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Impact of Different Barley-Based Cropping Systems on Soil Physicochemical Properties and Barley Growth under Conventional and Conservation Tillage Systems

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Abstract: This two-year study observed the influence of various barley-based cropping systems on soil physicochemical properties, allometric traits and biomass production of barley sown under different tillage systems. Barley was cultivated in different cropping systems (CS), i.e., fallow-barley (fallow-B), maize-barley (maize-B), cotton-barley (cotton-B), mungbean-barley (mungbean-B) and sorghum-barley (sorghum-B) under zero tillage (ZT), minimum tillage (MT), strip tillage (ST), conventional tillage (CT) and bed-sowing (BS). Interaction between different CS and tillage systems (TS) positively influenced soil bulk density (BD), total porosity, available phosphorus (P), ammonical and nitrate nitrogen (NH_4-N and NO_3-N), available potassium (K), allometric traits and biomass production of barley. The highest soil BD along with lower total porosity were noted in ZT leading to lesser leaf area index (LAI), leaf area duration (LAD), specific leaf area (SLA), crop growth rate (CGR) and net assimilation rate (NAR) of barley. Nonetheless, bed-sown barley produced the highest biomass due to better crop allometry and soil physical conditions. The highest postharvest soil available P, NH_4-N, NO_3-N, and K were recorded for zero-tilled barley, while BS followed by CT recorded the lowest nutrient contents. Barley in mungbean-B CS with BS produced the highest biomass, while the lowest biomass production was recorded for barely sown in fallow-B cropping system with ZT. In conclusion, barley sown after mungbean (mungbean-B cropping system) with BS seems a pragmatic choice for improving soil fertility and subsequently soil health.

Keywords: zero tillage; bed sowing; cropping systems; bulk density; leaf area index; barley

1. Introduction

World population is witnessing a rapid increase and expected to reach ~9100 million, which would require 3000 million tons of grain crops' production by 2050 [1]. Therefore, improving crop yields to fulfil the rising demand of massive population is a dire need of the time [2]. Barley (*Hordeum vulgare* L.), rice (*Oryza sativa* L.), maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.) are regarded as main cereal crops, which provide >50% of total caloric intakes for human population [3]. Barley is a fast-growing, annual cereal, grown during winter season. Commonly, it is cultivated as a cover crop to preserve soil and usually used as forage. Wheat crop could be substituted with barley as the later can withstand drought and adverse environmental conditions [4]. Similarly, barley performs better in low rainfall areas where other crops fail to establish [5]. Barley is an important food source for African countries, while it is primarily cultivated for animal feed in Pakistan [6]. It is an important cereal crop that ranks 4th (after wheat, rice, and maize crop) by production and 5th by cultivation among cereals throughout the world.

Tillage is regarded as the main soil management tool used to improve soil physical conditions and crop growth. Crop performance and soil properties are significantly altered by tillage practices [7]. Tillage exerts 20% impact on crop yields among the factors affecting crop production and ensures sustainable use of available resources through altering soil characteristics [8,9]. Management practices opted to alter soil structure could have positive or negative consequences [10–12]. Soil health is negatively affected by unsuitable management practices, which decrease crop productivity [13]. Lowering soil disturbance by reducing tillage intensity alters several physical, chemical and biological properties of soil [7,14–16]. Any change in soil physical condition modifies ecosystem functions [17]. Nonetheless, excessive tillage practices negatively affect soil physical conditions [14,18].

Conservation agriculture (CA) is a resource-saving and environment-friendly approach. It consists of least or no soil disturbance (zero or no tillage) along with stable soil cover [19]. The CA plays a significant role in water conservation and efficient utilization of natural resources through integrated management of soil moisture and nutrients [20]. The CA or minimum tillage results in better system productivity than conventional tillage practices [21,22]. Conservation tillage practices like zero tillage (ZT) combined with crop residues and nutrient management improve soil organic carbon (SOC) content and its retention in soil layer, resulting in moisture retention and improved hydraulic conductivity, soil porosity and soil aggregation [23]. Better soil physical conditions stimulate root growth and nutrient cycling [24]. Reduced tillage practices and residue retention influence soil properties such as organic matter, nutrients and pH [14,25,26]. Total nitrogen is increased by adoption of conservation tillage practices, including residues' retention followed by nutrient application and ZT [23].

Cropping systems exert significant impacts on soil physicochemical properties, which ultimately affect crop yield [27]. Soil physical properties are positively influenced by cropping systems and management practices, i.e., residue retention and tillage [26–29]. The CA could conserve soil from detrimental effects of excessive tillage and enhance soil fertility in different cropping systems [15]. However, limited literature is available for the impact of different tillage practices on soil properties in barley-based cropping systems [30,31]. Nonetheless, different barley-based cropping systems have rarely been compared for their impact on soil properties under conventional and conservation tillage practices.

Therefore, this two-year field study assessed the soil physicochemical properties, allometry and biomass production of barley crop grown in different barley-based cropping systems under conventional and conservation tillage systems. The major objective of the study was to infer the impact of different barley-based cropping systems on soil physicochemical properties. Moreover, exploring the impact of different tillage systems on soil physicochemical properties was the second major objective of the study.

2. Materials and Methods

2.1. Experimental Site

This 2-year field experiment was conducted at Agronomy Farm, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan (30.2° North, 71.43° East, and 122 m above sea level), Pakistan during winter seasons of 2017–2018 and 2018–2019.

Experimental soil was loamy in texture with 8.20 and 8.25 pH, 2.78 and 2.80 mS cm^{-1} EC, 0.03 and 0.03% total nitrogen (N), 7.25 and 7.18 mg kg^{-1} available phosphorus (P), 240 and 230 mg kg^{-1} available potassium (K) and 0.60 and 0.63% organic matter during 1st and 2nd year of study, respectively. Weather data during both cropping years are given in Table 1.

Table 1. Weather data for the period of research at the experimental site.

Months	2017–2018				2018–2019			
	Mean Temperature (°C)	Mean Relative Humidity (%)	Mean Daily Sunshine (h)	Total MonthlyRainfall (mm)	Mean Temperature (°C)	Mean Relative Humidity (%)	Mean Daily Sunshine (h)	Total MonthlyRainfall (mm)
May	34.0	63.0	4.8	0.1	32.9	52.6	10.3	0.0
June	33.1	74.9	4.5	45.6	34.6	64.7	3.5	0.0
July	33.6	73.0	7.2	4.9	33.2	71.2	5.5	0.0
August	31.8	85.2	7.7	30.0	32.4	75.1	4.3	0.0
September	30.6	77.1	8.0	10.0	29.8	77.1	6.8	0.0
October	27.0	77.6	7.4	4.2	23.0	75.1	5.5	0.0
November	18.0	81.4	3.7	16.0	18.9	82.2	4.4	0.0
December	14.6	75.0	5.2	16.0	14.2	85.0	5.9	0.0
January	13.6	83.1	4.4	0.0	12.2	86.3	4.3	11.0
February	17.5	75.4	4.9	6.8	14.4	80.6	6.7	25.1
March	23.5	70.9	7.2	0.0	19.5	75.9	7.3	21.0
April	29.4	56.7	5.4	3.0	28.6	73.1	7.7	12.7

2.2. Experimental Details

Barley was sown under five different tillage systems, i.e., zero tillage (ZT), minimum tillage (MT), strip tillage (ST), conventional tillage (CT) and bed-sowing (BS) in fallow-B, maize-B, cotton-B, mungbean-B and sorghum-B cropping systems. In case of ZT, barley seeds were directly drilled using a ZT drill and residues of previous summer crops were retained in the soil. In MT, seeds were sown with the help of manual drill by disturbing limited soil. In case of ST, seedbeds were made in the form of strips without interfering the remaining field. In CT, field was cultivated two times with tractor-drawn cultivator followed by planking. In BS, similar method of field preparation was used as in CT and beds were prepared with manual bed maker. Experiment was laid out using randomized complete block design with split-plot arrangement. Tillage systems were kept in main, while cropping systems were allocated to sub-plots. During both years, experiment was replicated three times with net plot size of 5 m × 2.7 m.

2.3. Crop Husbandry

During both seasons, experimental field was irrigated with a pre-soaking (locally called *rouni*) irrigation of 10 cm before sowing of all crops. When soil attained appropriate moisture level, field was prepared following respective tillage systems. Recommended production technologies (http://agripunjab.gov.pk/) were followed for the cultivation of all crops included in the study. The recommended crop production practices for all crops are summarized in Table 2. For barley crop, 75 kg N and 50 kg P ha^{-1} were applied using urea and di-ammonium phosphate as sources, respectively. Half of N and whole amount of P were applied at sowing, whereas remaining N was applied with 1st irrigation. Barley was irrigated four times during the whole growing season. Crop was harvested at 105 days after sowing (DAS) to record total biomass production.

Table 2. Crop husbandry of different crops sown in barley-based cropping systems of the study.

Crops	Sowing Time	Cultivars	Seed Rate (kg ha^{-1})	PP	Fertilizer NPK (kg ha^{-1})	Plant Spacing (cm)	Row Spacing (cm)
			Summer Seasons (2017 and 2018)				
Cotton	15th May	IUB-2013	25	6	250-200-0	20	75
Sorghum	10th June	YS-16	10	11	100-60-0	15	60
Mungbean	15th June	NIAB-Mung 2011	20	33	20-60-0	10	30
Maize	25th July	YH-1898	25	6	200-150-0	22	75
			Winter Seasons (2017–2018 and 2018–2019)				
Barley	10th Nov	Haider-93	80	400	50-25-0		25

PP = Plant population (plants or tillers m^{-2}).

2.4. Soil Physical Properties

Soil bulk density (BD) and total porosity were analyzed by taking soil samples with soil core sampler after barley harvest during both years of study. Three random samples from all experimental plots were taken from 0–15 cm depth, mixed, dried in an oven for 24 h at 105 °C and then BD was measured by following the procedure of Blake and Hartge [32]. Total soil porosity was estimated following Danielson and Sutherland [33].

2.5. Soil Chemical Properties

The soil available NH_4-N, NO_3-N, P and K contents were determined during both years after barley harvest by AB-DTPA method (Ammonium Bicarbonate-DTPA) devised by Soltanpour and Schwab [34] and modified by Soltanpour and Workman [35].

2.6. Allometric Traits of Barley

The barley plants were harvested (1.0 m length of two rows) after every fifteen days to determine different allometric traits. Three random samples were taken from each replication of every experimental unit. Thus, the average was computed from 9 different samples at each harvest for a given allometric trait. The sampling was started at 60 DAS and terminated at 105 DAS of barley crop. The leaves of harvested plants were separated from stem and leaf area was determined by using a leaf area meter (DT Area Meter, model MK2). Briefly, fresh weight of leaves was recorded and then area of pre-weighed leaves was measured. The measured leaf area was converted to total leaf area of the harvested samples by unitary method. Later, leaf area index (LAI) was determined following Watson [36] by dividing total leaf area to total ground area of the harvested samples. Specific leaf area (SLA) was assessed by following Garnier et al. [37], while leaf area duration (LAD) was determined following Hunt [38]. For SLA calculation, a pre-weighed quantity of leaves was taken, their area was measured and leaves were dried in an oven. The SLA was then computed by dividing leaf areas with dry biomass of the leaves. Moreover, the collected plant samples were chaffed and dried for 3 days under sunlight and further oven-died at 75 °C for constant weight. After that crop growth rate (CGR) and net assimilation rate (NAR) were determined by following Hunt [38]. The dry biomass produced by the harvested plants at each harvest was used to record CGR.

2.7. Barley Biomass Yield

Two central rows from each experimental unit were harvested at 105 DAS. The harvested samples were sun-dried for three days and then oven-dried at 75 °C until constant weight. Afterwards, dry weight of these samples was recorded by using spring balance to determine dry biomass yield.

2.8. Statistical Analysis

All data taken during both years of experiment were analyzed following Fisher's analysis of variance (ANOVA) technique and means of all treatments were compared by least significant difference (LSD) test at 5% level of probability [39]. Data relating to soil physicochemical properties had 9 values (3 replications and 3 samples from each replication) for each experimental unit, which were used in statistical analysis. Similarly, biomass yield had 3 values per experimental units included in the statistical analysis. The ANOVA indicated significant differences among experimental years; therefore, data of both years were analyzed, presented and interpreted, separately. The data were tested for normality before ANOVA using Shapiro-Wilk normality test, which indicated normal distribution. Therefore, statistical analysis was performed on original data. The tillage systems by cropping systems' interaction was significant during both years; therefore, only interactions were presented and interpreted in the manuscript. Likewise, graphical presentation of the data relating to LAI, LAD, SLA, CGR and NAR as well as nutrient dynamics was done with MS-Excel Program 2010 along with standard errors (S.E.) of means.

3. Results

3.1. Soil Physical Properties

Soil BD and total soil porosity were significantly affected by TS × CS interaction during both years (Table 3). Barley sown in fallow-B cropping system with ZT recorded the highest soil BD, while lower BD was recorded for barley sown in all CS with BS. Furthermore, higher porosity was noted for all cropping systems with BS except for sorghum-B during 1st year and maize-B systems during 2nd year of study. However, the lowest soil porosity was recorded in all cropping systems with ZT during 2017–2018, and maize-B cropping system with ST and fallow-B, maize-B and sorghum-B cropping systems with ZT during 2018–2019 (Table 3).

Table 3. Impact of barley-based cropping systems on soil bulk density, total porosity and biomass of barley under conservation and conventional tillage systems.

Cropping Systems	2017–2018					2018–2019				
	ZT	MT	ST	CT	BS	ZT	MT	ST	CT	BS
Soil bulk density (g cm^{-3})										
Fallow-B	1.52 a	1.48 c–e	1.49 b–d	1.46 fg	1.45 gh	1.53 a	1.48 de	1.48 de	1.46 fg	1.45 gh
Maize-B	1.50 b	1.49 bc	1.50 b	1.48 de	1.46 fg	1.50 bc	1.50 bc	1.51 b	1.49 cd	1.47 ef
Cotton-B	1.48 de	1.47 ef	1.48 de	1.45 gh	1.44 h	1.48 de	1.48 de	1.46 fg	1.45 gh	1.45 gh
Mungbean-B	1.48 de	1.46 fg	1.48 de	1.44 h	1.44 h	1.48 c–e	1.47 ef	1.47 ef	1.45 gh	1.44 h
Sorghum-B	1.50 b	1.48 de	1.49 b–d	1.46 fg	1.44 h	1.49 b–d	1.48 de	1.50 bc	1.47 ef	1.46 fg
LSD value ($p < 0.05$)	0.01					0.01				
Soil porosity (%)										
Fallow-B	40.5 n	43.7 fg	43.8 e–g	45.1 b–d	46.0 ab	40.4 kl	42.3 gh	42.6 g	44.2 f	46.3 ab
Maize-B	41.0 mn	41.7 k–m	41.9 kl	43.4 g	44.9 cd	40.4 kl	41.3 i–k	40.0 l	44.6 ef	44.8 c–f
Cotton-B	41.3 l–n	42.3 i–k	43.1 g–i	44.6 de	46.3 a	41.8 g–j	42.6 g	43.8 f	45.9 a–c	46.8 a
Mungbean-B	41.3 l–n	42.4 h–k	43.0 g–j	44.5 d–f	45.8 a–c	41.4 g–j	42.6 g	42.1 g–i	44.8 d–f	45.8 b–d
Sorghum-B	40.9 mn	42.1 j–l	42.1 kl	43.3 gh	43.5 g	41.0 j–l	42.4 gh	42.1 g–j	45.2 b–e	46.2 ab
LSD value ($p < 0.05$)			0.84					0.98		

Means not having common letter for interactive effects significantly vary from each other at $p \leq 0.05$., Here, ZT = zero tillage, MT = minimum tillage, ST = strip tillage, CT = conventional tillage, BS = bed sowing, Fallow-B = Fallow-barley, Maize-B = Maize-barley, Cotton-B = Cotton-barley, Mungbean-B = Mungbean-barley and Sorghum-B = Sorghum-barley.

3.2. Soil Chemical Properties

The TS × CS interaction had significant effect on soil NH_4-N and NO_3-N contents, and available P and K (Figures 1–4). The highest NH_4-N contents were recorded for mungbean-B (including maize-B during 2nd year) cropping system with ZT during both years. Likewise, mungbean-B and maize-B systems with ZT recorded higher NO_3-N contents during 1st year of study. However, the lowest NH_4-N and NO_3-N contents were noted in fallow-B cropping system with BS during both years (Figures 2 and 3). Mungbean-B system with ZT noted higher available P and K contents, while fallow-B system with BS had lower available P and K during both years (Figures 3 and 4).

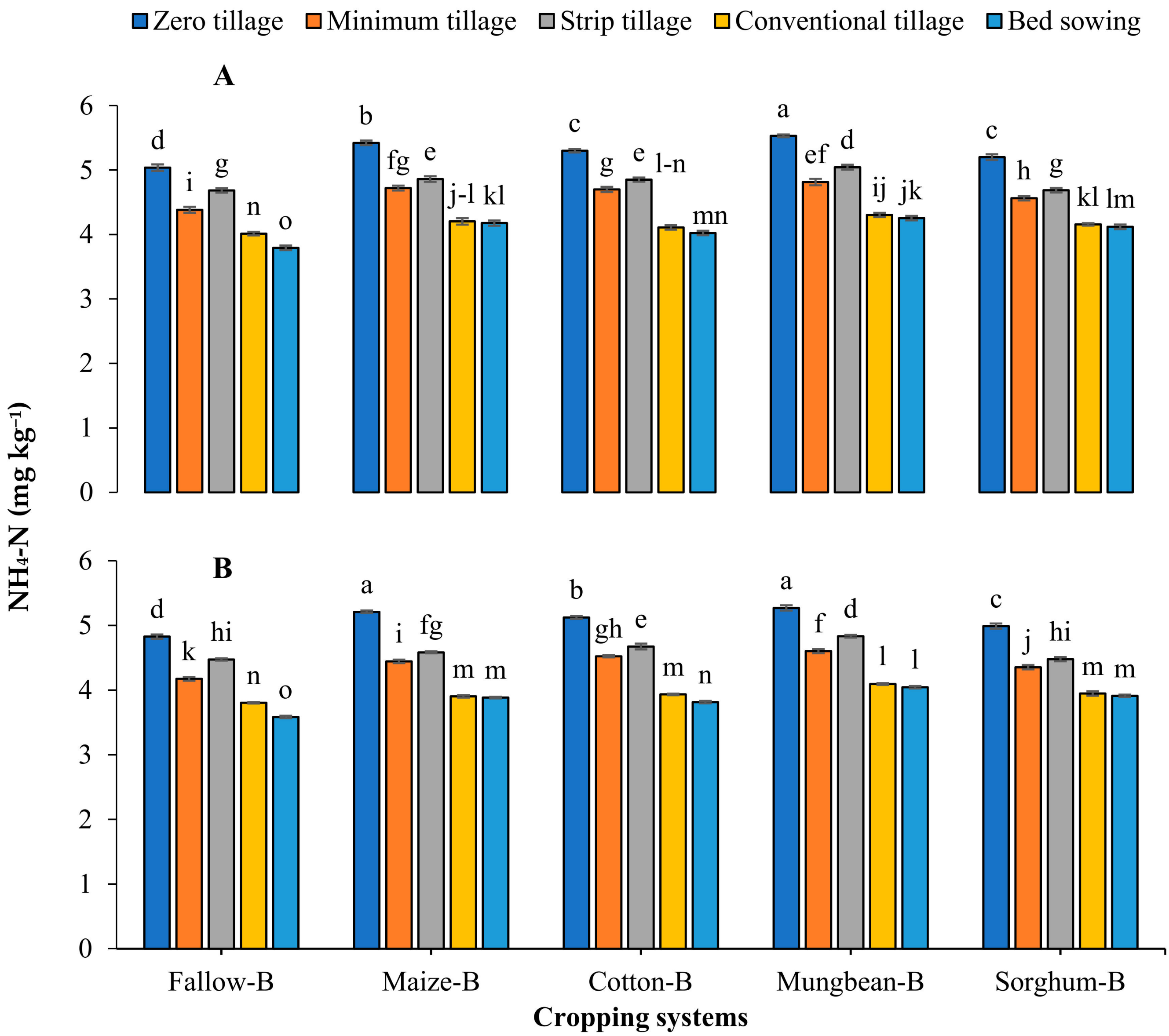

Figure 1. Interactive effect of tillage systems and barley-based cropping Scheme 4. N (mg kg^{-1}) after barley harvest during 2017–2018 (**A**) and 2018–2019 (**B**) ±S.E. In the legend, Fallow-B = Fallow-barley, Maize-B = Maize-barley, Cotton-B = Cotton-barley, Mungbean-B = Mungbean-barley and Sorghum-B = Sorghum-barley. The means sharing same letters do not differ significantly ($p > 0.05$). LSD 0.05 (2017–2018 = 0.10, 2018–2019 = 0.07).

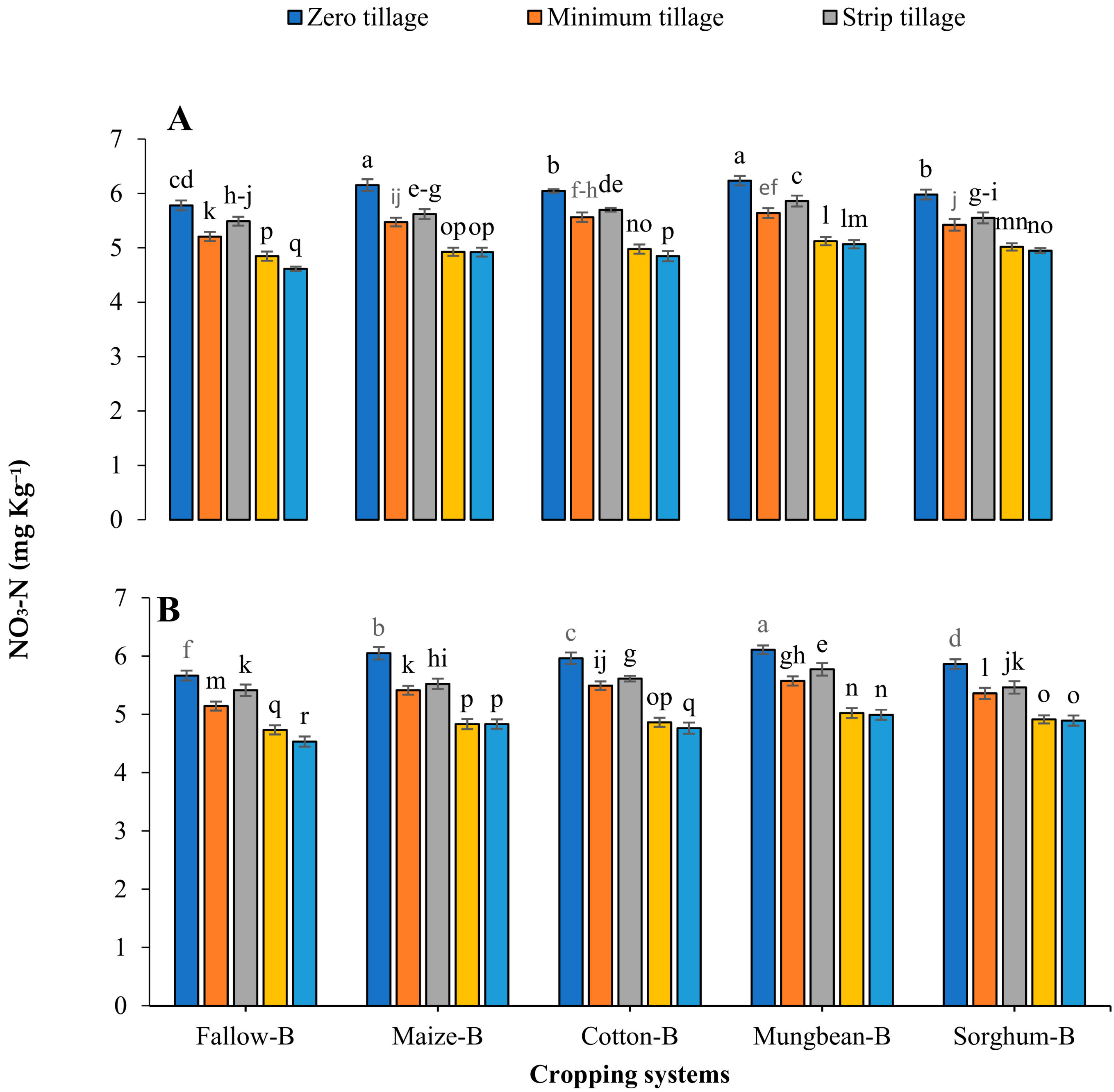

Figure 2. Interactive effect of tillage systems and barley-based cropping systems on soil NO_3-N (mg kg^{-1}) after barley harvest during 2017–2018 (**A**) and 2018–2019 (**B**) ±S.E. In the legend, Fallow-B = Fallow-barley, Maize-B = Maize-barley, Cotton-B = Cotton-barley, Mungbean-B = Mungbean-barley and Sorghum-B = Sorghum-barley. The means sharing same letters do not differ significantly ($p > 0.05$). LSD 0.05 (2017–2018 = 0.08, 2018–2019 = 0.05).

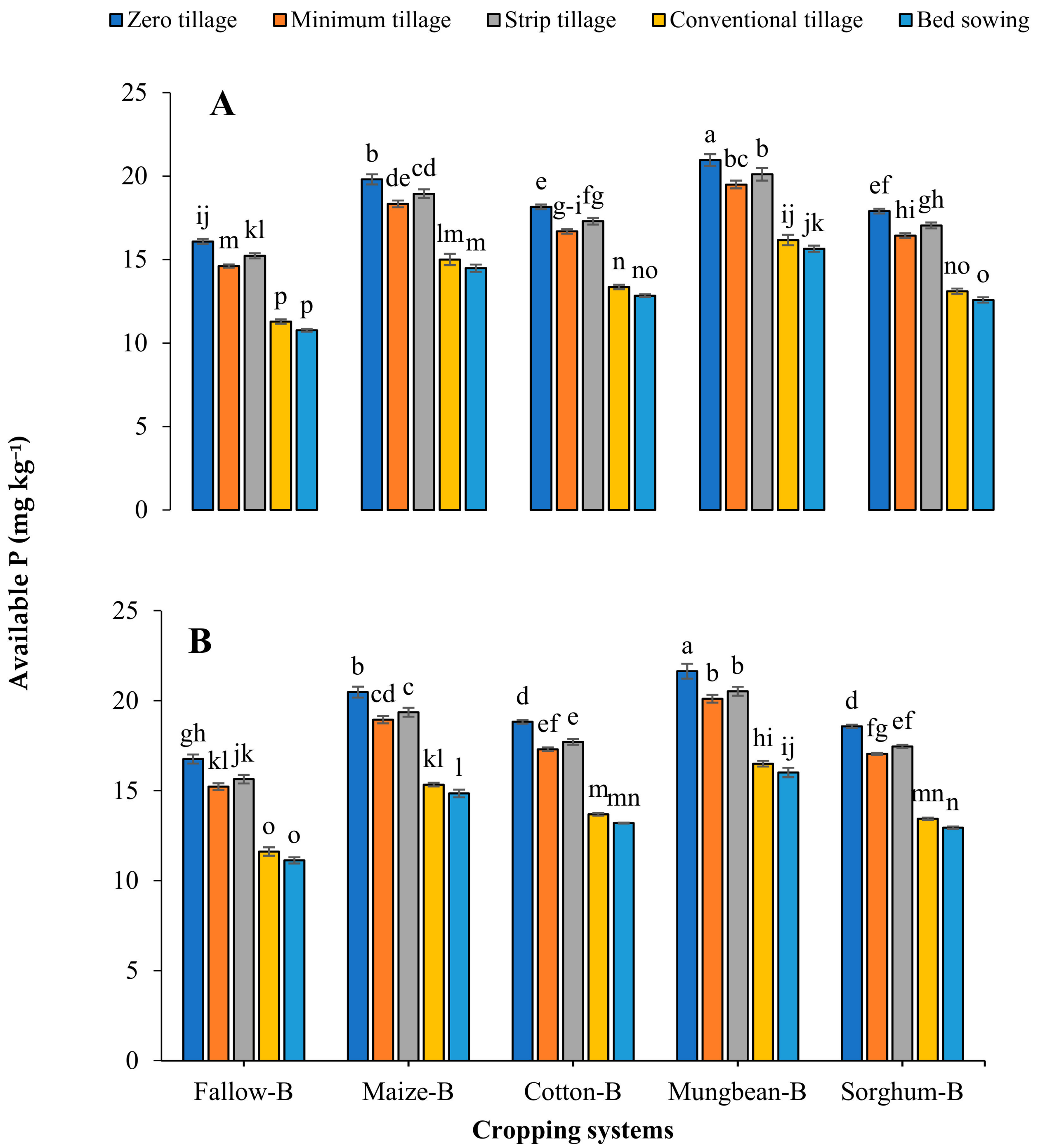

Figure 3. Interactive effect of tillage systems and barley-based cropping systems on soil available P (mg kg^{-1}) after barley harvest during 2017–2018 (**A**) and 2018–2019 (**B**) ±S.E. In the legend, Fallow-B = Fallow-barley, Maize-B = Maize-barley, Cotton-B = Cotton-barley, Mungbean-B = Mungbean-barley and Sorghum-B = Sorghum-barley. The means sharing same letters do not differ significantly ($p > 0.05$). LSD 0.05 (2017–2018 = 0.65, 2018–2019 = 0.56).

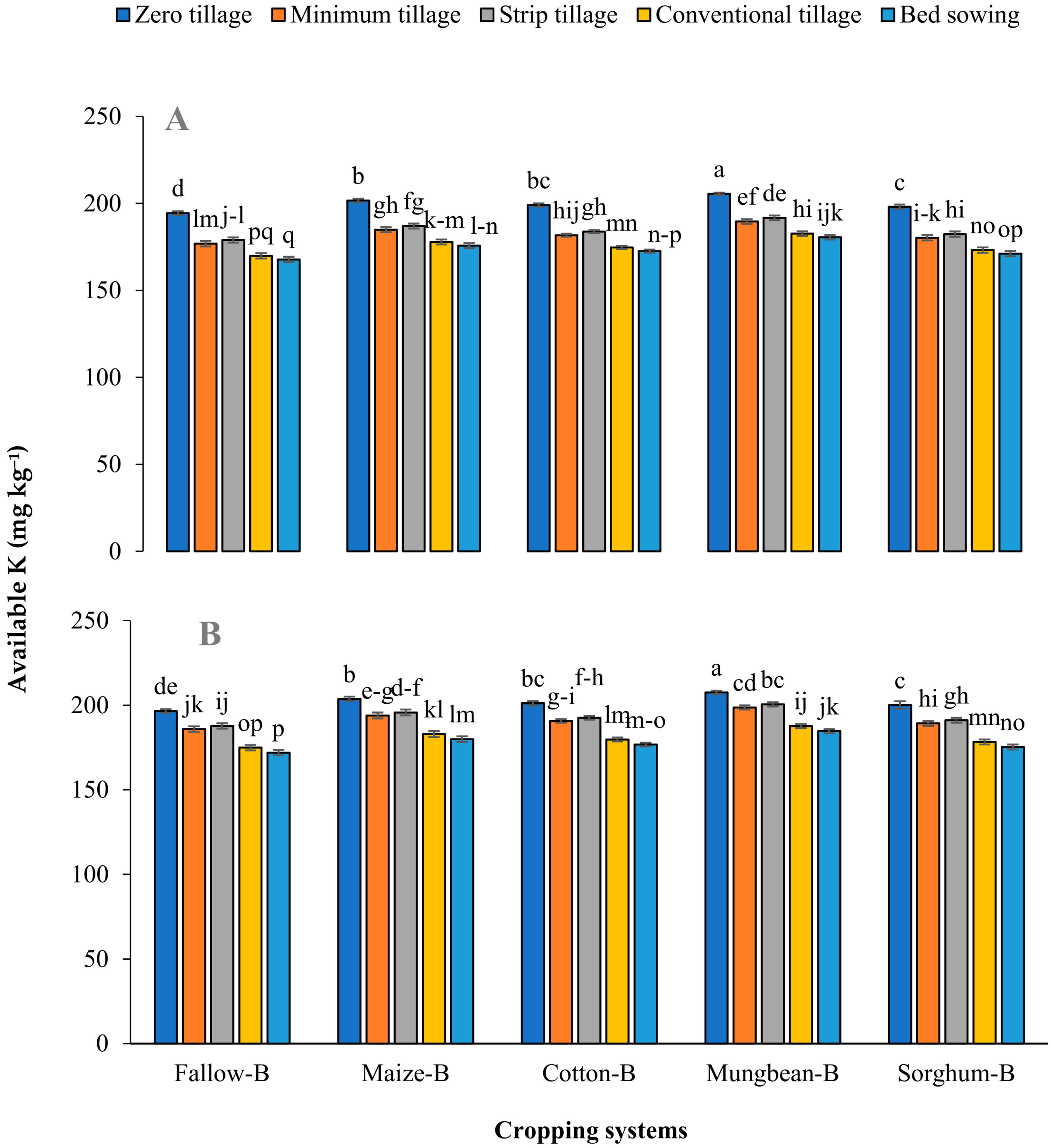

Figure 4. Interactive effect of tillage systems and barley-based cropping systems on soil available K (mg kg^{-1}) after barley harvest during 2017–2018 (**A**) and 2018–2019 (**B**) ±S.E. In the legend, Fallow-B = Fallow-barley, Maize-B = Maize-barley, Cotton-B = Cotton-barley, Mungbean-B = Mungbean-barley and Sorghum-B = Sorghum-barley. The means sharing same letters do not differ significantly ($p > 0.05$). LSD 0.05 (2017–2018 = 3.18, 2018–2019 = 3.24).

3.3. Crop Allometry

All cropping systems with ZT had lower values of LAI at 60, 75, 90 and 105 DAS, whereas all cropping systems with BS recorded the highest values of LAI during both years (Figure 5). The mungbean-B cropping system noted higher LAI values, while sorghum-B system recorded lower LAI values at all sampling dates (Figure 5). All cropping systems with ZT recorded the lowest SLA, while the highest SLA was noted for all cropping systems with BS at all sampling dates during both years (Figure 6). Periodic data showed that LAI and CGR increased from 60–75 DAS and then started to decline.

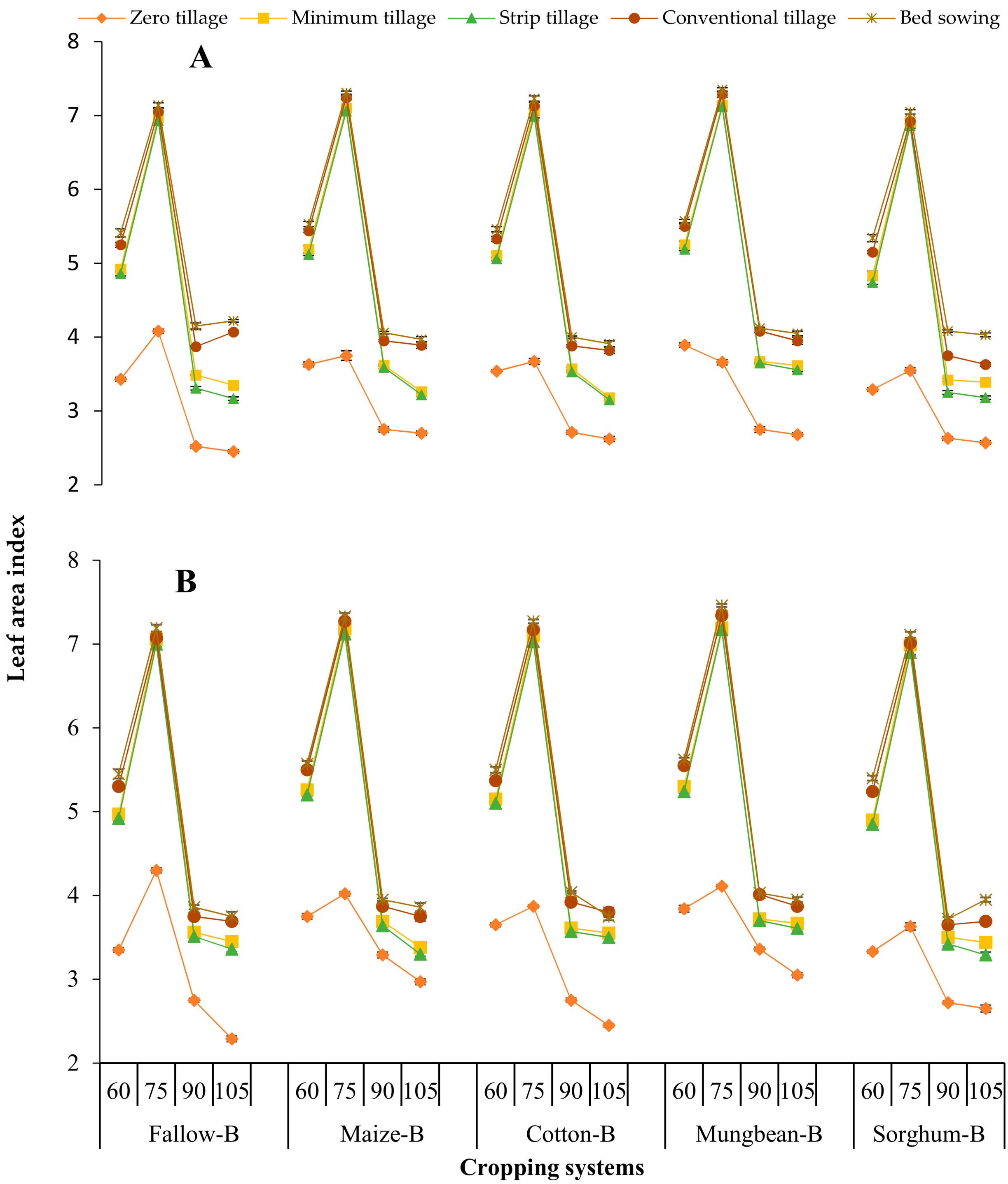

Figure 5. Interactive effect of tillage systems and barley-based cropping Scheme 2017. (**A**) and 2018–2019 (**B**) ±S.E. In the legend, Fallow-B = Fallow-barley, Maize-B = Maize-barley, Cotton-B = Cotton-barley, Mungbean-B = Mungbean-barley and Sorghum-B = Sorghum-barley.

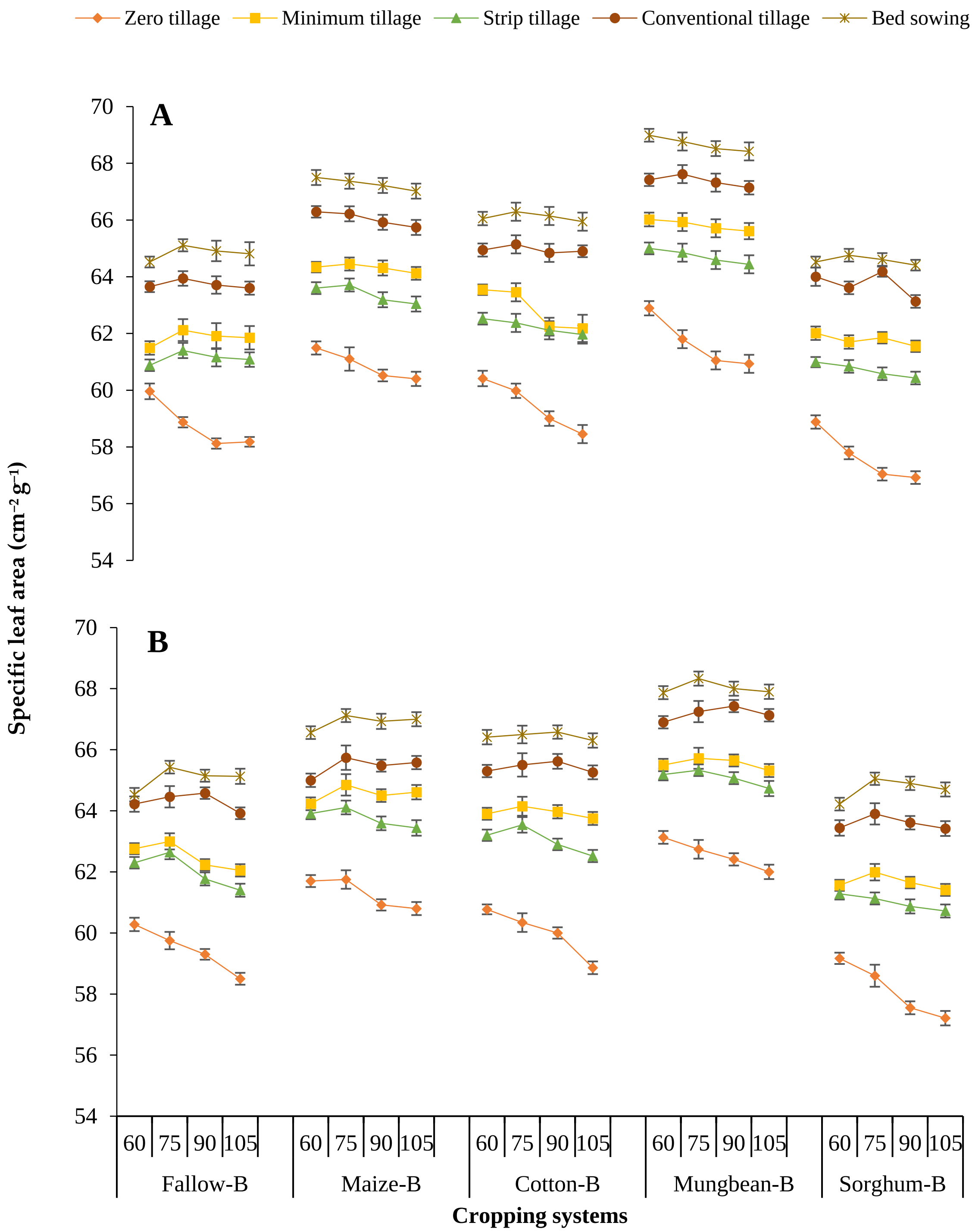

Figure 6. Interactive effect of tillage systems and barley-based cropping systems on specific leaf area (cm-2g-1) of barley during 2017–2018 (**A**) and 2018–2019 (**B**) ±S.E. In the legend, Fallow-B = Fallow-barley, Maize-B = Maize-barley, Cotton-B = Cotton-barley, Mungbean-B = Mungbean-barley and Sorghum-B = Sorghum-barley.

Barley sown under all CS with ZT observed the lowest CGR, while all CS with BS as well as CT had the highest values of CGR during both years (Figure 7). The NAR progressively reduced throughout the growing season during both years (Figure 8). Barley sown under BS and CT noted more NAR, while ZT had least NAR during both years (Figure 8). However, the fallow-B cropping systems recorded the lowest, whereas maize-B and cotton-B systems documented the highest NAR during both years (Figure 8).

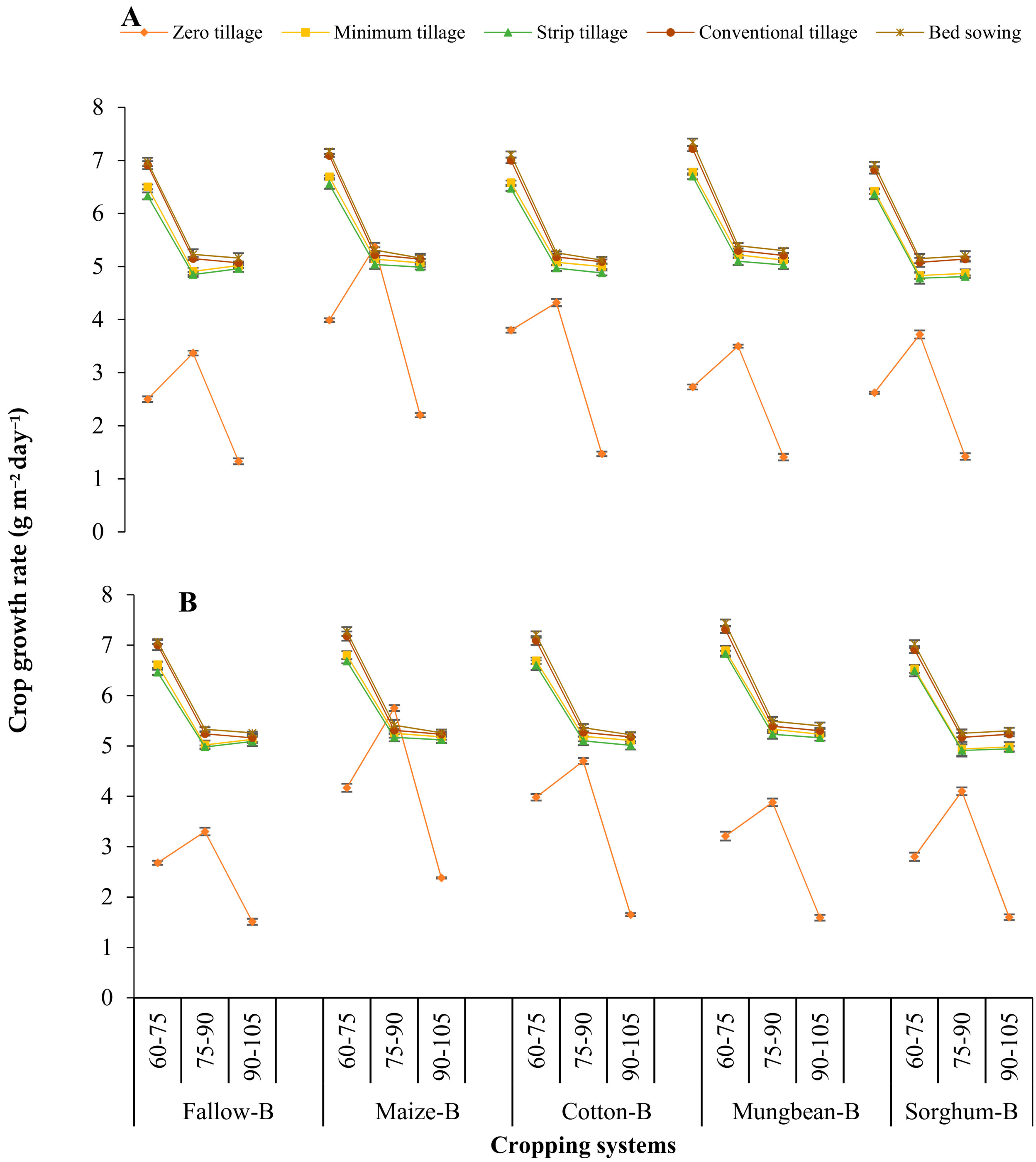

Figure 7. Interactive effect of tillage systems and barley-based cropping on crop growth rate (g m^{-2} day^{-1}) of barley during 2017–2018 (**A**) and 2018–2019 (**B**) ±S.E. In the legend, Fallow-B = Fallow-barley, Maize-B = Maize-barley, Cotton-B = Cotton-barley, Mungbean-B = Mungbean-barley and Sorghum-B = Sorghum-barley.

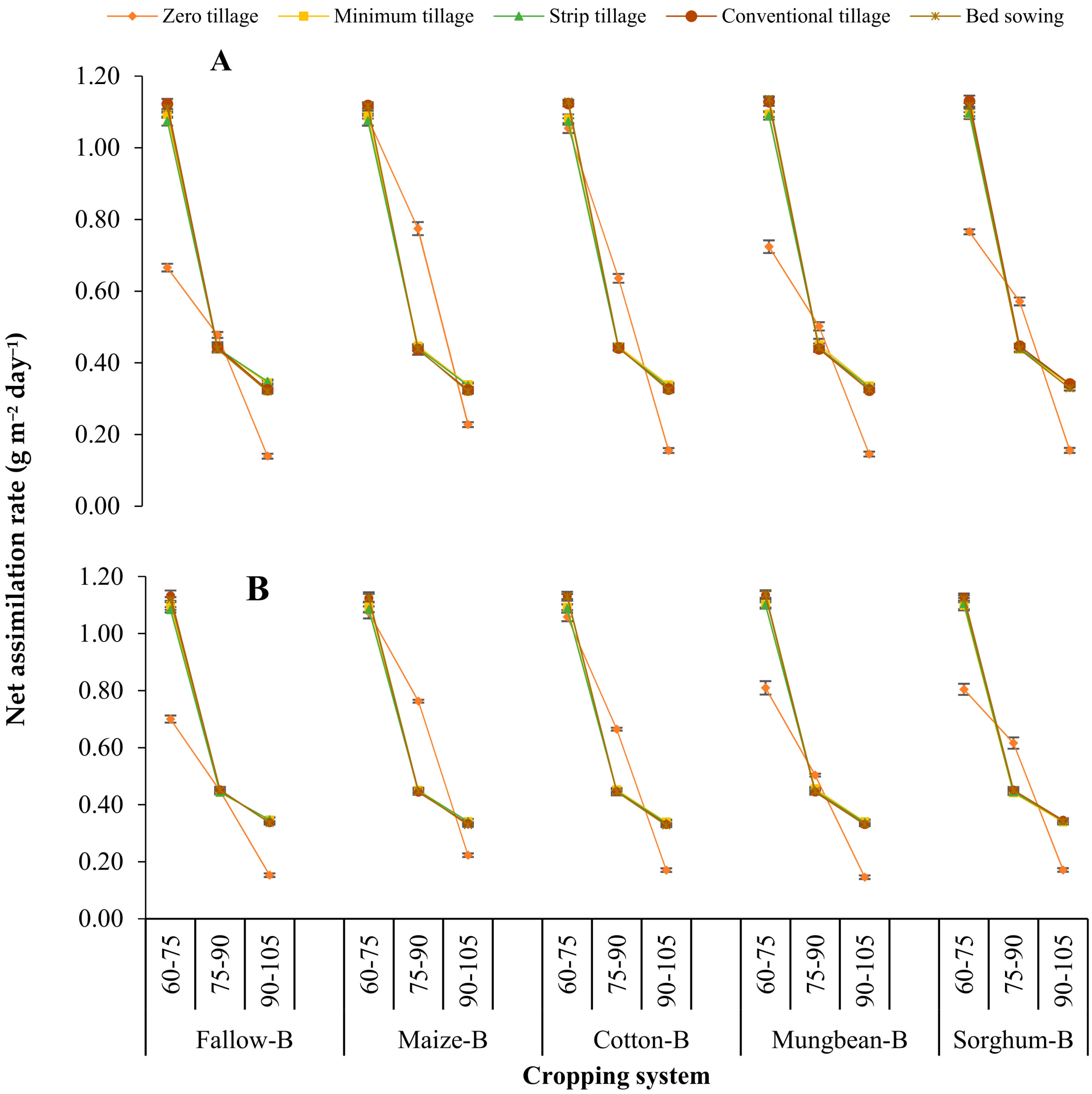

Figure 8. Interactive effect of tillage systems and barley-based cropping systems on net assimilation rate (g m^{-2} day^{-1}) of barley during 2017–2018 (**A**) and 2018–2019 (**B**) ±S.E. In the legend, Fallow-B = Fallow-barley, Maize-B = Maize-barley, Cotton-B = Cotton-barley, Mungbean-B = Mungbean-barley and Sorghum-B = Sorghum-barley.

3.4. Biomass Yield

The dry biomass yield of barley was significantly influenced by TS × CS interaction during both years (Table 4). Barley sown in fallow-B cropping system with ZT recorded the lowest, whereas the mungbean-B system with BS noted the highest value of biomass during both years (Table 4).

Table 4. Impact of different barley-based cropping systems on dry biomass yield (g) of barley under conservation and conventional tillage systems.

Cropping Systems	2017–2018					2018–2019				
	ZT	MT	ST	CT	BS	ZT	MT	ST	CT	BS
Fallow-B	222.8 r	254.0 kl	240.9 op	275.8 g	297.4 d	231.5 r	253.0 o	264.9 m	281.3 h	312.3 e
Maize-B	244.7 no	262.2 hi	249.2 mn	285.1 ef	310.8 b	246.7 p	266.2 lm	273.7 ij	290.3 g	326.6 c
Cotton-B	236.8 pq	259.6 ij	250.2 lm	284.3 ef	307.3 bc	255.8 o	268.7 kl	267.6 lm	287.5 g	317.8 d
Mungbean-B	226.3 r	264.7 h	259.1 ij	288.1 e	325.3 a	238.8 q	275.9 i	275.7 i	294.5 f	336.0 a
Sorghum-B	232.7 q	257.3 jk	250.2 lm	282.8 f	303.0 c	244.2 p	259.6 n	271.1 jk	294.3 f	330.5 b
LSD value ($p < 0.05$)		4.72						3.30		

Means not having common letter for interactive effects significantly vary from each other at $p \leq 0.05$. Here, ZT = zero tillage, MT = minimum tillage, ST = strip tillage, CT = conventional tillage, BS = bed sowing, Fallow-B = Fallow-barley, Maize-B = Maize-barley, Cotton-B = Cotton-barley, Mungbean-B = Mungbean-barley and Sorghum-B = Sorghum-barley.

4. Discussion

Different tillage and cropping systems significantly altered soil physicochemical properties. Nonetheless, tillage systems and barley-based cropping systems also differed for allometric traits and biomass production of barley. The least soil BD and higher soil porosity were noted for BS, while the highest soil BD and low soil porosity were recorded for ZT during both years (Table 3). The CA approach helps in conserving soil physical conditions by minimizing BD and penetration resistance, improves water penetration in the soil profile and hydraulic conductivity, and protect soil against different weathering conditions [40]. Different CA practices, like ZT have various beneficial impacts, like minimum soil damage by erosion, reduced soil disturbance and less soil evaporation [41]. Several studies have indicated that BS plays a significant role in improving root development due to better nutrient and water use efficiencies as a result of reduced mechanical impedance [42,43]. Khan et al. [44] also reported that ridge sowing method resulted in loose fertile soil with better moisture availability and soil aeration. The BS reduces mechanical impedance offered by the soil to germinating seeds and growing roots. The loose soil in BS allows the roots to proliferate in deeper soil layers and extract moisture and nutrients. Conversely, tillage systems resulting in hard soil structure restrict root growth; thus, prohibiting the growing plants to extract nutrients and moisture from deeper soil layers. Tillage and cropping systems exert strong impact on soil physicochemical properties [45]. Conventional tillage or deep ploughing have negative impact on soil organic matter and exposes soils to erosion [46]. Thus, conservative agricultural practices are alternative of conventional deep ploughing for improving the physicochemical properties of the soil [47]. Likewise, legumes are incorporated in the cropping systems to improve the soil fertility, particularly N contents [48]. Although, the role of legumes in improving soil fertility is greatly understood, interaction among cropping systems having legumes in rotation and tillage systems remains unclear. This study inferred the interaction of different cropping and tillage systems on soil properties and allometric traits of main crop.

Among different cropping systems, mungbean-B and cotton-B had minimum soil BD and high soil porosity, whereas maize-B recorded the highest bulk density and the lowest soil porosity (Table 3). Cropping systems significantly alter physicochemical properties of soil [26,27]. Similarly, crop rotation improves soil aggregate stability, water contents in the soil and organic matter [49,50]. Appropriate crop rotation practices produce numerous macro and micro-pores in the soil, which permit the circulation of nutrients, air and moisture encouraging healthier root growth [49,50]. Cotton, maize and sorghum are exhaustive crops, whereas mungbean is a restorative crop. The differences in nutrients contents of different barley-based cropping systems can be linked to the nature of the crops sown before barley. Lu et al. [51] reported that inclusion of legumes in cropping systems increases available N and K, while reduces P contents. Similar results have been recorded in the current study where addition of mungbean in the cropping system improved soil available N and K and lowered available P contents. Nevertheless, ZT has been reported to increase P, total N, and mineral N contents in the soil surface [52]. The combination of ZT and mungbean-B cropping system improved soil nutrients in the current study, which can be linked to the N fixing ability of mungbean and lower uptake of nutrients in ZT due to compacted soil. Hence, inclusion of legume in the cropping system can improve soil fertility if ZT is inevitable.

The BS resulted in the lowest NH_4-N, NO_3-N, P and K contents, whereas ZT observed the highest values of these nutrients. As explained above ZT has been reported to increase P, total N, and mineral N contents in the soil surface [52]. Thus, the results of the current study are in a god agreement with the earlier reports of improved N contents in soil with ZT. It may be due to higher uptake of nutrients from loose soil due to better root growth and moisture uptake in BS. However, barley extracted lesser nutrients in ZT due to compacted soil layer and hence more nutrients were recorded in ZT. Muhammad et al. [53] described that reduced or minimum tillage had the highest NPK and organic matter contents in soil as compared to deep or conventional tillage. Furthermore, higher NH_4-N, NO_3-N, P and K contents were recorded in mungbean-B cropping system, while least was noted in fallow-B cropping system (Figures 1–4). Mungbean is capable of fixing atmospheric nitrogen and well-known for improving soil physical conditions and N availability. The inclusion of legumes in cropping systems increases available N and K, while reduces P contents [51]. The higher nutrient contents of mungbean-B are directly linked to N-fixing ability of mungbean. Venkatesh et al. [54] reported that crop rotation enhances soil fertility and ability of crops to absorb nutrients. Aref and Wander [55] noted that organic matter content was lowest in fallow-maize, highest in maize-oat-hay rotation, while intermediate in maize-oat rotation. In the same way, organic matter content was reduced as a result of reduced practices of legume, green manure and jute-based rotation [56]. Thus, adding legumes in crop sequence of different cropping systems could enhance organic matter contents as well as N.

Better allometric traits of barley were observed for all cropping systems under BS, whereas ZT resulted in poor allometric traits (Figures 5–8). The loose fertile soil of BS had more soil porosity, which resulted in more CGR. Continuous tillage practices can cause soil compaction [29,57], which result in lower crop yield. Soil compaction adversely affect soil properties, which cause obstruction in plant root development and hence result in lower crop yield [29,58]. Selection of appropriate tillage system can efficiently minimize compaction [59]. In an experiment, zero-tilled wheat performed poor due to limited availability of nutrients and moisture, which caused weaker allometric traits and finally lesser crop yield [60]. However, in the current study, ZT had higher available nutrients, but barley was unable to utilize these properly. Allometric traits and biomass production of barley were poor under ZT, although nutrients were available in sufficient quantities. Allometric traits of barley were significantly improved with BS method owing to loose fertile soil. The BS system enhanced root growth due to suitable soil conditions, which ensured better nutrient and moisture uptake and utilization than other tillage systems [44]. Similarly, it has also been reported that deep tillage, i.e., BS had considerable effect on crop performance through better root development in addition to nutrient accumulation and use [61].

Barley cultivated under BS recorded the highest dry biomass, while the lowest was noted with ZT (Table 4). It may be due to better soil condition (more soil porosity) in BS method, which played its role in healthier root growth. These roots have ability to consume more nutrients and water ensuing higher LAI and CGR. These results are in line with Khan et al. [44] and Bakht et al. [62] who found that the root growth of ridge-sown maize crop was improved due to better soil condition. In the same way, raised beds or ridges had less compacted soil, which is suitable for circulation of air and moisture than flat seedbed [62]. Likewise, BS method can save irrigation water, decrease weed flora and increase crop yield [63].

The highest biomass yield was noted in mungbean-B system, while the lowest was resulted in barley sown after fallow condition (Table 4). The reduction in yield-related traits of barley in fallow-B cropping system may be owing to more weed population [64]. The mungbean-B system increased dry biomass and associated traits due to improved soil condition, which helped in better root growth and finally ensured greater allometric traits. Thus, plants uptake more water and nutrients, which lead to high dry matter yield of barley and other yield components. In case of CS, legume-based system enhanced different components of soil fertility like humus, N, P and SOC contents [65]. It was also reported that pulses could increase SOC through the addition of organic C, N and biomass [66]. Similar findings were observed in the current study. The cropping systems containing pulses can restore the soil nutrients, particularly N. Furthermore, legumes also play their role in protecting the soil profile by bringing organic matter and soil fertility back to the soil [67]. The mungbean-B cropping systems could lower the fertilizer use due to N fixing ability of mungbean crop compared to the rest of the cropping systems.

5. Conclusions

Mungbean-barley cropping system with bed sowing significantly improved soil physicochemical properties and barley growth. It may be due to more nutrients' uptake from loose fertile soil in bed-sown barley after mungbean crop, which resulted in higher LAI and CGR, and ultimately total biomass yield. Nonetheless, mungbean-barley cropping system and bed-sowing can be opted for improving barley growth and soil health. Additional studies are needed to find the soil organic carbon contents and possible mechanism(s) of nutrients removal from soil under different tillage systems as observed in the current experiment.

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