp. 982-985.
18. Donald, C.M. Competition among crop and pasture plants. In: Advances in agronomy, Vol. 15. Academic Press. 1963; pp. 1-118.
19. Willey, R.W. The Use of Shade in Coffee, Cocoa and Tea. Horticultural Abstracts. 1975; 45(12), pp. 791-798.
20. Sarkar, R.K., Shit, D. and Maitra, S. Competition Functions, Productivity and Economics of Chickpea (*Cicer arietinum*)-Based Intercropping System Under Rainfed Conditions of Bihar Plateau. Indian Journal of Agronomy. 2000; 45(4), pp. 681-686.
21. Abate, M. and Alemayehu, G. Biological Benefits of Intercropping Maize (*Zea mays* L) with Fenugreek, Field Pea and Haricot Bean Under Irrigation in Fogera Plain, South Gonder Zone, Ethiopia. Agriculture, Forestry and Fisheries. 2018; 7(1), pp. 19-35.
22. Radford, P.J. Growth Analysis Formulae-Their Use and Abuse 1. Crop science. 1967; 7(3), pp. 171-175.
23. Warren Wilson, J. Analysis of growth, photosynthesis and light interception for single plants and stands. Ann. Bot. 1981; 8, 507-12.
24. Cao, W., and Moss, D. N. Temperature effect on leaf emergence and phyllochron in wheat and barley. Crop Science. 1989; 29, 1018-1021.

Table 1. The number of days and phyllochrones between each two successive growth intervals for each plant component.

Plant	Time scale (days)				Thermal scale (phyllochron)			
	GS_1	GS_2	GS_3	GS_4	GS_1	GS_2	GS_3	GS_4
Wheat	81	20	20	20	6.52	2.68	3.42	4.30
Chickpea	73	20	20	20	5.75	2.68	3.42	4.30
Mustard	67	20	20	20	5.30	2.68	3.42	4.30

Note: GS= growth stage.

Table 2. Meteorological data during the field experimental period rainfall season of 2016-2017.

Months	Temperature ℃			Relative Humidity (%)	Atmospheric Pressure	Wind Direction Avg.	Maximum Wind Speed	Soil Temp.	Precipitation (mm)
	Max.	Mini.	Average						
Nov.2016	21.9	9.7	15.2	29.3	971.0	165.4	3.0	16.7	21.1
Dec.2016	12.5	4.9	8.5	68.9	971.4	171.2	3.1	11.0	110.0
Jan.2017	12.5	2.0	7.3	59.0	970.2	180.7	3.0	9.2	27.9
Feb.2017	13.2	1.9	7.6	50.3	970.9	167.9	3.2	9.0	14.2
Mar.2017	18.3	8.3	13.3	55.6	965.7	153.5	3.9	13.4	4.5
Aprl.2017	25.2	12.6	18.9	45.0	965.8	179.9	4.1	18.5	38.0
May.2017	33.5	16.9	25.2	22.2	961.5	180.4	4.3	24.2	2.4

Table 3. Biological weight (BIO) and crop growth rate based on time (CGR) and temperature (CGRf) for three plant species in mono-cultures.

Parameters		Biological weights g at days after establishment					Crop Growth Rate g $m^{-2}d^{-1}$ Interval by days				Crop Growth Rate g $m^{-2}phyl^{-1}$ Thermal (phyllocrone)			
		20	40	60	80	maturity	0-20	20-40	40-60	60-80	5.86	2.68	3.42	4.30
		BIO_a	BIO_b	BIO_c	BIO_d	BIO_e	CGR_{a-b}	CGR_{b-c}	CGR_{c-d}	CGR_{d-e}	$CGRf_{a-b}$	$CGRf_{b-c}$	$CGRf_{c-d}$	$CGRf_{d-e}$
Species	Wheat (A)	1.43 a	4.12 a	14.57 a	19.98 b	21.46 b	0.033 a	0.522 a	0.271 b	0.074 b	0.413 a	3.898 a	1.584 b	0.344 b
	Chickpea (B)	0.97 b	1.72 c	7.37 c	12.79 c	13.56 c	0.010 c	0.282 c	0.271 b	0.038 c	0.115 b	2.107 c	1.586 b	0.178 c
	Mustard (C)	1.09 b	2.30 b	9.20 b	25.22 a	31.24 a	0.018 b	0.345 b	0.801 a	0.301 a	0.186 b	2.575 b	4.684 a	1.400 a
Tuckey $_{HSD}$ 0.05		0.2878	0.5196	0.6635	1.2868	1.5448	0.0073	0.0412	0.0546	0.0327	0.0755	0.3022	0.3177	0.1521

Table 4. Relative growth rate based on time (RGR) and temperature (RGRf) for three plant species in mono-cultures.

Parameters		Relative growth rate mg $g^{-1}d^{-1}$ Interval by days				Relative growth rate mg $g^{-1}phyl^{-1}$ Thermal (phyllochron)			
		0-20	20-40	40-60	60-80	5.86	2.68	3.42	4.3
		RGR_{a-b}	RGR_{b-c}	RGR_{c-d}	RGR_{d-e}	$RGRf_{a-b}$	$RGRf_{b-c}$	$RGRf_{c-d}$	$RGRf_{d-e}$
Species	Wheat (A)	0.0059 a	0.0278	0.0068 c	0.0016 b	0.0737 a	0.2075	0.0395 c	0.0073 b
	Chickpea (B)	0.0035 b	0.0321	0.0120 b	0.0012 b	0.0396 b	0.2397	0.0705 b	0.0058 b
	Mustard (C)	0.0052 a	0.0313	0.0220 a	0.0046 a	0.0533 b	0.2335	0.1284 a	0.0214 a
Tuckey $_{HSD}$ 0.05		0.0034	N.S	0.0019	0.0022	0.0169	N.S	0.0089	0.0035

Table 5. Biological weight (BIO) and crop growth rate based on time (CGR) and temperature (CGRf) for three plant species in mix-cultures.

Parameters	Biological weights g at days after establishment					Crop growth rate g $m^{-2}d^{-1}$ Interval by days				Crop growth rate g $m^{-2}phyl^{-1}$ Thermal (phyllocrone)			
	20	40	60	80	maturity	0-20	20-40	40-60	60-80	5.86	2.68	3.42	4.3
	BIO_a	BIO_b	BIO_c	BIO_d	BIO_e	CGR_{a-b}	CGR_{b-c}	CGR_{c-d}	CGR_{d-e}	$CGRf_{a-b}$	$CGRf_{b-c}$	$CGRf_{c-d}$	$CGRf_{d-e}$

Row-species treatments													
1A2B3C	0.86 b	2.28	10.9	20.85 a	23.86 a	0.019	0.431 a	0.498 a	0.151	0.218	3.217 a	2.909 a	0.701
1A3B2C	1.02 ab	2.91	10.7	20.19 ab	23.12 ab	0.025	0.389 ab	0.474 ab	0.147	0.29	2.906 ab	2.774 ab	0.681
2A1B3C	1.06 ab	2.84	9.83	19.06 ab	22.16 ab	0.024	0.349 b	0.461 ab	0.155	0.274	2.608 ab	2.697 ab	0.723
2A2B2C	1.39 ab	2.57	10.21	19.25 ab	22.37 ab	0.015	0.382 ab	0.452 ab	0.156	0.181	2.852 ab	2.642 ab	0.726
2A3B1C	1.19 ab	2.61	10.38	19.19 ab	21.92 ab	0.019	0.388 ab	0.441 ab	0.136	0.218	2.898 ab	2.576 ab	0.635
3A1B2C	1.13 ab	2.73	10.5	18.23 b	20.45 b	0.021	0.388 ab	0.387 b	0.111	0.245	2.898 ab	2.261 b	0.516
3A2B1C	1.50 a	3.04	10.12	18.57 ab	20.72 b	0.02	0.354 ab	0.422 ab	0.108	0.237	2.641 b	2.469 ab	0.501
Tuckey HSD 0.05	0.5607	N.S	N.S	2.5061	3.0085	N.S	0.0803	0.1063	N.S	N.S	0.5885	0.6188	N.S

Table 6. Relative growth rate based on time (RGR) and temperature (RGRf) for three plant species in mix-cultures.

Parameters		Relative growth rate mg $g^{-1}d^{-1}$				Relative growth rate mg $g^{-1}phyl^{-1}$			
		Interval by days				Thermal (phyllochron)			
		0-20	20-40	40-60	60-80	5.86	2.68	3.42	4.3
		RGR_{a-b}	RGR_{b-c}	RGR_{c-d}	RGR_{d-e}	$RGRf_{a-b}$	$RGRf_{b-c}$	$RGRf_{c-d}$	$RGRf_{d-e}$
Row-species treatments	1A2B3C	0.0057	0.0342	0.0143	0.0025	0.0647	0.2555	0.0836	0.0114
	1A3B2C	0.0055	0.0305	0.0135	0.0024	0.0634	0.2278	0.0788	0.0113
	2A1B3C	0.0059	0.0281	0.0143	0.0027	0.0656	0.2102	0.0835	0.0123
	2A2B2C	0.0036	0.0305	0.0141	0.0029	0.042	0.2279	0.0824	0.0137
	2A3B1C	0.0045	0.0315	0.0134	0.0025	0.0513	0.2348	0.0783	0.0118
	3A1B2C	0.0051	0.0311	0.0122	0.0022	0.0571	0.2322	0.0716	0.0101
	3A2B1C	0.0039	0.0268	0.0133	0.0021	0.0448	0.1999	0.078	0.0098
Tuckey HSD 0.05		N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S

Table 7. Biological weight (BIO) and crop growth rate based on time (CGR) and temperature (CGRf) for three plant species in mix-cultures.

Interaction		Biological weights g					Crop growth rate g $m^{-2}d^{-1}$				Crop growth rate g $m^{-2}phyl^{-1}$			
		at days after establishment					Interval by days				Thermal (phyllochron)			
Species	Row-species treatments	20	40	60	80	maturity	0-20	20-40	40-60	60-80	5.86	2.68	3.42	4.3
		BIO_a	BIO_b	BIO_c	BIO_d	BIO_e	CGR_{a-b}	CGR_{b-c}	CGR_{c-d}	CGR_{d-e}	$CGRf_{a-b}$	$CGRf_{b-c}$	$CGRf_{c-d}$	$CGRf_{d-e}$
Wheat (A)	1A2B3C	1.00 ab	3.20 a-d	16.37 a	23.80 a-d	25.16 b-e	0.027 a-d	0.658 a	0.372 b	0.068 c	0.337 a-d	4.913 a	2.173 b	0.317 c
	1A3B2C	1.20 ab	4.97 a	14.23 ab	20.52 b-e	21.81 ed	0.047 a	0.463 bd	0.315 b	0.064 c	0.578 a	3.458 b-d	1.839 b	0.299 c
	2A1B3C	1.43 ab	3.83 a-c	13.50 b	18.59 de	20.33 e-f	0.030 a-d	0.483 bc	0.254 b	0.087 c	0.368 a-d	3.607 bc	1.487 b	0.406 c
	2A2B2C	1.43 ab	3.83 a-c	14.60 ab	19.86 c-e	22.24 c-e	0.030 a-d	0.538 ab	0.263 b	0.119 bc	0.368 a-d	4.017 ab	1.537 b	0.553 bc
	2A3B1C	1.67 ab	4.37 ab	14.20 ab	19.14 de	20.51 e-f	0.033 a-d	0.492 a-c	0.247 b	0.068 c	0.414 a-c	3.669 a-c	1.445 b	0.318 c
	3A1B2C	1.77 a	4.30 ab	15.03 ab	18.36 ef	19.50 e-g	0.031 a-d	0.537 ab	0.166 b	0.057 c	0.389 a-d	4.005 ab	0.972 b	0.267 c
	3A2B1C	1.50 ab	4.33 ab	14.03 ab	19.63 c-e	20.68 e-f	0.035 a-c	0.485 bc	0.279 b	0.053 c	0.435 ab	3.619 bc	1.635 b	0.246 c
Chickpea (B)	1A2B3C	1.00 ab	2.07 cd	7.47 de	12.72 g	13.23 g	0.015 b-d	0.270 e	0.262 b	0.026 c	0.164 b-d	2.015 e	1.535 b	0.120 c
	1A3B2C	0.80 ab	1.67 d	7.47 de	12.74 g	13.35 g	0.012 b-d	0.290 e	0.264 b	0.031 c	0.133 b-d	2.164 e	1.543 b	0.142 c
	2A1B3C	1.10 ab	1.70 cd	7.50 de	12.98 g	13.45 g	0.008 cd	0.290 e	0.274 b	0.024 c	0.092 d	2.164 e	1.601 b	0.111 c
	2A2B2C	1.10 ab	1.63 d	7.10 e	13.15 fg	14.33 fg	0.007 d	0.273 e	0.302 b	0.059 c	0.082 d	2.040 e	1.768 b	0.274 c
	2A3B1C	0.80 ab	1.53 d	7.00 e	12.74 g	13.81 g	0.010 b-d	0.273 e	0.287 b	0.054 c	0.112 cd	2.040 e	1.678 b	0.250 c
	3A1B2C	0.70 ab	1.40 d	7.37 de	12.47 g	13.20 g	0.010 b-d	0.298 d-e	0.255 b	0.037 c	0.107 cd	2.226 de	1.492 b	0.171 c
	3A2B1C	1.30 ab	2.03 cd	7.67 c-e	12.76 g	13.51 g	0.010 b-d	0.282 e	0.254 b	0.038 c	0.112 cd	2.102 e	1.488 b	0.176 c
Mustard (C)	1A2B3C	0.57 b	1.57 d	8.87 c-e	26.04 a	33.20 a	0.015 b-d	0.365 c-e	0.858 a	0.358 a	0.153 b-d	2.724 c-e	5.019 a	1.667 a
	1A3B2C	1.07 ab	2.10 cd	10.40 c	27.30 a	34.19 a	0.015 b-d	0.415 b-e	0.845 a	0.345 a	0.158 b-d	3.097 b-e	4.940 a	1.603 a
	2A1B3C	0.63 ab	3.00 a-d	8.50 c-e	25.60 ab	32.71 a	0.035 ab	0.275 e	0.855 a	0.355 a	0.363 a-d	2.052 e	5.001 a	1.652 a
	2A2B2C	1.63 ab	2.23 b-d	8.93 c-e	24.74 a-c	30.53 ab	0.009 b-d	0.335 c-e	0.790 a	0.290 a	0.092 d	2.500 c-e	4.620 a	1.349 a
	2A3B1C	1.10 ab	1.93 cd	9.93 cd	25.68 ab	31.42 ab	0.012 b-d	0.400 b-e	0.787 a	0.287 a	0.128 b-d	2.985 b-e	4.604 a	1.336 a
	3A1B2C	0.93 ab	2.50 b-d	9.10 c-e	23.87 a-d	28.64 a-c	0.023 b-d	0.330 c-e	0.739 a	0.239 ab	0.240 b-d	2.463 c-e	4.319 a	1.110 ab
	3A2B1C	1.70 ab	2.77 b-d	8.67 c-e	23.32 a-e	27.97 a-d	0.016 b-d	0.295 e	0.733 a	0.233 ab	0.164 b-d	2.201 e	4.285 a	1.082 ab

Tuckey $_{HSD}$ 0.05	1.195	2.1563	2.7536	5.3406	6.4114	0.0303	0.1711	0.2265	0.1356	0.3135	1.2541	1.3187	0.6312

Table 8. Biological weight (BIO) and relative growth rate based on time (RGR) and temperature (RGRf) for three plant species in mix-cultures.

Interaction		Relative growth rate mg $g^{-1}d^{-1}$				Relative growth rate mg $g^{-1}phyl^{-1}$			
Species	Row-species treatments	Interval by days				Thermal (phyllochron)			
		0-20	20-40	40-60	60-80	5.86	2.68	3.42	4.3
		RGR_{a-b}	RGR_{b-c}	RGR_{c-d}	RGR_{d-e}	$RGRf_{a-b}$	$RGRf_{b-c}$	$RGRf_{c-d}$	$RGRf_{d-e}$
Wheat (A)	1A2B3C	0.0065 ab	0.0356	0.0079 b-e	0.0013 d	0.0807 a-c	0.2656	0.0465 b-e	0.0058 d
	1A3B2C	0.0076 ab	0.0233	0.0077 b-e	0.0014 d	0.0946 ab	0.1739	0.0448 b-e	0.0064 d
	2A1B3C	0.0052 ab	0.0281	0.0069 de	0.0019 cd	0.0648 a-c	0.2098	0.0404 de	0.0089 cd
	2A2B2C	0.0062 ab	0.0291	0.0067 de	0.0024 b-d	0.0772 a-c	0.2169	0.0392 de	0.0114 b-d
	2A3B1C	0.0054 ab	0.0257	0.0065 de	0.0015 d	0.0675 a-c	0.1915	0.0377 de	0.0070 d
	3A1B2C	0.0048 ab	0.0272	0.0043 e	0.0013 d	0.0596 a-c	0.203	0.0254 e	0.0061 d
	3A2B1C	0.0058 ab	0.0257	0.0073 c-e	0.0011 d	0.0714 a-c	0.1919	0.0426 c-e	0.0053 d
Chickpea (B)	1A2B3C	0.0044 ab	0.0281	0.0116 b-d	0.0009 d	0.0492 a-c	0.2097	0.0676 b-d	0.0040 d
	1A3B2C	0.0044 ab	0.0325	0.0118 b-d	0.0010 d	0.0496 a-c	0.2425	0.0692 b-d	0.0047 d
	2A1B3C	0.0024 b	0.0333	0.0119 b-d	0.0008 d	0.0274 bc	0.2486	0.0697 b-d	0.0037 d
	2A2B2C	0.0025 b	0.0323	0.0134 b	0.0018 cd	0.0282 bc	0.2408	0.0782 b	0.0086 cd
	2A3B1C	0.0043 ab	0.0332	0.0131 bc	0.0017 cd	0.0481 a-c	0.2478	0.0764 bc	0.0080 cd
	3A1B2C	0.0041 b	0.0364	0.0114 b-d	0.0013 d	0.0456 a-c	0.2714	0.0669 b-d	0.0058 d
	3A2B1C	0.0026 b	0.0291	0.0112 b-d	0.0012 d	0.0293 bc	0.2172	0.0652 b-d	0.0056 d
Mustard (C)	1A2B3C	0.0063 ab	0.039	0.0234 a	0.0053 a	0.0643 a-c	0.2913	0.1368 a	0.0245 a
	1A3B2C	0.0045 ab	0.0358	0.0210 a	0.0049 a	0.0460 a-c	0.267	0.1226 a	0.0227 a
	2A1B3C	0.0102 a	0.0231	0.0240 a	0.0053 a	0.1047 a	0.1722	0.1403 a	0.0245 a
	2A2B2C	0.0020 b	0.0303	0.0222 a	0.0046 ab	0.0206 c	0.226	0.1297 a	0.0212 ab
	2A3B1C	0.0037 b	0.0355	0.0207 a	0.0043 ab	0.0382 a-c	0.2651	0.1208 a	0.0202 ab
	3A1B2C	0.0064 ab	0.0298	0.0210 a	0.0040 a-c	0.0660 a-c	0.2222	0.1226 a	0.0184 a-c
	3A2B1C	0.0033 b	0.0256	0.0216 a	0.0040 a-c	0.0336 bc	0.1907	0.1262 a	0.0184 a-c
Tuckey $_{HSD}$ 0.05		0.0142	N.S	0.0079	0.009	0.701	N.S	0.0368	0.0145