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Research Article

Growth analysis and land equivalent ratio of fenugreek-buckwheat intercrops at different fertilizer types

Wachstumsanalyse und Flächenäquivalenz von Gemengen aus Bockshornklee und Buchweizen bei unterschiedlichen Düngerarten

Aliyeh Salehi[1 2]*, Sina Fallah[1], Reinhard W. Neugschwandtner[2], Bano Mehdi[2], Hans-Peter Kaul[2]

[1] Faculty of Agriculture, Shahrekord University, Rahbar Bolvar, 64165478 Shahrekord, Iran
[2] Division of Agronomy, Department of Crop Sciences, University of Natural Resources and Life Sciences Vienna (BOKU), Konrad-Lorenz-Straße 24, 3430 Tulln, Austria
* Corresponding author: aliyeh.salehi@boku.ac.at

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Summary

Intercropping can increase crop growth and yield due to improved resource use efficiency. A two-year field experiment was performed in Shahrekord (Iran) to determine the effect of crop stand composition and fertilizer type on the productions of above-ground dry matter and growth parameters of fenugreek-buckwheat intercrops. Sole crops of fenugreek (F) and buckwheat (B) were compared to the three substitutive intercropping ratios (F:B = 2:1, 1:1 and 1:2). Crop stands were fertilized with chemical fertilizer or broiler litter. Fenugreek could produce in intercrops a similar amount of above-ground dry matter compared to its corresponding share on the sowing ratio. Contrary to that, buckwheat could produce in intercrops more above-ground dry matter than its share on the sowing ratio, especially with a low to medium share of buckwheat. Consequently, the intercrops with F:B (2:1) and F:B (1:1) had an above-ground dry matter yield advantage compared to the pure crop stands of both crops. Broiler litter was more effective in increasing the growth rates and thus the above-ground dry matter production compared to the chemical fertilizer. Thus, growing fenugreek and buckwheat in intercrops fertilized with broiler litter can be beneficial for increasing the biomass production in semi-arid environments.

Keywords: Intercropping, growth rate, above-ground dry matter, broiler litter, chemical fertilizer

Zusammenfassung

Der Gemengeanbau kann zu höherem Pflanzenwachstum und Biomasseerträgen aufgrund einer verbesserten Resourcennutzung führen. Ein zweijähriger Feldversuch wurde in Shahrekord (Iran) durchgeführt, um den Einfluss von Pflanzenbestand und Düngerform auf den Ertrag der oberirdischen Biomasse und die Wachstumsparameter von Gemengen aus Bockshornklee (F) und Buchweizen (B) zu untersuchen. Reinbestände von Bockshornklee und Buchweizen wurden mit drei substitiven Gemengen (F:B = 2:1, 1:1 and 1:2) verglichen. Die Pflanzenbestände wurden mit Mineraldünger oder Hühnermist gedüngt. Bockshornklee konnte in den Gemengen einen ähnlichen Anteil an oberirdischer Biomasse im Vergleich zum Saatanteil produzieren. Hingegen konnte Buchweizen in den Gemengen einen höheren Anteil an oberirdischer Biomasse im Vergleich zum Saatanteil produzieren, insbesondere bei geringem bis mittlerem Anteil an Buchweizen. Folglich hatten die Gemenge mit F:B (2:1) und F:B (1:1) einen Ertragsvorteil bei der oberirdischen Biomasse gegenüber den Reinsaaten der beiden Kulturpflanzen. Hühnermist konnte die Wachstumsparameter und somit die Produktion der oberirdischen Biomasse effizienter erhöhen als Mineraldünger. Somit ist der Anbau von Bockshornklee und Buchweizen in Gemengen mit Hühnermistdüngung vorteilhaft für die Steigerung der Biomasseproduktion in semi-ariden Umwelten.

Schlagworte: Gemengeanbau, Wachstumsrate, oberirdische Biomasse, Hühnermist, Mineraldünger

1. Introduction

There is an increasing interest to diversify the agricultural production systems in order to enhance several valuable eco-agricultural strategies, such as to produce sufficient food and feed, to obtain higher crop protection, to increase biodiversity and increasingly to meet the requirements of sustainable intensification. Intercropping can be a solution to diversify agroecosystems by using more leguminous crops and also applying less mineral fertilizers (Kübler et al., 2006; Gomiero et al., 2011; Branca et al., 2013; Zając et al., 2013; Neugschwandtner and Kaul, 2014; 2015).

Previous studies indicated that growing crops in intercrops is an important strategy for enhancing sustainability and yields, as well as to improve soil conservation (Zając et al., 2013; Branca et al., 2013; Klimek-Kopyra et al., 2015; Scalise et al., 2015). Reasonable intercropping could increase crop growth and productivity (Cecilio et al., 2011), efficient use of the resources water, nitrogen and radiation (Lithourgidis et al., 2011), macronutrients (Kübler et al., 2010; Neugschwandtner and Kaul, 2016a; Salehi et al., 2018) and micronutrients (Neugschwandtner and Kaul, 2016b), yield quality (Klimek-Kopyra et al., 2017) and lower the damage caused by diseases and pests (Hauggaard-Nielsen et al., 2001). However, yield decreases in intercropping have also been reported (Ebrahimi et al., 2017). Functional groups or typical species used in intercropping include legumes (e.g., clover, fenugreek, vetch, beans and peas) and non-legumes (e.g., barley, buckwheat, rye, oat, wheat and flax) (Petropoulos, 2002; Hamzei and Seyyedi, 2016). Advantages of intercropping legumes with non-legumes are explained by the complementary use of resources due to non-competition for the same resource niche (Bedoussac and Justes, 2010).

Fenugreek (*Trigonella foenum-graecum* L.) is a small-seeded annual legume crop, originally grown from Eastern Europe to Central Asia. It is grown today in many parts of the world as a spice or forage crop (Kenny et al., 2013). Fenugreek seeds are known for their health benefits including anti-diabetic, anti-obesity and anti-carcinogenic effects (Handa et al., 2005; Raju and Bird, 2006), and they are also used to flavor many foods (Betty, 2008). Fenugreek is a suitable plant for intercropping due to its ability to support the biological nitrogen fixation of rhizobia and its subsequent improvement of soil fertility (Petropoulos, 2002; Dadrasan et al., 2015).

Common buckwheat (*Fagopyrum esculentum* M.) is a non-legume crop belonging to the family of *Polygonaceae* (Koyama et al., 2013). It is an important crop in organic farming (Kalinova and Vrchotova, 2011) with important medical characteristics as well as a high nutritional value. Buckwheat seeds are rich in natural antioxidants, digestible proteins, vitamins, minerals, favorable fatty acids, flavonoids (rutin, catechins) and dietary fiber (Halbrecq et al., 2005; Alamprese et al., 2007).

Nitrogen (N) is plant's most required nutrient that plays an essential role for growth and crop yield (Yin et al., 2014). N fertilization increases the values of growth rates (Sugár et al., 2017). Fertilizer requirements and nutrient use efficiency in intercropping are still important research issues and may be different compared to sole crops (Ghosh et al., 2009). Ghosh et al. (2009) reported that dry matter production in sole sorghum and soybean-sorghum intercropping was significantly improved with the increase in NPK rates. Applying high rates of chemical fertilizer to increase growth and yield will not only lead to increased production costs, but may also lead to environmental pollution and a reduction of soil health (Peng et al., 2010; Ahmadian et al., 2011). Furthermore, it may not be possible to supply sufficient N at suitable times to meet the plant demand for N by relying on chemical fertilizer as the only source of N (Ahmadian et al., 2011). In order to decrease chemical fertilizer inputs while keeping crop yields high, ecosystem functions (i.e., nutrient cycling) that are disturbed must be restored (Damour et al., 2012). One important strategy for this is to use fertilizer alternatives, such as manure or other organic amendments (Stockdale et al., 2002; Tejada and Gonzalez, 2008). Organic fertilizers release nutrients over time due to not only their high content of micronutrients and minerals but also their slower release and therefore longer lasting availability. The application of organic manure is more effective and positive compared to chemical fertilizer in improving the quality and fertility of the soil, soil nutrient exchange capacity, soil ecological processes, soil health and crop productivity (Fereidooni et al., 2013; Shrestha et al., 2013; Bajelia et al., 2015, Salehi et al., 2017a). The application of farm yard manure has been shown to have a beneficial effect on the growth parameters of fenugreek. The dry matter accumulation and crop growth rate (CGR) were significantly higher with increasing doses of farmyard manure (up to 15 t ha^{-1}) at all stages of crop growth (Khiriya et al., 2002). Mirhashemi et al. (2009) demonstrated for ajowan (*Carum copticum*) and fenugreek grown organically in pure stands and intercrops that the CGR of ajowan was highest in double-row intercrops and the dry matter production was highest in triple-row intercrops, while for fenugreek, the triple-row intercrops had the highest CGR and the single-row intercrops had the highest dry matter. Both dry matter production and CGR were increased by farm yard manure for ajowan and fenugreek.

Cultivation systems are often evaluated and compared to the sole crops using the land equivalent ratio (LER). Salehi et al. (2017b) reported that LERs of intercropped fenugreek-buckwheat varied from 0.99 to 1.72 with the highest LER in F:B (2:1) treated with broiler litter.

While the efficient utilization of the available resources by legume/non-legume intercropping systems has been shown as mentioned above, the diverse influence of organic and inorganic fertilizer on growth parameters in intercropping systems is poorly researched and only scarce information is available on fenugreek-buckwheat intercrops grown under different fertilization regimes. Therefore, we assessed how the application of organic and chemical fertilizer can improve plant growth in both sole and intercropped fenugreek and buckwheat. In the present study, the objectives were to assess: (1) above-ground dry matter (AGDM) production, (2) crop growth rate (CGR), (3) relative growth rate (RGR) and (4) land equivalent ratio of the above-ground dry matter (AGDM-LER) of fenugreek-buckwheat intercrops compared to the corresponding sole crops as affected by sowing ratio and fertilizer type. A comprehensive assessment of seed yield, yield components, nutrient use efficiency and nutrient land equivalent ratio is provided in Salehi et al. (2017b) and Salehi et al. (2018).

2. Materials and methods

2.1 Experimental site and treatments

The field experiment was performed at the research farm of Shahrekord University (32°21′ N, 50°49′ E; 2050 m a.s.l.) of Iran, in the years 2014 and 2015. This two-factorial experiment in a randomized complete block design was conducted with three replications. The first factor was the cropping system with five levels: sole cropping of fenugreek (F), sole cropping of buckwheat (B) and three substitutive intercropping ratios (F:B = 2:1 – two rows of fenugreek + one row of buckwheat; 1:1 – one row of fenugreek + one row of buckwheat and 1:2 – one row of fenugreek + two rows of buckwheat). The second factor was N fertilizer type with two levels: chemical fertilizer (CF) or broiler litter (BL). The amount of nitrogen applied was 60 kg N ha^{-1} for buckwheat and 80 kg N ha^{-1} for fenugreek, respectively. The broiler litter application of 7.5 to 10 Mg ha^{-1} provided on annual average 60 and 80 kg N ha^{-1}, respectively, assuming 50% mineralization of broiler litter N under the given environmental conditions in the Shahr-e Kord region (Alizadeh et al., 2012). In the chemical fertilizer treatments, urea was applied. Phosphorus (P) was applied as triple superphosphate, and Fe, Mn, Cu, and Zn were applied to the urea-fertilized plots at a rate equivalent to the total amounts added by the broiler litter treatments in order to compensate for the nutrient inputs of these elements with the organic fertilizer. In the integrated fertilizer treatments, 50% of chemical fertilizer and 50% of broiler litter was applied to each plot.

Detailed information on the environmental conditions, analysis of soil and broiler litter, experimental design, experimental set-up and management are given in Salehi et al. (2017b) and Salehi et al. (2018).

2.2 Growth analysis and land equivalent ratio and calculations

Fenugreek and buckwheat crops were sampled to determine above-ground dry matter (AGDM) by randomly harvesting plants of each crop at 10-day intervals starting from HD 1 (HD = harvest date) until final harvest (HD 7) (Table 1). The plant samples were oven-dried at 65°C for 72 h to obtain a constant weight. Crop growth rate (CGR) and relative growth rate (RGR) were calculated for each period between subsequent harvest dates according to Hunt (1982) as follows:

$$(1)\ \text{CGR}\ (\text{g m}^{-2}\ \text{d}^{-1}) = (W_2 - W_1)/(t_2 - t_1)$$

$$(2)\ \text{RGR}\ (\text{mg g}^{-1}\ \text{d}^{-1}) = (\ln W_2 - \ln W_1)/(t_2 - t_1)$$

where W_2 and W_1 represent the final and initial dry weight, and t_2 and t_1 indicate the end and the start day of each period.

The land equivalent ratio (LER) indicating the possible yield advantages of intercrops of the above-ground dry matter at each harvested date was calculated according to Mead and Willey (1980) as follows:

$$(3)\ \text{LER} = (Y_{1.2} / Y_{1.1}) + (Y_{2.1} / Y_{2.2})$$

where $Y_{1.1}$ and $Y_{2.2}$ are the above-ground dry matter for crop 1 and crop 2 grown in sole cropping and $Y_{1.2}$ and $Y_{2.1}$ are the yields of the crops grown in intercropping. The LER is the sum of the partial LERs of the individual crops in the intercropping. A LER > 1 indicates a production advantage of the intercropping system, whereas a LER < 1 indicates a production disadvantage. Partial LERs show the relative competitive abilities of individual crops in the intercropping.

2.3 Statistics

An analysis of variance for the two factorial experiments was performed on data from each year considering intercropping ratio as the first factor and N source as the second factor by using SAS version 9.2. Means were separated by least significant differences (LSD), when the F-test indicated factorial effects on the significance level of $p < 0.05$.

3. Results

3.1 Above-ground dry matter

3.1.1 Total above-ground dry matter of crop stands ($AGDM_T$)

For all harvest dates, the total above-ground dry matter ($AGDM_T$) in both years was significantly affected by crop stand × fertilizer type (Figures 1 a-d). $AGDM_T$ increased for all the crop stands exponentially up to HD 4 and then started to level off. $AGDM_T$ was generally highest in F:B (2:1) in both years and with both fertilizer treatments. In 2014, in the chemical fertilizer (CF) treatment, the $AGDM_T$ of F:B (2:1) had the highest values, followed by F:B (1:1) which had significantly higher values than Sole F, Sole B and F:B (1:2). For the BL treatment, F:B (2:1) had significantly higher $AGDM_T$ than the other four crop stands from HD 4 onward (Figures 1 a–b). In 2015, in the CF treatment, the $AGDM_T$ was from HD 6 onwards ranked from highest to lowest as follows: F:B (2:1), F:B (1:1) > Sole F > Sole B, F:B (1:2). For BL from HD 4 onward, the values were ranked as follows: F:B (2:1) > Sole B, F:B (1:1) > Sole F, F:B (1:2) (Figures 1 c–d).

On the final harvest date (HD 7) in 2014 with CF, the $AGDM_T$ of F:B (2:1) was 54% and 107% higher compared to the second best and the worst yielding crop stand, respectively. In 2014 with BL, the differences were 34% and 41%, respectively. In 2015 with CF, the differences were 7% and 70%, respectively, and in 2015 with BL, the differences were 25% and 61%, respectively. On average overall crop stands at HD 7, BL increased $AGDM_T$ by 13% in 2014 and by 19% in 2015, compared with CF.

3.1.2 Above-ground dry matter of fenugreek ($AGDM_F$) or buckwheat ($AGDM_B$)

The above-ground dry matter of fenugreek is shown in Figures 1 e–h and of buckwheat in Figures 1 i–l. In 2014, at the early growth stage (HD 1), the $AGDM_B$ was much higher than that of $AGDM_F$. In the pure crop stands, Sole F had a lower AGDM than Sole B with CF up to HD 3 and also with BL up to HD 4. Final AGDM, however, did not differ between Sole F and Sole B. In 2015, AGDM of Sole F was lower with CF up to HD 4 but higher for Sole F from HD 6 onward, whereas it was lower for Sole F than for Sole B with BL throughout the vegetation period.

A significant interaction of crop stand × fertilizer type was observed for $AGDM_F$ at all the harvest dates in 2014 and for some harvest dates in 2015 (Figures 1 e–f). For all the harvest dates in 2014, $AGDM_F$ was ranked in both CF and BL treatments as followed: Sole F > F:B (2:1) >

Table 1. Sowing and harvest dates (HD) of fenugreek and buckwheat in 2014 and 2015
Tabelle 1. Anbau- und Ernteterminen von Bockshornklee und Buchweizen in den Jahren 2014 und 2015

Dates	Crops	2014	DOY[1]	2015	DOY
Sowing	F, B	29 May	149	23 May	143
HD 1	F, B	8 July	189	3 July	184
HD 2	F, B	18 July	199	13 July	194
HD 3	F, B	28 July	209	23 July	204
HD 4	F, B	7 August	219	2 August	214
HD 5	F, B	17 August	229	12 August	224
HD 6	F, B	27 August	239	22 August	234
HD 7	B	6 September	249	1 September	244
	F	12 September	255	15 September	258

[1]DOY = day of year

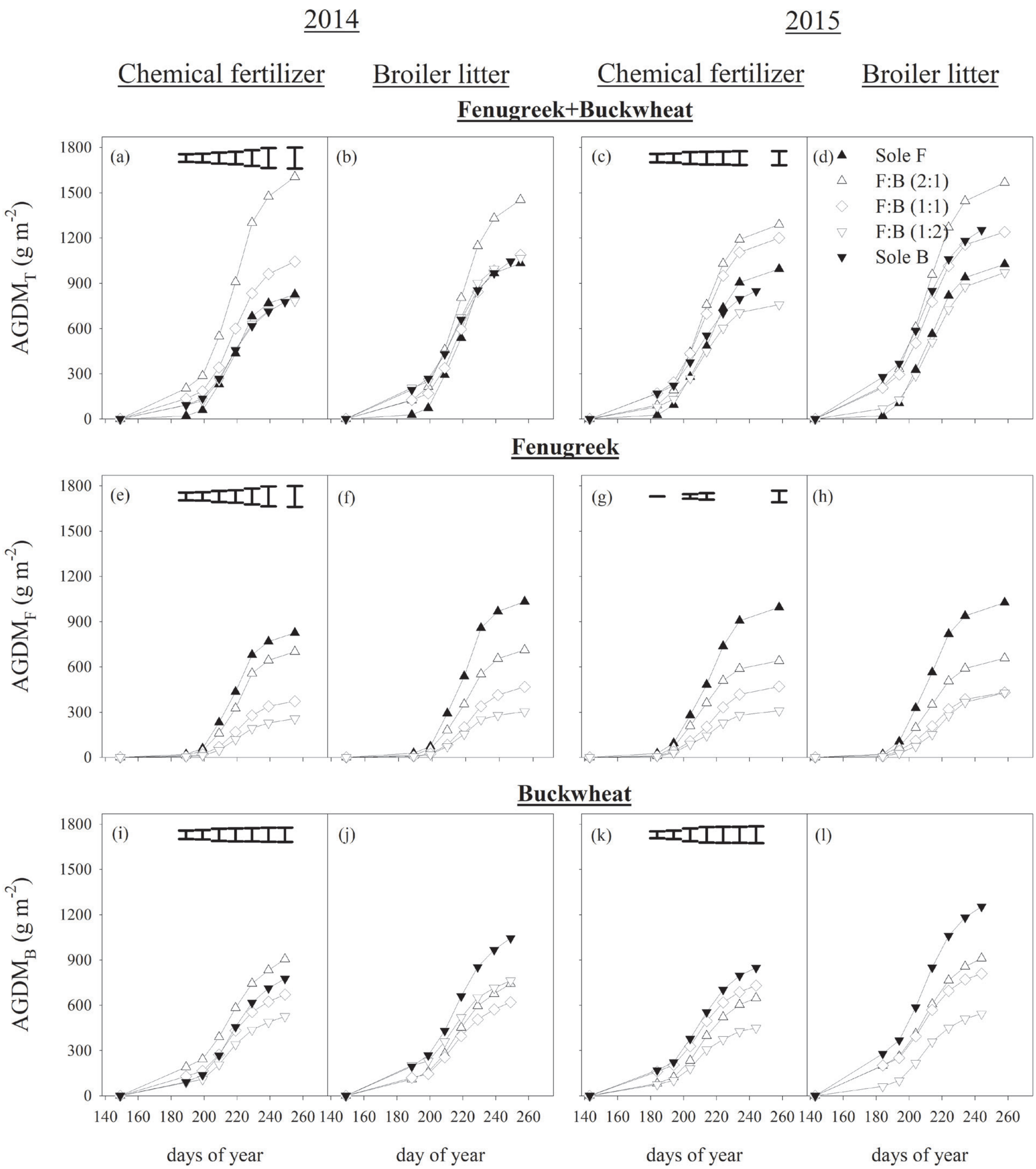

Figure 1. Total above-ground dry matter ($AGDM_T$) (a–d) and above-ground dry matter of fenugreek ($AGDM_F$) (e–h) and buckwheat ($AGDM_B$) (i–l) at different harvest dates (HD) as affected by crop stand × fertilizer type in 2014 and 2015. Sole F and Sole B are sole cropping of fenugreek and buckwheat, respectively. F:B (2:1), F:B (1:1) and F:B (1:2) are two rows of fenugreek + one row of buckwheat, one row of fenugreek + one row of buckwheat, and one row of fenugreek + two rows of buckwheat, respectively. Error bars are LSD ($p < 0.05$); error bars are valid for the graph where they are shown, plus the adjoining right graph.

Abbildung 1. Gesamte oberirdische Biomassse ($AGDM_T$) (a-d) und die oberirdische Biomasse von Bockshornklee ($AGDM_F$) (e-h) und Buchweizen ($AGDM_B$) (i-l) zu verschiedenen Ernteterminen (HD) beeinflusst von Pflanzenbestand × Düngerart in den Jahren 2014 und 2015. Sole F and Sole B sind die Reinsaaten von Bockshornklee und Buchweizen. F:B (2:1), F:B (1:1) und F:B (1:2) stehen für zwei Reihen Bockshornklee + eine Reihe Buchweizen, eine Reihe Bockshornklee + eine Reihe Buchweizen und eine Reihe Bockshornklee + zwei Reihen Buchweizen. Fehlerbalken zeigen die Grenzdifferenz (LSD, $p < 0,05$), wobei die Fehlerbalken für die Graphik, in der sie gezeigt werden, sowie in der rechts angrenzenden Graphik gültig sind.

F:B (1:1) > F:B (1:2). The same observations were made for CF in 2015, whereas for BL, the ranking of $AGDM_F$ was: Sole F > F:B (2:1) > F:B (1:1), F:B (1:2). At HD 7, the $AGDM_F$ was compared to Sole F at 71% for F:B (2:1), 45% for F:B (1:1) and 33% for F:B (1:2) (means over both fertilizers and both years) (Figures 1 g–h).

In 2014, from HD 1 onward, the $AGDM_F$ of Sole F was higher with BL than with CF, whereas the $AGDM_F$ of other crop stands did not differ between fertilizer treatments. In 2015, at HD 7, BL resulted in a higher $AGDM_F$ with F:B (1:2) compared to CF. At HD 7, BL resulted in an increase of $AGDM_F$ by 17% in 2014 and 5% in 2015, compared to CF (means overall crop stands).

A significant interaction of crop stand × fertilizer type was observed for $AGDM_B$ at all the harvest dates in both years (Figures 1 i–l). Sole B had the highest $AGDM_B$ in BL treatments in 2014 and with CF and BL in 2015, but not with CF in 2014, since the F:B (2:1) showed higher values. In 2014, with CF at HD 7, $AGDM_B$ was ranked as follows: F:B (2:1) > Sole B > F:B (1:1) > F:B (1:2). For the BL, the ranking was as follows: Sole B > F:B (1:2), F:B (2:1) > F:B (1:1). In 2015, at HD 7, independent of fertilizer treatment, the $AGDM_B$ was ranked as follows: Sole B > F:B (1:1), F:B (2:1) > F:B (1:2).

The $AGDM_B$ compared to Sole B at 84% for F:B (2:1), 74% for F:B (1:1) and 59% for F:B (1:2) (means over both fertilizers and both years). Consequently, the $AGDM_B$ of F:B (2:1) and F:B (1:1) was higher than the share of buckwheat in the sowing ratio (i.e., 33% or 50%, respectively, of Sole B); whereas, the $AGDM_B$ of F:B (1:2) was slightly below its sowing ratio share (66%). In 2014, from HD 1 onward, the $AGDM_B$ was higher with BL than with CF for Sole B and F:B (1:2), but higher with CF than with BL for F:B (2:1), whereas no differences between fertilizer treatments were observed for F:B (1:1). In 2015, from HD 1 onward, the BL resulted in a higher $AGDM_B$ for Sole B and F:B (2:1) for BL than for CF, whereas no differences between fertilizer treatments were observed for F:B (1:2) and for F:B (1:1). At HD 7, BL resulted in an increase of $AGDM_B$ by 10% in 2014 and by 31% in 2015 compared to CF (means over all crop stands).

3.2 Crop growth rates

3.2.1 Total crop growth rates (CGR_T) of crop stands

The total crop growth rates of crop stands (CGR_T) were significantly affected by crop stand × fertilizer type in both years in four out of six harvest dates (Figures 2 a–d). CGR_T increased with time, reaching the highest values between HD 3–5, and declined thereafter. The CGR_T was generally the highest between HD 3–4 and HD 4–5 with 25.1 and 24.2 g m^{-2} d^{-1}, respectively, and lowest between sowing and HD 1 and HD 6–7 with 3.1 and 4.4 g m^{-2} d^{-1}, respectively (means for all crop stands, fertilizers and years).

The CGR_T was generally the highest with a high share of fenugreek in intercrops (F:B (2:1)), followed by Sole F and F:B (1:1); the lowest CGR_T was observed for Sole B and F:B (1:2). The mean CGR_T for pure crop stands between sowing and HD 7 were as follows: 13.1 (Sole F) and 11.6 g m^{-2} d^{-1} (Sole B) and for intercrops: 18.6 (F:B (2:1)), 14.0 (F:B (1:1)) and 11.1 (F:B (1:2)) g m^{-2} d^{-1} (means over both fertilizers and both years).

The mean CGR_T between sowing and HD 7 was higher by 14% with BL (14.6 g m^{-2} d^{-1}) than with CF (12.8 g m^{-2} d^{-1}) (means overall crop stands and both years).

3.2.2 Crop growth rates of fenugreek (CGR_F) or buckwheat (CGR_B)

The crop growth rates of fenugreek (CGR_F) were in both years in all sampling intervals significantly affected by crop stand × fertilizer type (Figures 2 e–h). The CGR_F increased with crop growth reaching the highest values between HD 4–5 (at 16.7 g m^{-2} d^{-1}) before declining again; the lowest values were between sowing and HD 1 and HD 6–7 with 0.3 and 2.7 g m^{-2} d^{-1}, respectively (means overall crop stands, fertilizers and years).

The CGR_F were generally the highest with Sole F and diminished with a decreasing share of fenugreek in the intercrops. The mean CGR_F for Sole F between sowing and HD 7 was 13.1 g m^{-2} d^{-1} and for fenugreek in F:B (2:1), F:B (1:1) and F:B (1:2) was 9.0, 5.8 and 4.3 g m^{-2} d^{-1}, respectively (means over both fertilizers and both years); which represents 69%, 44% and 34% of Sole F. Consequently, the CGR_F of fenugreek in intercrops reflected its sowing share (compared to Sole F). The mean CGR_F from sowing to HD 7 was 10% higher with BL (8.5 g m^{-2} d^{-1}) than with CF (7.7 g m^{-2} d^{-1}) (means overall crop stands and both years).

The crop growth rates of buckwheat (CGR_B) were in most sampling intervals significantly affected by crop stand × fertilizer type in both years (Figures 2 i–l). The CGR_B increased with crop growth reaching the highest values between HD 3–5 (15.2 g m^{-2} d^{-1}) before declining again; lowest values were observed between sowing and HD 1 with 3.5 g m^{-2} d^{-1} (means overall crop stands, fertilizers and years).

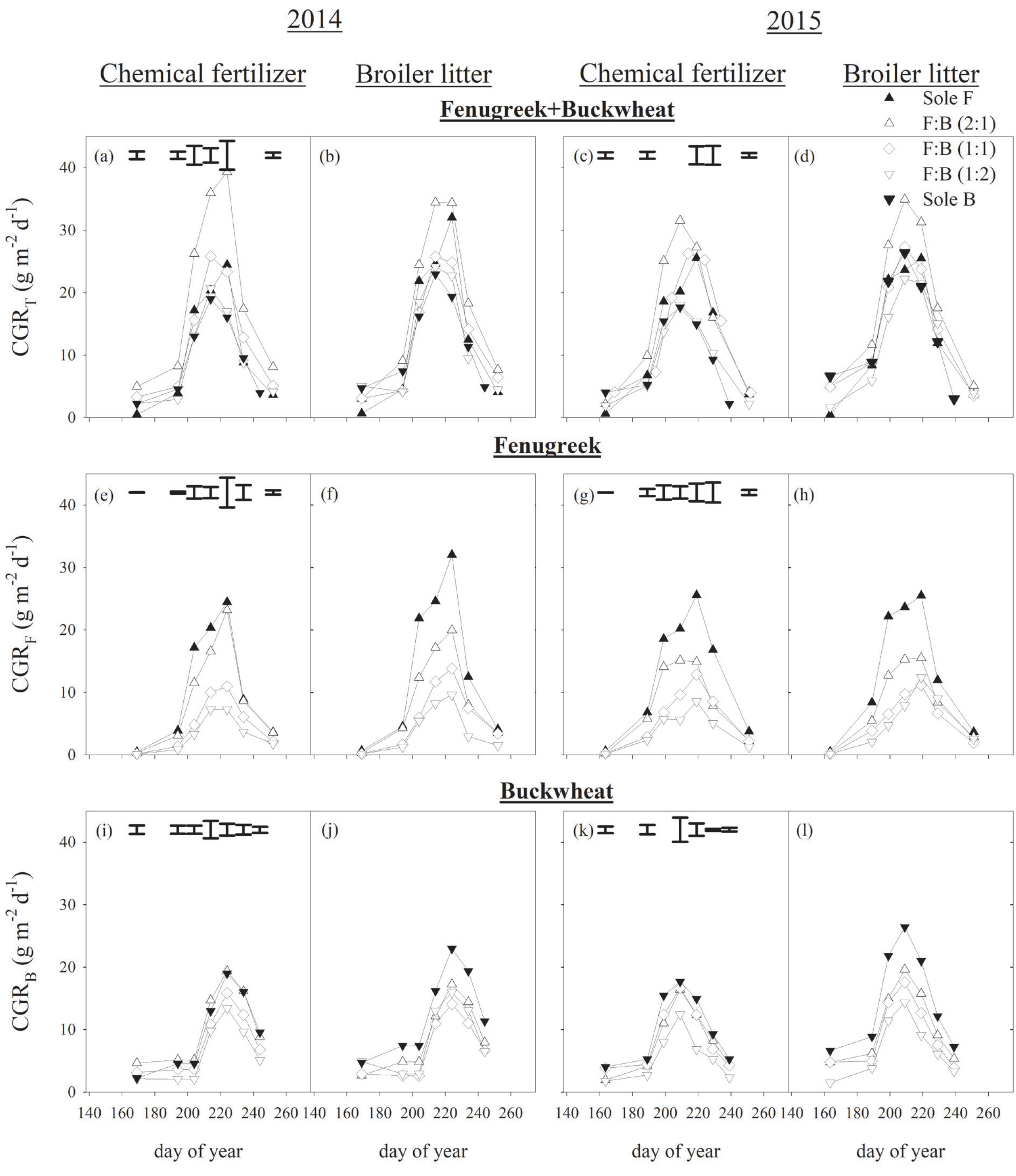

Figure 2. Total crop growth rates (CGR_T) (a–d) and crop growth rates of fenugreek (CGR_F) (e–h) or buckwheat (CGR_B) (i–l) between different harvest dates (HD) as affected by crop stand × fertilizer type in 2014 and 2015. Error bars are LSD ($p < 0.05$); error bars are valid for the graph where they are shown, plus the adjoining right graph. See Figure 1 for description of treatments.

Abbildung 2. Gesamte Wachstumsraten (CGR_T) (a-d) und die Wachstumsraten von Bockshornklee (CGR_F) (e-h) und Buchweizen (CGR_B) (i-l) zwischen verschiedenen Ernteterminen (HD) beeinflusst von Pflanzenbestand × Düngerart in den Jahren 2014 und 2015. Fehlerbalken zeigen die Grenzdifferenz (LSD, p < 0,05), wobei die Fehlerbalken für die Graphik, in der sie gezeigt werden, sowie in der rechts angrenzenden Graphik gültig sind. Siehe Abbildung 1 für die Beschreibung der Behandlungen.

The CGR_B were generally highest with Sole B. The mean CGR_B for Sole B between sowing and HD 7 was at 11.9 g m^{-2} d^{-1} and for buckwheat in F:B (2:1), F:B (1:1) and F:B (1:2) was 9.7, 8.3 and 6.9 g m^{-2} d^{-1}, respectively (means over both fertilizers and both years), which represents 81%, 70% and 58% compared to Sole B. Thus, the CGR_B in the intercrops F:B (2:1) and F:B (1:1) was considerably higher than its sowing share (compared to Sole B).
The mean CGR_B from sowing to HD 7 was higher by 18% for BL (10.0 g m^{-2} d^{-1}) than for CF (8.5 g m^{-2} d^{-1}) (means overall crop stands and both years).

3.3 Relative growth rates

3.3.1 Total relative growth rates (RGR_T) of crop stands

The total relative growth rates of fenugreek-buckwheat (RGR_T) were generally highest between HD 2–3 before declining until the final harvest (Figures 3 a–d). The highest value was 76.4 mg g^{-1} d^{-1} (between HD 1–2) and the lowest values were 3.9 and 4.2 mg g^{-1} d^{-1} between HD 5–6 and HD 6–7, respectively (means overall crop stands, fertilizers and years).
The mean RGR_T between HD 1–7 was highest for Sole F (61.1 mg g^{-1} d^{-1}) and lowest for Sole B (27.9 mg g^{-1} d^{-1}). The intercrops showed the following values: 35.0 (F:B (2:1)), 32.4 (F:B (1:1)) and 34.9 (F:B (1:2)) mg g^{-1} d^{-1} (means over both fertilizers and both years).
The mean RGR_T from HD 1–7 was 3.6% higher for CF (39.0 mg g^{-1} d^{-1}) than for BL (37.6 mg g^{-1} d^{-1}) (means overall crop stands and both years).

3.3.2 Relative growth rate of fenugreek (RGR_F) or buckwheat (RGR_B)

The relative growth rate of fenugreek (RGR_F) was highest between HD 2–3 in 2014 (128.2 mg g^{-1} d^{-1}) and HD 1–2 in 2015 (159.2 mg g^{-1} d^{-1}) (Figures 3 e–h). Then RGR_F declined until the final harvest. The lowest values of RGR_F were observed between HD 6–7 with 5.7 mg g^{-1} d^{-1} (means over all crop stands, fertilizers and years).
The mean RGR_F between HD 1–7 for Sole F, F:B (2:1), F:B (1:1) and F:B (1:2) were 61.2, 65.1, 67.5 and 66.5 mg g^{-1} d^{-1}, respectively. Thus, the RGR_F for F:B (2:1), F:B (1:1) and F:B (1:2) was higher by 6.4%, 10.3% and 8.6%, respectively compared with Sole F (means over both fertilizers and both years). Regarding fertilizer, both CF and BL had a mean RGR_F between HD 1–7 of 64.9 mg g^{-1} d^{-1} (means overall crop stands and both years).

The relative growth rate of buckwheat (RGR_B) was highest between HD 2–3 (55.1 mg g^{-1} d^{-1}) and declined with time to have the lowest values between HD 6–7 (7.0 mg g^{-1} d^{-1}) (means over all crop stands, fertilizers and years) (Figures 3 i–l).
The mean RGR_B between HD 1–7 for Sole B, F:B (2:1), F:B (1:1) and F:B (1:2) was 29.2, 30.2, 26.0 and 29.8 mg g^{-1} d^{-1}, respectively. Thus, the RGR_B for F:B (2:1) and F:B (1:2) were higher by 3.1% and 1.8% whereas for F:B (1:1) lower by 11.0% compared with Sole B (means over both fertilizers and both years). Regarding fertilizer, CF and BL had a mean RGR_B between HD 1-7 of 29.8 and 27.8 mg g^{-1} d^{-1}, respectively (means over all crop stands and both years). Thus, the RGR_B with CF was by 6.8% higher than with using BL.

3.4 Land equivalent ratios

3.4.1 Total land equivalent ratios of above-ground dry matter (AGDM-LER_T) of crop stands

The AGDM-LER_T were significantly affected by crop stand × fertilizer type in seven (2014) and in four (2015) out of seven harvest dates (Figures 4 a–d). The AGDM-LER_T were generally highest at HD 1 with 1.27 and lowest at HD 3 with 1.18 (means over all crop stands, fertilizers and years). The mean AGDM-LER_T between HD 1–7 for F:B (2:1), F:B (1:1) and F:B (1:2) were 1.56, 1.19 and 0.91, respectively (means over both fertilizers and both years). At HD 7, the AGDM-LER_T were for F:B (2:1), F:B (1:1) and F:B (1:2) were 1.55, 1.19 and 0.98, respectively (means over both fertilizers and both years).
The mean AGDM-LER_T between HD 1–7 was by 28.9% higher with CF than with BL and at HD 7 by 17.5% higher with CF than with BL (means overall crop stands and both years).

3.4.2 Partial land equivalent ratio of above-ground dry matter (AGDM-LER_F) of fenugreek or buckwheat (AGDM-LER_B)

The AGDM-LER_F was highest at HD 6–7 with 0.49 and lowest between sowing and HD 1 with 0.37 (means overall crop stands, fertilizers and years). The mean AGDM-LER_F between HD 1–7 for F:B (2:1), F:B (1:1) and F:B (1:2) were 0.68, 0.38 and 0.28, respectively (means over both fertilizers and both years). For the fertilizer type, the mean AGDM-LER_F between HD 1–7 was by 6.6% higher with CF than with BL (means over all crop stands and both years) (Figures 4 e–h).

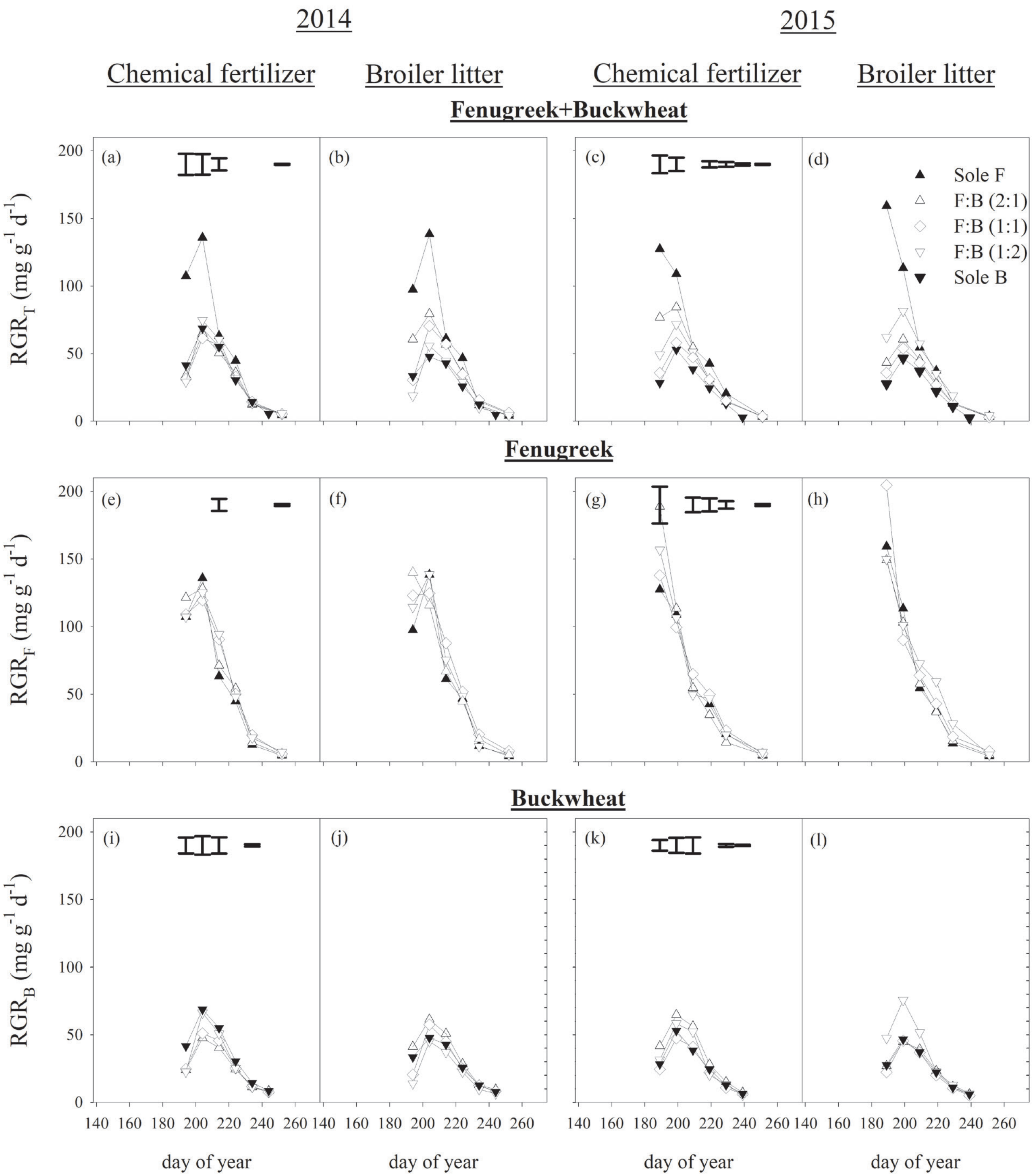

Figure 3. Total relative growth rates (RGR_T) (a–d) and relative growth rate of fenugreek (RGR_F) (e–h) or buckwheat (RGR_B) (i–l) at different harvest dates (HD) as affected by crop stand × fertilizer type in 2014 and 2015. Error bars are LSD ($p < 0.05$); error bars are valid for the graphs where they are shown, plus the adjoining right graph. See Figure 1 for description of treatments.

Abbildung 3. Gesamte relative Wachstumsraten (RGR_T) (a-d) und die relative Wachstumsraten von Bockshornklee (RGR_F) (e-h) und Buchweizen (RGR_B) (i-l) zwischen verschiedenen Ernteterminen (HD) beeinflusst von Pflanzenbestand × Düngerart in den Jahren 2014 und 2015. Fehlerbalken zeigen die Grenzdifferenz (LSD, $p < 0{,}05$), wobei die Fehlerbalken für die Graphik, in der sie gezeigt werden, sowie in der rechts angrenzenden Graphik gültig sind. Siehe Abbildung 1 für die Beschreibung der Behandlungen.

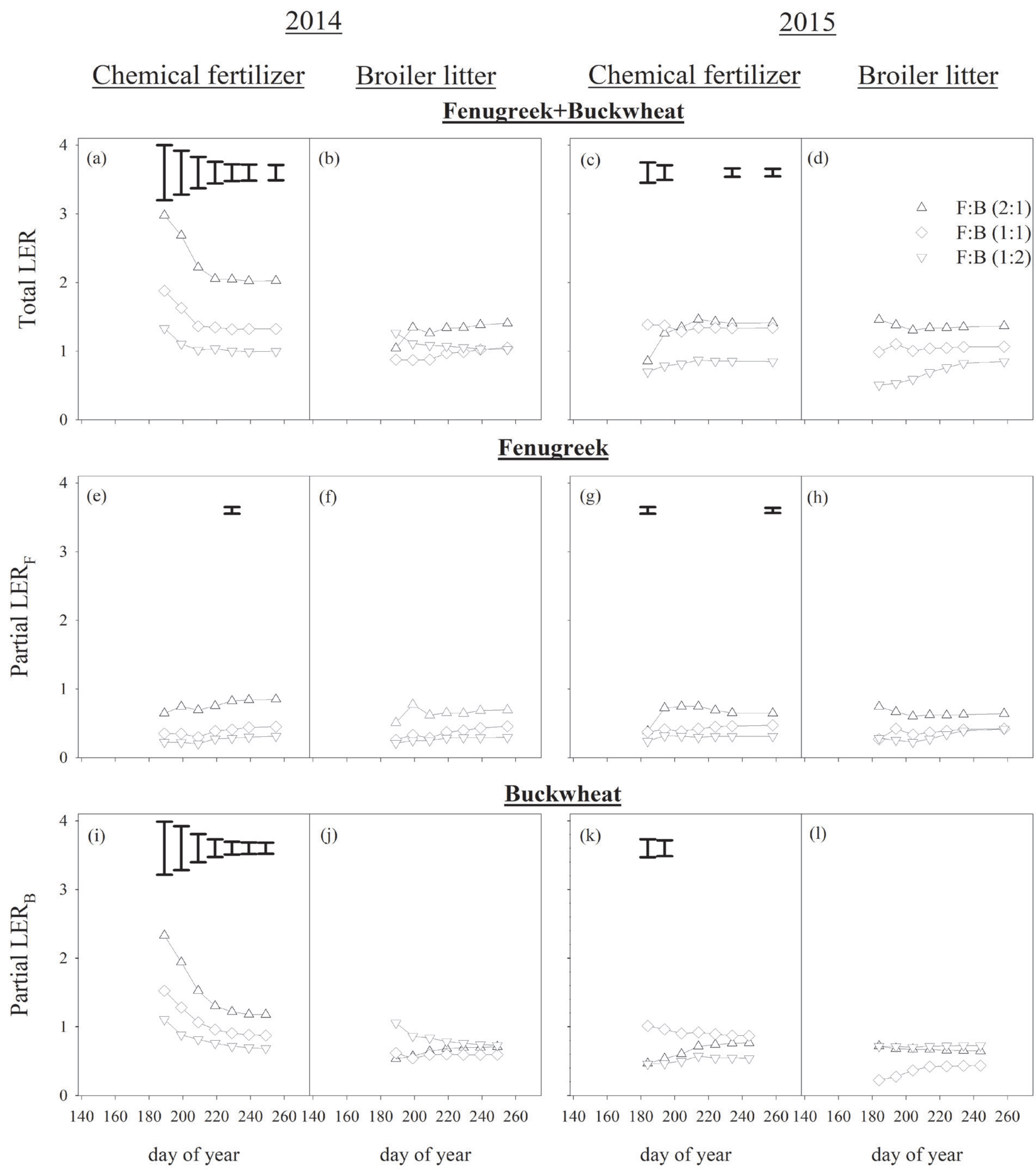

Figure 4. Total land equivalent ratio (LER_T) (a–d) and partial land equivalent ratio of fenugreek (LER_F) (e–h) or buckwheat (LER_B) (i–l) at different harvest dates (HD) as affected by crop stand × fertilizer type in 2014 and 2015. Error bars are LSD ($p < 0.05$); error bars are valid for the graph where they are shown, plus the adjoining right graph. See Figure 1 for description of treatments.

Abbildung 4. Gesamte Flächenäquivalenz (LER_T) (a-d) und die Flächenäquivalenz von Bockshornklee (LER_F) (e-h) und Buchweizen (LER_B) (i-l) zu verschiedenen Ernteterminen (HD) beeinflusst von Pflanzenbestand × Düngerart in den Jahren 2014 und 2015. Fehlerbalken zeigen die Grenzdifferenz (LSD, $p < 0,05$), wobei die Fehlerbalken für die Graphik, in der sie gezeigt werden, sowie in der rechts angrenzenden Graphik gültig sind. Siehe Abbildung 1 für die Beschreibung der Behandlungen.

The AGDM-LER_B was the highest between sowing and HD 1 with 0.90 and lowest at HD 6–7 with 0.73 (means over all crop stands, fertilizers and years). The mean AGDM-LER_B between HD 1–7 for F:B (2:1), F:B (1:1) and F:B (1:2) were 0.87, 0.74 and 0.72, respectively (means over both fertilizers and both years). For the fertilizer type, the mean AGDM-LER_B between HD 1–7 was by 43.9% higher for CF than for BL (means over all crop stands and both years) (Figures 4 i–l).

4. Discussion

A higher $AGDM_T$ could be achieved by intercropping fenugreek and buckwheat with a medium to high share of fenugreek and a low to medium share of buckwheat (F:B (2:1) and F:B (1:1)) compared to the pure stands of the two crops in both years. The $AGDM_T$ was higher than for pure stands for F:B (1:1) and F:B (2:1) amended with BL and for F:B (2:1) amended with CF. Similar to these results, Wasaya et al. (2013) have reported for wheat-fenugreek intercrops a yield increase of 19% to 38% compared to sole crops, with the lower increase obtained in intercrops using a 1:1 wheat-fenugreek share, whereas the higher increase was obtained in intercrops using a 1:3 wheat-fenugreek share. Similarly, Osman and Nersoyan (1986) reported that the highest dry matter yields were observed with a high proportion of the legume in cereal-common vetch intercrops grown for forage production.

At the final harvest, the distribution of the AGDM of fenugreek was similar with its sowing shares. Whereas, the distribution of the AGDM of buckwheat was in F:B (2:1) and F:B (1:1) intercrops higher compared to its initial sowing share. This indicates, that neither competition nor growth promotion were observed for fenugreek through intercropping, whereas the growth of individual buckwheat plants was enhanced by intercropping (compared to individual buckwheat plants in pure stands) in intercrops where buckwheat was grown with a low to medium share.

Advantages of intercropping are attributed to a more efficient utilization of finite resources such as light, nutrients and water (Musa et al., 2010). Yield advantages have been realized mainly due to the higher AGDM production of buckwheat in the intercrops (compared to its sowing ratio). The $AGDM_F$ in intercrops was mainly governed by its sowing ratio, whereas the $AGDM_B$ appeared to be governed by less interspecific competition and/or growth promotion processes (Hauggaard-Nielsen et al., 2008). Yield increases in intercrops have previously been explained by the increased growth of the non-legume component when the non-legumes were taller than the legumes (Rerkasem et al., 1988). This provided buckwheat plants with more available radiation for an improved photosynthesis (Nasiri et al., 2014) due to their taller growth than fenugreek (data not shown). Furthermore, there is a higher N availability for the individual non-legume plant in intercrops with low non-legume density (compared to the pure stand) (Kübler et al., 2008).

Highest CGR_T was generally obtained by F:B (2:1). Agegnehu et al. (2006) reported that a high seeding ratio of the legume decreased the growth rate of the cereal in intercrops. Contrary to those findings, we observed the highest CGR_B within the intercrops with highest F and lowest B share. The CGR_F was lower in intercrops. This is in agreement with Ghosh (2004) who reported that the crop growth rate of groundnut was significantly lower in groundnut-pearl millet intercrops than for sole groundnut. The relative growth rates were generally highest between HD 1–3 before declining until final harvest. These results are similar to findings of Neugschwandtner et al. (2013) who also observed that the RGR declined with time. This is due to the increase of the share of non-assimilatory tissues (e.g., stems, inflorescences) with time (Nogueira et al., 1994). The RGR of fenugreek from HD 1–7 was much higher than the RGR_B principally because the $AGDM_B$ was considerably higher at the first harvest date (HD 1) than the $AGDM_F$ (the final AGDMs do not differ very much). Consequently, the final yields could be obtained in a similar range despite the lower RGR_B from HD 1–7.

Both crops showed a similar growth pattern in 2015; their growth rates were highest between HD 4–5 and the relative crop growth rates were highest between HD 2–3 (but between HD 1–2 in 2014). Anyhow, intercrops are most productive when the partner differ greatly in their growth duration as this allows for an asynchronicity of peak resource requirements (Fukai and Trenbath, 1993).

Broiler litter generally led to a higher $AGDM_T$. $AGDM_F$ was higher with BL than with CF only in Sole F, whereas the $AGDM_F$ of the intercrops did not differ between the fertilizer treatments. $AGDM_B$ was generally higher with BL than with CF. Consequently, the partly higher $AGDM_T$ was a result of higher $AGDM_B$ in the BL amended intercropped treatments. From our results in the present study, and also the results explained by Salehi et al. (2018), it appears that the broiler litter fertilizer increased N and P content of plants and soil fertility more effectively than the chemical fertilization that led to better plant development. A higher AGDM production with BL than with CF could be due to an appropriate supply of soil nutrients by broiler litter which provide an optimum balance between N and P in the calcareous soils of the study site (Ghosh et al., 2004; Singh et al., 2009; Fereidooni et al., 2013). Also, Siavoshi et al. (2010) have shown that organic fertilizer resulted in higher yields of rice (*Oryza sativa* L.) than with chemical fertilizer. As with AGDM, the crop growth rates were generally higher with BL than with CF, whereas RGR were generally higher with CF than with BL. The reason for that is $AGDM_T$ at HD 1 was much higher with BL than with CF. This explains why the RGR was lower for BL than for CF from HD 1–7.

The highest AGDM-LER_T were generally achieved with the highest F and the lowest B share (F:B (2:1)). Similar to our observations, Szumigalski and Van Acker (2008) reported that intercropping produced LER values for dry matter yield that were significantly higher than unity. A value greater than 1.0 indicates a beneficial association between the two crops. In our study, a higher partial AGDM-LER_F and partial AGDM-LER_B were obtained with increasing the share of fenugreek and decreasing the share of buckwheat. Similar to the AGDM-LER_T, with a F:B (2:1) the fenugreek and buckwheat accumulated a relatively higher above-ground dry matter.

The main advantage was achieved due to a higher partial LER of buckwheat in early growth stages (especially for buckwheat grown with a low to medium share on the intercrops). A LER > 1 can often be attributed to enhanced nitrogen fixation and nitrogen uptake in intercropping (Salehi et al., 2018). In a previous study, we demonstrated that the seed harvest of fenugreek-buckwheat intercrops obtained similar LER_T of > 1 and a higher total and partial LER for both crops were also found with a low to medium share of buckwheat (Salehi et al., 2017b). The AGDM-LER_T was higher with CF than with BL, as with BL, the AGDM at the final harvest was higher than with CF (except for fenugreek in 2015); thus, the advantages through intercrops were lower.

5. Conclusion

We observed a higher $AGDM_T$ and AGDM-LER_T for intercrops of fenugreek and buckwheat with a medium to high share of fenugreek and a low to medium share of buckwheat compared to their corresponding pure stands grown in semi-arid conditions. Growth analysis revealed that fenugreek produced at all sowing ratios per area and per day similar amounts of AGDM compared to its corresponding share on the sowing ratio; whereas, buckwheat could produce in intercrops with a low to medium share of buckwheat more AGDM per area and per day compared to its share on the sowing ratio. Broiler litter was more effective to enhance $AGDM_T$ and CGR_T than chemical fertilizer. Thus, growing fenugreek and buckwheat in suitable intercrops with broiler litter can be beneficial for increasing the biomass productivity of these crops in semi-arid environments.

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