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Yield and yield components of common bean as influenced by wheat residue and nitrogen rates under water deficit conditions

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ABSTRACT

Incorporation of crop residues into agricultural system has become a worldwide efficient practice for enhancing crop production. The main objectives of this experiment was to investigate the major role of incorporating wheat (*Triticum aestivum* L.) residues and nitrogen (N) fertilizers rates under different water requirements (WR) on growth, seed yield and yield components of common bean (*Phaseolus vulgaris* L.). The results showed that seed yield under 80% WR in retained crop residue plots was ∼11% higher than WR treatment with no residue incorporation. Seed yield was not significantly different between residue retention and removal treatments in 2016, whereas it was higher (12% and 17%) under residue retained plots compared to removed ones in subsequent years. Seed yields responded to N up to 170 and 225 kg ha^{-1} in removed and retained residue treatments, respectively in 2017 and 2018. Annual increment of seed yield in residue retained plots (36%) was 2.11 times higher than the residue removed ones (17%). There was higher soil N content in 50% residue retention with 225 kg N ha^{-1} under both water deficit treatments in all years. The highest soil organic carbon (SOC) was achieved with normal irrigation in retained residue plots with 225 kg N ha^{-1} in all years. Overall, wheat residue incorporation into the soil and N-supply substantially contributed to counteracting yield declines of common bean under water deficit conditions.

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1. Introduction

World's rapid population growth and increasing demand for water resources are the major challenges for agricultural development worldwide, particularly in arid and semi-arid areas (Haghverdi et al., 2017; Abdelhafez et al., 2020). Therefore, it is crucial to find out new methods that can lessen evaporation from the soil surface; hence, increase water use efficiency (Dastranj and Sepaskhah, 2019). Rainfall is often insufficient in such regions (e.g., most parts of Iran and Egypt) while the evaporation rate is high; accordingly, many agricultural practices such as incorporation of crop residues into the soil, nutrient management and cultivating drought-tolerant crops/cultivars should be considered thereon to increase soil productivity (Agami et al., 2018; Motazedian et al., 2019).

It is widely accepted that incorporation of crop residues prevents evaporation (Van et al., 2010), maintain soil moisture (Kazemeini et al., 2014; Liu et al., 2015), decrease soil erosion (Abd El-Waheda et al., 2017), minimize soil nutrient depletion (Busari et al., 2015), improve seedbed conditions (Bahrani et al., 2007), raise soil organic matter (Dabney et al., 2001), retain soil moisture (Motazedian et al., 2019) and improve water infiltration in heavy textures soils (Assouline, 2004). These points highlighted the beneficial effects of incorporation of crop residues into the soil surface to increase soil moisture content (Govaerts et al., 2007; Sharma et al., 2011) hence improve water use efficiency as well (Zhang et al., 2009). In this context, it was found that incorporation of wheat residue (between 25%–50% by weight of soil) into the soil could reduce the adverse effects of water deficient stress on sweet corn (*Zea mays* L. Var. saccharata) (Motazedian et al., 2019). Likewise, application of both rice straw (*Oryaza sativa* L.) and farmyard manure as ground cover could save 15% of irrigation water without any reduction in common bean yield (Abd El-Waheda et al., 2017). On the other hand, managing N-inputs is important practice to improve crop productivity under such conditions; unless considerable losses in crop yield might be occurs (Wu et al., 2008; Brueck et al., 2010). It is well known that plant residues with wide C/N ratios may lessen temporarily the available contents of soil nutrients via bio-immobilization; accordingly more nutrient inputs are needed to overcome such problems such as N (Gangwar et al., 2006; Alijani et al., 2019). These are extra costs on farmers; yet the costs of removing these wastes from soil to be prepared in the form of organic amendments are also high. Also, these soils suffer from limited available water resources and these residues are needed to lessen water loss from soils. A point to note is that Yadvinder-Singh et al. (2009) and Singh et al. (2015) found that similar N rates were needed in rice–wheat cropping system in presence and absence of rice straw. Accordingly, proper management of nutrient inputs might have positive consequences on crop productivity. Although several studies highlighted the response of some crops to N in presence of crop residues (Bahrani et al., 2012; Alijani et al., 2019) while others studied crop productivity under water limited-supply and crop residues (Motazedian et al., 2019). However, the role of crop residue and nitrogen fertilizers in reducing the negative impacts of water stress in common bean has not been thoroughly examined. Results in this work could provide insight relevant to (i) the impacts of deficit water and N-fertilization levels on the growth, yield and yield components of common beans, i.e., pod length, number of pods, 100-seed weight, seed yield, biological yield and harvest index; (ii) the response of soil properties (SOC, pH and N content) to wheat residue and different N-fertilization levels; and (iii) the alleviative effect of the combined wheat residue and N-fertilization levels treatments on water stress of common bean during grain filling period. It was hypothesized that enhancing N availability contribute to more N uptake and its accumulation in shoot and seeds in common bean suffering from water deficiency.

2. Materials and methods

2.1. Experimental site description

A 3-year (2016–2018) study was conducted at the Bajgah Agricultural Experimental Station of Agricultural School, Shiraz University, 21 km away from Shiraz town (Fig. 1), Fars Province, Iran (52°35′E; 29°43′N, 1787 m above mean sea level). According to available meteorological information provided by Weather Station, School of Agriculture, Shiraz University, Shiraz, Iran, the region has a semi-arid climate with a long-term mean air temperature, relative humidity and total precipitation values of 13.4 °C, 52.2% and 357 mm, respectively (Fig. 2).

The soil in Agricultural School of Shiraz University is classified as fine textured, carbonatic, mesic, and Typic Calcixerpets (Moosavi and Sepaskhah, 2013). Soil texture was a silty clay loam (Soil Survey Staff, 1992) with pH of 7.25 and electrical conductivity (ECe) of 0.83 dSm^{-1}. The initial soil properties including N, P, K, soil organic carbon (SOC), ECe, $CaCO_3$ and pH were determined by collecting 10 random samples per replicate before planting. After this, the soil was sampled by collecting 5 cores across each plot at a soil depth of 0 to 30 cm to determine N (Bremner, 1996), SOC (Nelson and Sommers, 1996) and pH (Thomas, 1996). The soil was air-dried in an oven at 25 °C and ground to pass through a 2-mm sieve. The value of organic carbon (OC) was 10.1 mg g^{-1}, nitrogen (N) content was 1 mg g^{-1}, and calcium carbonate ($CaCO_3$) was 140 mg g^{-1}. Initial values of phosphorus (P) and potassium (K) concentrations in the top 30 cm soil were 20 and 542 mg kg^{-1}, respectively.

2.2. Agronomic practices and experimental design

The experiment was carried out as a split–split-plot design with three replications. The treatments included two wheat residues (with or without) incorporated into the soil as main plots, two irrigation regimes (80 and 100% of the water requirements) as subplots and four N-fertilizer rates as sub–sub plots (0, 85, 170 and 225 kg N ha^{-1}). Each sub–sub-plot was 5 × 5 m. After wheat (Pishtaz cultivar) harvest in each year, seeds of common bean [Sayyad cultivar (pedigree: RAB50 provided from Falat Co, Tehran, Iran)] were manually sown on 20 June 2016, 9 July 2017 and 25 June 2018 into a depth of 1–2 cm along 60 cm-spaced rows, with 10 cm spacing between successive seeds on the same line. To provide the residues prior to the common bean experiments, winter wheat was sown (rate of 200 kg ha^{-1}) in early November and was harvested by hand in early June in 2017 and 2018. Two wheat residue treatments includes returned residues and no residues. In returned residue treatment, all remaining crop materials were left at soil surface after harvesting. To determine the appropriate amount of wheat residues, crop residues were estimated per 1 m^2 after harvesting which was found to be approximately 3 t ha^{-1}. It is notable that the residue treatments remained in exactly the same position through all successive years.

Triple superphosphate (45% P_2O_5) at the rate of 200 kg ha^{-1} was applied according to soil test recommendation as basal application during the time of field preparation in all treatments each year. The soil was naturally high in K availability, so no additional K fertilizers were applied.

Soil water content was measured using tensiometers by taking samples from the soil depths 0 to 30 cm increments in each plot at sowing, before irrigations, and at the final harvesting date (McMaster et al., 2002). A drip-irrigation system was used to apply water for each plot based on water demands and weather conditions during the growing seasons based.

$$V = \frac{(ET_0 \times Kc \times A)}{Ei} \quad (1)$$

Crop water requirements (ETc) were determined by using Eq. (1).
Where, V — amounts of irrigation water (m^3), ET0 — crop reference evapotranspiration (mm day^{-1}), Kc — crop coefficient, A — irrigated area (m^2), and Ei — irrigation efficiency.

Water requirement of common bean plants was estimated based on evapotranspiration using Eq. (2) of Penman–Monteith (Razzaghi and Sepaskhah, 2012).

$$ET0 = \frac{0 \cdot 0408\Delta\,(R_n - G) + \gamma[\frac{890}{T+273}]u_2(ea - ed)}{\Delta + \gamma(1 + \frac{0}{34u_2})} \quad (2)$$

where ET0 is reference evapotranspiration (mm day^{-1}), Rn the net radiation at the crop surface (MJ m^{-2} day^{-1}), G the soil heat flux density (MJ m^{-2} day^{-1}), T the mean daily air temperature at 2 m height (°C), u2 the wind speed at 2 m height (m s^{-1}), ea–ed the saturation vapor pressure deficit (kPa), Δ the slope of saturated vapor pressure curve (kPa $°C^{-1}$), and γ the psychrometric constant (kPa $°C^{-1}$). Climatic data were collected from the weather station, School of Agriculture, Shiraz University, Shiraz, Iran less than a km away from the experimental site. Crop coefficient (Kc) was as assumed to be 0.35 at the beginning season (Kc ini), 1.15 for medium season (Kc mid), and 0.35 for end season (Kc end) (Allen et al., 1998). The application efficiency of irrigation was considered as 80% for the drip system. Water-deficit treatment was imposed at third trifoliolate leaf stage (BBCH 33) and continued until the end of growing season.

The agricultural organization of Iran recommended application of 100–150 kg urea h^{-1} during growth for the soil-climatic conditions of Iran. Therefore, the applied doses of urea stand for the recommended dose. These applications were done at sowing between the plant rows at four-leaf (BBCH 34) and flowering (BBCH 60) stages using urea (46% N). All treatments were applied in three applications: 60% at sowing, 20% at four-leaf stage, and 20% at flowering stage.

2.3. Plant sampling and analysis

Biomass samples from the two central middle rows of plant were taken using quadrat of 1.1 m^2 then oven dried at 60 °C for 3 days to calculate total above ground dry weight (biological yield).

Pod numbers were counted and pod length was measured using a meter scale. Seed yield (12% moisture), 100-seed weight and harvest index (seed yield/biological yield) were determined. Water use efficiency was calculated as seed yield m-3 of applied irrigation water according to Jensen method (1980). Shoot and seed N contents were measured according to the Kjeldahl method using Foss Kjeldahl Digestion equipment (Thermo Fisher Scientific Inc., Seventeen Mile Rocks, QLD, Australia) (Bremner, 1996).

2.4. Statistical analysis

A general linear model (GLM) of the SAS system (SAS Institute, Cary, NC, USA) was used for the data analyses. When the F test was significant, means were compared with least significant difference (LSD) ($P < 0.05$). Before combined analysis, a Bartlett test (Bartlett, 1937) was performed to test the homogeneity of error variances. Residue management (main plot effect), irrigation regimes (sub-plot effect) and N management (sub–sub plot effect) were tested against their interaction with replication to find out the main and sub plot errors. When there was a significant interaction between year and the treatments, the results were reported, separately.

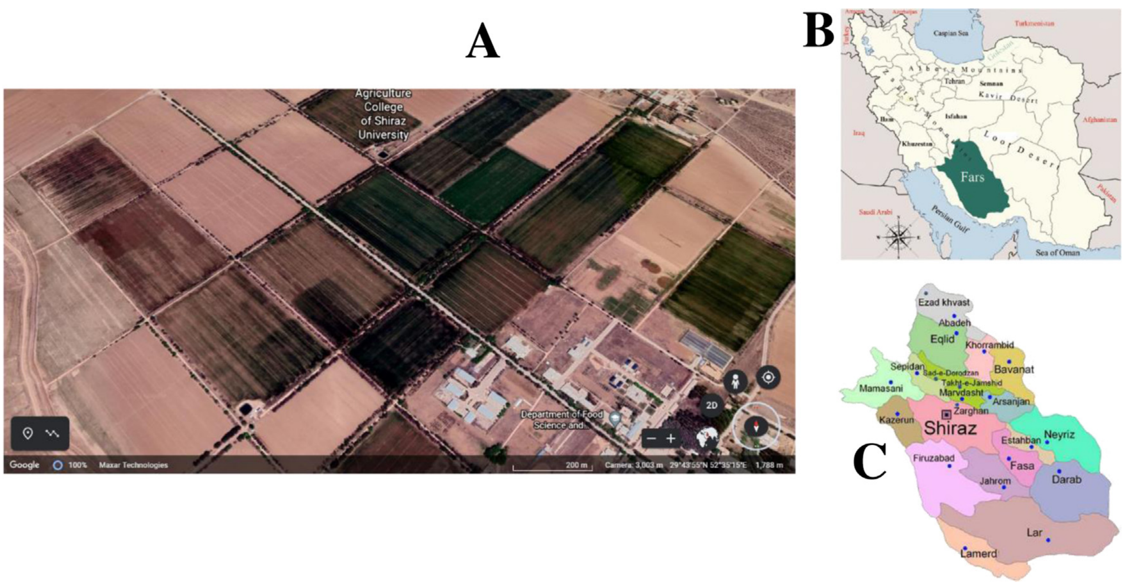

Fig. 1. Geographical map of study area. (A) Map is from Google Earth (earth.google.com). (B) Map of Iran; green color indicates Fars Province. (C) Map of Fars Province. . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3. Results

3.1. Seed yield and its components

The effects of N-dose and irrigation levels were significant on each of 100-seed weight and seed yield (Table 2). In this concern, the highest increases in seed yield and its components were attained for plants that received the highest dose of urea. Also, irrigation with I100 exhibited better results than I80. Likewise, the effect of applying plant residues was also significant on both seed yield per plant and the total seed yield per hectare in the second and third years after application, but not in the first one. On the other hand, 100-seed weight was not affected significantly by the application of these residues during the three successive years of application. It is worthy to mention that the interactions between these three factors were also significant on seed yield and its components. Increasing the level of urea application in soil not amended with straw residues from 170 kg to 225 kg ha^{-1} did not affect significantly seed yield per plant; and sometimes this dose led to significant reductions in both 100-seed weight and seed yield per hectare. On the contrary, increasing the dose of applied urea in soil that was amended with straw residues led to concurrent significant increases in yield and yield components. A point to note is that the seed yield of common bean decreased significantly in the first growing season with approximately 25% owing to reducing the level of irrigation from I100 to I80 in soil not amended with rice straw while received the highest dose of urea versus the reference one that was not amended with rice straw while received 170 kg urea ha^{-1} and irrigated with I100. Such reductions reached only 10 and 8% in the second and third years of application, respectively. This result also signifies that covering soil plant residues can be a long-term strategy to rationalize irrigation water.

Pod length was significantly affected by interaction between year and crop residues, year, and N rates and year and irrigation regimes. The highest pod length was achieved when crop was normally irrigated and residues retained in 2018 (Fig. 3a and b). The highest pod length was obtained with 170 and 225 kg N ha^{-1} in 2018 (Fig. 3c). Number of pods per plant was significantly affected by interaction between year and irrigation regimes, year and N rates, crop residues and N rates, and N rates and irrigation regimes (Table 1).

The highest number of pods was obtained when plants were normally irrigated and received 225 and 170 kg N ha^{-1} in 2018 (Fig. 4a and c). The interaction between crop residues and N rates showed that the plants sown into wheat residues receiving 170 and 225 kg N ha^{-1} had the highest pods number per plant (Fig. 4b). Pods per plant significantly increased with increasing N rate under water-deficit conditions (Fig. 4d). 100-seed weight increased with average values of 15.8% and 35.1% in all treatments, in 2017 and 2018 compared to 2016. Main effect of crop residues was not significant on 100-seed weight, while it was significant for N rates and irrigation regimes in all years (Table 2). In 2016, the highest 100-seed weight (41 g) was found in removed-crop-residue treatment with 170 kg N ha^{-1} under normal irrigation conditions, which was significantly higher than other treatments (Table 2), while, in either 2017 or 2018, retention of crop residues with 225 kg N ha^{-1} under normal irrigation produced the highest 100-seed weight (Table 2).

Number of seeds per plant was significantly higher in 2016 than 2017 and 2018, respectively (Fig. 5b). Although the main effect of crop residues was not significant on number of seeds per plant in 2016, it was significantly increased in

Table 1
P values for pod length, number of pods, 100-seed weight, seeds plant^{-1}, seed yield, biological yield and harvest index of common bean in response to crop residue, N rates and irrigation regimes.

Source of variation	df	Pod length	Number of pods	100-seedweight	Seeds plant^{-1}	Seed yield	Biological yield	Harvest index
		P value						
Year (Y)	2	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Residue (R)	1	ns	ns	ns	<0.0001	0.005	ns	ns
Y × R	2	0.001	ns	<0.0001	<0.0001	0.002	0.0002	0.002
Nitrogen (N)	3	ns	0.006	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
R × N	3	ns	0.002	<0.0001	0.0002	ns	<0.0001	0.0008
Y × N	6	0.044	0.001	0.006	<0.0001	0.0008	<0.0001	<0.0001
Y × R × N	6	ns	ns	<0.0001	<0.0001	0.0005	<0.0001	0.0004
Irrigation (I)	1	0.001	<0.0001	<0.0001	<0.0001	<0.0001	0.004	ns
R × I	1	ns	ns	ns	<0.0001	ns	0.002	ns
N × I	3	ns	0.039	<0.0001	0.082	0.001	ns	<0.0001
R × N × I	3	ns	ns	<0.0001	<0.0001	0.001	<0.0001	0.0089
Y × I	2	0.042	<0.0001	ns	<0.0001	<0.0001	0.001	<0.0001
Y × R × I	2	ns	ns	0.007	0.028	ns	ns	ns
Y × N × I	6	ns	ns	0.002	<0.0001	0.001	ns	ns
Y × R × N × I	6	ns	ns	0.003	<0.0001	0.034	0.003	<0.0001

ns: non-significant; WR: water requirement.

Table 2
Effect of crop residues, N rates and irrigation regimes on common bean 100-seedweight, seeds plant^{-1} and seed yield.

Crop residue (R)	N rate (kg ha^{-1})	Irrigation regimes (I)	100-seedweight (g)			Seeds plant^{-1}			Seed yield (t ha^{-1})		
			2016	2017	2018	2016	2017	2018	2016	2017	2018
Removed	0	100% WR	18.41	23.57	29.18	39.68	52.02	68.00	1.36	1.41	1.69
		80% WR	15.82	22.90	28.59	31.85	41.18	46.32	1.23	1.18	1.46
	85	100% WR	23.69	29.02	35.83	54.73	70.73	75.79	1.78	2.13	2.75
		80% WR	22.16	24.68	32.16	42.65	68.75	70.21	1.45	1.79	2.11
	170	100% WR	41.00	35.97	39.49	95.66	90.63	96.88	3.23	3.09	3.20
		80% WR	27.85	29.68	33.00	58.00	80.22	78.39	2.09	2.37	2.23
	225	100% WR	36.16	33.10	37.45	91.23	92.59	90.92	2.81	2.93	2.98
		80% WR	23.79	31.64	34.40	71.93	80.60	81.67	2.36	2.58	2.73
	Mean		26.11	28.82	33.76	60.71	72.09	76.02	2.04	2.19	2.40
Retained	0	100% WR	18.28	24.02	31.56	37.79	53.78	68.81	1.37	1.62	2.11
		80% WR	15.94	23.07	29.10	35.00	49.09	57.49	1.27	1.38	1.67
	85	100% WR	23.62	29.62	36.41	49. 89	72.64	76.52	1.71	2.33	2.92
		80% WR	23.09	25.29	32.50	44.39	68.98	74.83	1.62	2.09	2.32
	170	100% WR	37.37	36.74	44.65	77.43	100.14	107.45	3.12	3.20	3.75
		80% WR	24.88	32.63	33.29	57.00	85.86	82.00	2.28	2.65	2.90
	225	100% WR	35.60	42.12	42.20	88.81	113.13	112.33	2.68	3.37	3.88
		80% WR	24.20	32.80	36.69	65.49	86.69	86.00	2.42	2.78	2.94
	Mean		25.37	30.78	35.80	57.98	78.78	83.17	2.06	2.44	2.81
LSD (0.05) for R			ns	ns	ns	ns	3.28	4.45	ns	0.23	0.36
LSD (0.05) for R × N × I			1.95	4.13	3.86	5.95	4.77	8.13	0.20	0.28	0.29
N	0		17.11	23.39	29.60	36.08	49.01	60.15	1.31	1.40	1.73
	85		23.14	27.15	34.22	47.91	70.27	74.33	1.64	2.09	2.53
	170		32.77	33.75	36.99	72.02	89.13	91.18	2.68	2.85	3.02
	225		29.93	34.91	37.68	79.36	93.25	92.73	2.57	2.92	3.13
	LSD (0.05)		2.95	3.11	1.98	2.97	2.26	5.88	0.18	0.41	0.26
I	100%		29.26	31.77	37.09	66.90	80.70	87.08	2.26	2.52	2.91
	80%		22.21	27.87	32.46	50.78	70.09	72.11	1.84	2.10	2.30
	LSD (0.05)		2.57	1.22	2.39	2.19	2.69	3.52	0.31	0.39	0.51

ns: non-significant; WR: water requirement.

both 2017 and 2018 (Table 2). The highest seeds per plant were obtained when crop was normally irrigated and 170 kg N applied under removed-crop residues compared to other treatments in 2016, while it was the highest in 2017 and 2018 when crop was normally irrigated, residues retained and 225 kg N ha^{-1} applied (113.13 and 112.33 seeds plant^{-1}, respectively) (Table 2). Seeds per plant was significantly higher with 170 and 225 kg N ha^{-1} than 85 kg N ha^{-1} and control plot in 2018 (Table 2).

Seed yield was significantly influenced by interaction between residues and N rates and irrigation regimes in all years (Table 2). Despite the non-significant effect of crop residues on seed yield, it increased 12 and 17% when they were retained

Table 3
Effect of crop residues, N rates and irrigation regimes on common bean biological yield and harvest index.

Crop residue (R)	N rate (kg ha^{-1})	Irrigation regimes (I)	Biological yield (t ha^{-1})			Harvest index		
			2016	2017	2018	2016	2017	2018
Removed	0	100% WR	5.97	6.62	6.39	0.23	0.21	0.27
		80% WR	5.19	5.39	5.77	0.24	0.22	0.25
	85	100% WR	7.16	7.48	7.42	0.25	0.29	0.37
		80% WR	6.76	7.14	6.56	0.21	0.25	0.32
	170	100% WR	10.74	9.55	10.14	0.30	0.32	0.32
		80% WR	8.46	8.48	8.63	0.25	0.28	0.26
	225	100% WR	9.26	9.40	9.83	0.30	0.31	0.30
		80% WR	8.67	8.76	9.13	0.27	0.29	0.30
	Mean		7.78	7.85	7.98	0.26	0.28	0.30
Retained	0	100% WR	6.28	6.45	6.70	0.22	0.25	0.32
		80% WR	5.31	6.07	6.55	0.24	0.23	0.26
	85	100% WR	7.50	7.96	8.84	0.23	0.29	0.33
		80% WR	7.03	7.10	7.46	0.23	0.30	0.31
	170	100% WR	9.68	10.51	12.58	0.32	0.31	0.29
		80% WR	9.14	9.20	10.51	0.25	0.29	0.28
	225	100% WR	9.38	11.12	12.89	0.29	0.30	0.30
		80% WR	9.19	9.34	10.74	0.26	0.30	0.27
	Mean		7.94	8.47	9.53	0.26	0.29	0.29
LSD (0.05) for R			ns	ns	1.12	ns	ns	ns
LSD (0.05) for R × N × I			0.75	0.82	0.87	0.02	0.04	0.02
N	0		5.69	6.13	6.35	0.23	0.22	0.27
	85		7.12	7.42	7.57	0.23	0.28	0.33
	170		9.51	9.44	10.46	0.30	0.30	0.28
	225		9.13	9.65	10.65	0.28	0.30	0.29
	LSD (0.05)		0.48	0.65	0.92	0.03	0.03	0.01
I	100%		8.25	8.64	9.35	0.26	0.28	0.31
	80%		7.46	7.68	8.17	0.24	0.27	0.28
	LSD (0.05)		0.62	0.78	1.01	ns	ns	0.02

ns: non-significant; WR: water requirement.

in soil in 2017 and 2018 than 2016, respectively (Table 2). In addition, the seed yield increased ∼13% and 27% on average in the 2018 compared to the 2017 and 2016 (Fig. 5c). Water deficit conditions significantly reduced seed yield and its components in all years (Table 2). Seed yield was higher when wheat residues were retained under water deficit (80% WR) conditions compared to normal irrigation and lower N rate (Table 2). In 2016, the highest seed yield was obtained when crop residues were removed and 170 kg N ha^{-1} applied under normal irrigation (Table 2).

While, in both 2017 and 2018, the highest seed yield was achieved when residues were retained, and 225 kg N ha^{-1} applied under normal irrigation with no significant difference with retained residues and 170 kg ha^{-1} N application under normal irrigation (Table 2). Seed yield increased about 7% and 17% in 2017 and 2018 compared to 2016 when residues were removed, while it increased 18% and 36% when residues were retained (Table 2). Crop residue retention improved seed yield of the plants grown under water deficit conditions, therefore the seed yield of the plants sown into the crop residues under 80% WR were higher than those grown under water deficit conditions alone (Table 2). On average, the seed yield was 11% more in retained crop residues treatment than removed ones (Table 2). Interaction between crop residues, N rates and irrigation regimes was significant on biological yield for all years (Tables 1 and 3). Main effect of crop residues was significant on biological yield only in 2018 (Table 3). Furthermore, biological yield significantly increased with increasing N rate in all years (Table 3). In 2016, although the highest biological yield (10.74 t ha^{-1}) was obtained in residues removed treatment with 170 kg ha^{-1} of N application under normal irrigation, retention of wheat residues with 170 or 225 kg ha-1 of N application under normal irrigation conditions led to the highest biological yield in 2017 and 2018 (Table 3). Wheat residue retaining under 80% WR produced higher biological yield than those plants grown under the same irrigation conditions without crop residues retention in 2017 and 2018 (Table 3). On average, there was no significant difference between years for biological yield (Fig. 5d).

Response of harvest index to treatments was very variable among years. For example, in 2016, the highest harvest index (0.32) was obtained when the plants were normally irrigated, grown into crop residues with 170 kg N ha^{-1}, while in 2017, the same plants had the highest harvest index under removed residues conditions (Table 3). Interestingly, crop residues removed treatment with 85 kg N rate and normal irrigation had the highest harvest index in 2018 (Table 3). Inducing water deficit conditions significantly decreased harvest index only in 2018 (Table 3).

Table 4
Effect of crop residue, N rates and irrigation regimes on seed, shoot and soil N contents.

Crop residue (R)	N rates (kg ha^{-1})	Irrigation regimes (I)	Seed N (mg g^{-1})			Shoot N (mg g^{-1})			Soil N (mg g^{-1})		
			2016	2017	2018	2016	2017	2018	2016	2017	2018
Removed	0	100% WR	43.21	43.34	44.69	18.15	19.96	17.73	1.03	1.32	1.55
		80% WR	36.65	42.11	42.90	17.97	19.11	15.09	1.13	1.45	1.60
	85	100% WR	50.82	46.85	45.78	24.31	21.49	23.30	1.37	1.74	1.77
		80% WR	44.88	46.59	45.45	19.13	20.91	22.94	1.49	1.61	2.10
	170	100% WR	56.34	48.25	54.24	29.45	23.36	30.10	1.70	2.04	2.65
		80% WR	52.15	47.12	51.03	20.40	22.20	25.32	1.84	1.99	2.72
	225	100% WR	53.73	49.29	53.78	33.11	24.93	30.60	1.50	2.14	2.90
		80% WR	52.44	47.56	51.94	21.27	24.67	25.95	1.57	2.05	2.82
	Mean		48.78	46.39	48.73	22.97	22.08	23.88	1.45	1.79	2.26
Retained	0	100% WR	41.78	45.62	45.33	19.22	20.52	20.49	1.19	1.57	2.20
		80% WR	30.82	44.61	44.90	15.05	20.38	17.80	1.25	1.60	1.97
	85	100% WR	49.15	47.04	49.11	22.49	22.03	24.63	1.10	1.83	2.41
		80% WR	45.33	46.96	48.68	20.20	21.66	24.40	1.41	1.90	2.30
	170	100% WR	45.91	49.40	53.80	24.87	25.61	36.11	1.37	2.31	3.29
		80% WR	46.47	49.37	52.48	21.19	25.07	26.53	1.49	2.25	3.04
	225	100% WR	48.40	52.81	55.13	26.35	28.16	37.44	1.93	2.60	3.64
		80% WR	46.84	51.60	52.60	22.10	26.74	29.51	2.06	2.36	3.50
	Mean		44.34	48.43	50.25	21.43	23.77	27.11	1.48	2.05	2.79
LSD (0.05) for R			ns	ns	ns	ns	1.50	2.21	ns	ns	0.40
LSD (0.05) for R × N × I			4.50	4.12	3.79	3.91	2.72	3.36	0.31	0.22	0.32
N	0		38.01	43.96	44.40	17.54	19.92	17.73	1.19	1.42	1.84
	85		47.55	46.81	47.27	21.51	21.46	23.80	1.31	1.70	2.15
	170		49.57	48.52	52.81	23.96	24.09	29.57	1.50	2.18	2.89
	225		50.99	50.20	53.35	25.68	26.01	30.89	1.74	2.22	3.21
	LSD (0.05)		3.51	2.72	4.81	2.80	1.83	1.51	0.40	0.35	0.51
I	100%		48.64	47.71	50.19	24.73	23.22	27.51	1.30	1.95	2.57
	80%		44.40	46.96	48.72	19.67	22.55	23.40	1.48	1.89	2.41
	LSD (0.05)		3.90	ns	ns	3.23	ns	2.72	ns	ns	ns

ns: non-significant; WR: water requirement.

3.2. Seed, shoot and soil N contents

Seed, shoot and soil N contents were responsive to interaction between crop residue, N rates and irrigation regimes in all years (Table 4). In 2016, the highest seed N content was achieved in removed crop residue treatments when they were normally irrigated and 170 kg N ha^{-1} applied with no significant difference with 225 kg N ha^{-1} under both irrigation regimes, whereas crop residues retention plots with 225 kg N ha^{-1} application under both irrigation regimes had higher seed N content in 2017 and 2018 (Table 4). Seed nitrogen content did not significantly change between years (Fig. 6a). Although the highest shoot N content was found in the plants, which were normally irrigated and receiving 225 kg N ha^{-1} in removed crop residue plots in 2016, and was the highest under normal irrigation, crop residue retention and 225 kg ha^{-1} of N application in 2017 and 2018 (Table 4). Shoot N content significantly increased in 2018 compared to those of 2016 and 2017, respectively (Fig. 6b). Withholding irrigation, especially in lower N treatments, significant reduction of N in the aerial organs was occurred (Table 4). The higher soil N content was found in the plots where crop residues was retained, 225 kg N ha^{-1} applied under both irrigation regimes in all years (Table 4). Furthermore, soil N content significantly increased in 2017 (26%) and 2018 (71%) as compared to 2016 (Fig. 6c). Irrigation regimes had no significant effect on soil N content in all years (Table 4).

3.3. Soil organic carbon and pH

Increasing N rates increased soil organic carbon (SOC) in both crop residue managements in all years (Supplementary material Appendix A, Table 5). In addition, the highest SOC content was found in the plants which were normally irrigated, and 225 kg N ha^{-1} applied under residue retained conditions (Supplementary material Appendix A, Table 5). SOC significantly increased in 2018 compared to 2017 and 2016 (Supplementary material Appendix A, Figure 7) and was not significantly affected by irrigation regimes in all years (Supplementary material Appendix A, Table 5). Interaction between year and treatments was not significant for soil pH, while soil pH was significantly affected by interaction between crop residues, N rates and irrigation regimes (data not shown). Residue retained treatments had higher soil pH than removed ones. Only in crop residues removal treatment increased, increasing N rates substantially decreased soil pH. Irrigation regimes had no significant effect on soil pH (Supplementary material Appendix A, Figure 8).

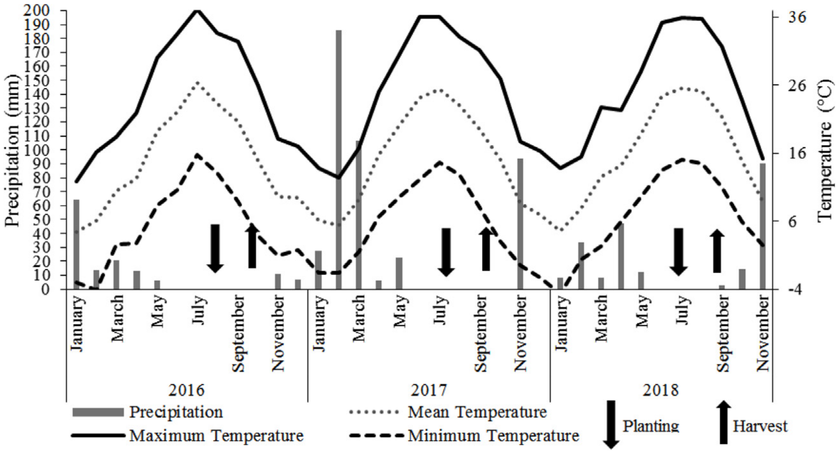

Fig. 2. The daily meteorological parameters for the three-year experiment period. Data are from the weather station, School of Agriculture, Shiraz University, Shiraz, Iran.

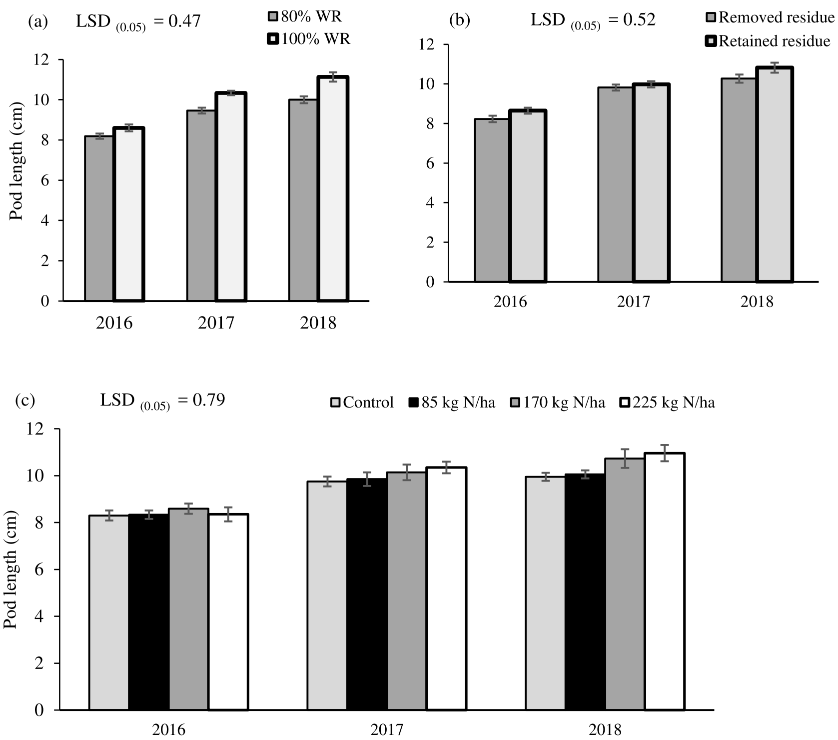

Fig. 3. Effect of year and irrigation regimes (a), year and crop residues (b) and year and N rates (c) on common bean pod length. Vertical bars represent the standard division.

4. Discussion

4.1. Seed yield and its components

As indicated the seed yield and yield attributes were significantly higher in 2017 and 2018 than 2016. Despite the relative similarity of temperatures of three years, the rainfall values during January–May and November of 2017 was 349.6 and 94 mm, respectively which were ∼66% and 88% higher than corresponding months in 2016 (Fig. 2). Although soil moisture content was not measured in this investigation, the crop period of 2017 received more rainfall resulting unfavorable crop establishment, growth and yield. The higher moisture availability in 2017 seemed to also have facilitated the absorption of nutrients and accelerated residue decomposition leading to improved growth of common bean (Misra

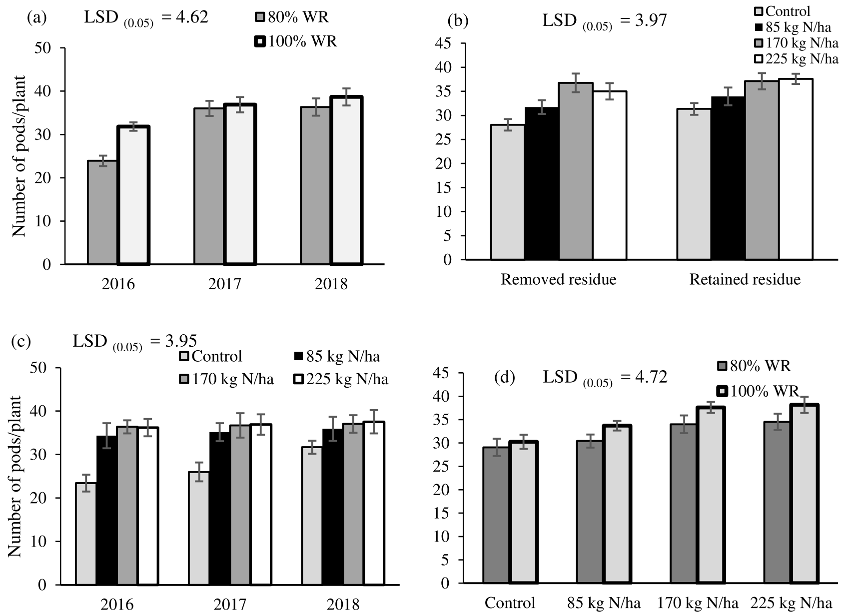

Fig. 4. Effect of year and irrigation regimes (a), N rates and crop residues (b), N rates year^{-1} (c) and N rates and irrigation regimes (d) on number of common bean pods plant^{-1}. Vertical bars represent the standard division.

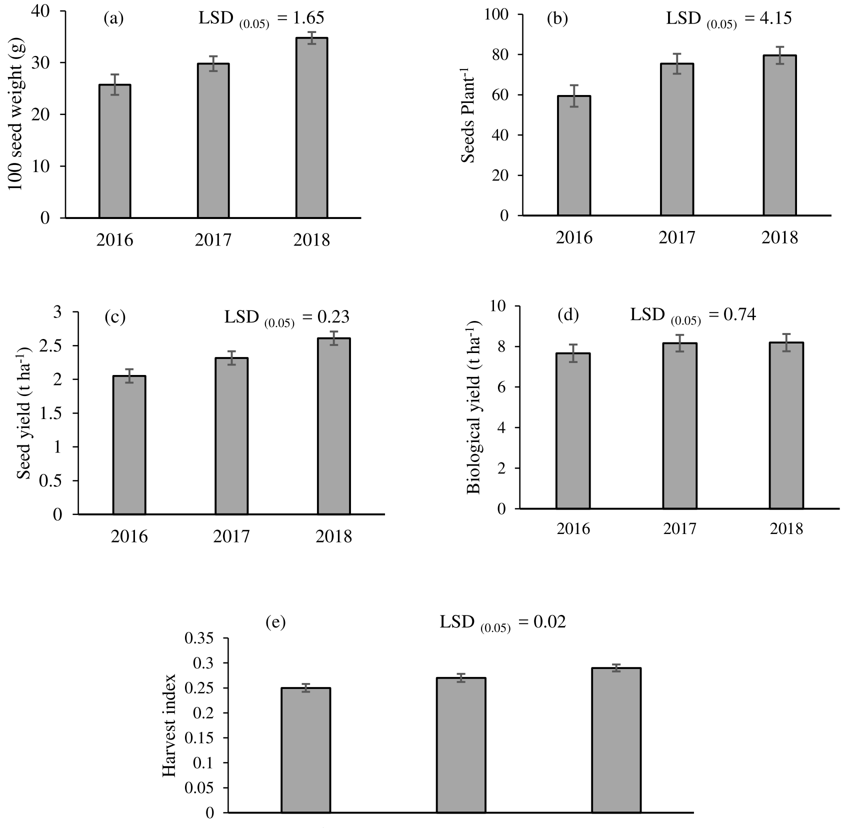

Fig. 5. 100-seed weight (a), seeds plant^{-1} (b), seed yield (c), biological yield (d) and harvest index of common bean (e) for three years. Vertical bars represent the standard division.

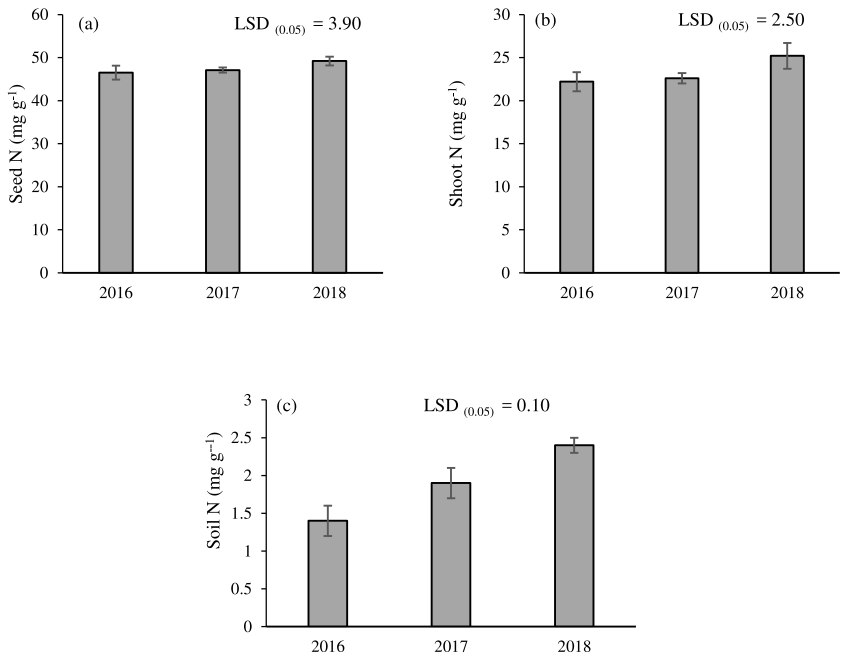

Fig. 6. Seed (a), shoot (b) and soil (c) N contents in different years. Vertical bars represent the standard division.

and Tyler, 1999). It is widely accepted that retention of crop residues protects the soil from direct impact of raindrops and sunlight and can provide sufficient nutrients for plant growth (Van et al., 2010; Busari et al., 2015; Liu et al., 2015). Incorporation of crop residues into the soil in cereal-legume rotation could moderate soil temperature and improve soil organic matter, soil structure and the infiltration, storage and utilization of soil water. Seed yield was not significantly influenced by crop residues retention in 2016. Jat et al. (2019) reported that N immobilization during the early stages of decomposition of wheat residue will result in N deficiency in the succeeding crop. In 2016, seed yield increased with increasing N rate up to 170 kg N ha^{-1} under both wheat residues management treatments (Table 2). In 2017 and 2018, while response to N application was obtained up to 170 kg N ha^{-1} in removal residue treatments, it was up to 225 kg N ha^{-1} in retained-crop-residue ones (Table 2). As a result of microbial requirement for residue decomposition, wheat residue retention needs higher N rates. Exposure of plants to water deficit conditions decreased seed yield and its components. Similarly, Asfaw and Blair (2014) found significant reductions in pod number per plant, seed number per pod, 100-seed weight and seed yield of common beans under drought-stressed conditions. Ambachew et al. (2015) suggested that reduction in number of pods per plant at water-deficit conditions. Furthermore, the reduction in seed yield and 100-seed weight in the plants exposed to water-deficit conditions may have been due to a decrease in photosynthetic assimilates (Darkwa et al., 2016).

Adequate N supply in some cases could ameliorate the adverse effects of water-deficit stress. For example, in 2017, seed yield was higher in plants which were 80% irrigated and 170 kg ha^{-1} of N applied (2.37 t ha^{-1} than those which were normally irrigated, and 85 kg N ha^{-1} applied (2.13 t ha^{-1}) (Table 2). In addition, in 2017 and 2018, seed yield of plants which were 80% irrigated, residues retained and 225 kg N ha^{-1} applied was not significant with the similar irrigation regime and crop residue treatments and 170 kg ha^{-1} of N application. These results are in agreement with Lalelou and Fateh (2014) and Agami et al. (2018) who found that sufficient N nutrition could improve wheat yield under water-deficit conditions by maintaining the metabolic activities. In addition, the results indicated positive impact of crop residue retention on seed yield and yield attributes under water deficit conditions which are consistent with Motazedian et al. (2019) on sweet corn, Haghverdi et al. (2017) in sugar beet (*Beta vulgaris* L.) and Kazemeini et al. (2014) on corn. Jin et al. (2009) stated higher crop performance by residues incorporation due to the improved soil water holding capacity. Therefore, applying adequate N rates and wheat residues in the present investigation was found to be useful practice to mitigate the harmful effects of water stress on crop performance.

4.2. Seed, shoot and soil N contents

Increased seed and shoot N accumulation due to N application and crop residue retention have been reported by Chen et al. (2014) and Alijani et al. (2019). Retained crop residues may lead to an increase in soil nutrient contents such as N (Chen et al., 2014). Dass and Bhattacharyya (2017) have reported improved soil conditions and enhanced moisture availability facilitating better nutrient uptake under residues retained conditions. In addition, Jat et al. (2019) showed that with residue retention, soil N availability will increase due to improved moisture availability. Nutrient absorption and translocation to aerial organs is strongly correlated to water availability. Therefore, water deficit conditions might restrict N absorption from the soil solution (Xiong et al., 2018), especially when N supply was limited.

4.3. Soil organic carbon and pH

Distribution pattern of SOC is influenced by factors such as tillage practices, crop residues management, amount of rainfall, etc. (Chen et al., 2018; Sarikhani et al., 2018). For e.g., Alijani et al. (2012, 2019) and Motazedian et al. (2019) showed that residues incorporation into the soil increased SOC compared to removed ones. Chen et al. (2018) and Nie et al. (2014) reported that stored SOC increased with increased rainfall, as shown in this study. Indeed, it seems that soil profile stored more water from higher rainfall in 2017 and enhanced the decomposition of wheat residues and increased SOC storage (Pasricha, 2017). According to Fuentes et al. (2009) and Alijani et al. (2012), the soil pH values in residues included plots are correlated to increased SOC concentrations. Lower pH value of higher N rate treatment agrees with Fuentes et al. (2009) findings, which revealed that pH decreased with increasing N rates due to the acidity created from nitrification process.

5. Conclusions

Residue incorporated plots stored higher SOC and N than removed ones which led to higher accumulation of N in seed and shoot. Soil pH was the highest in residue incorporated plots without N application. In general, not only seed yield and yield components, but also N uptake in seed and shoot and soil properties were improved at the end of the experiment compared to the first year. Therefore, it can be concluded that adopting proper management practices, like crop residue retention and N rate by farmers can improve soil properties and common bean yield under water stress conditions. In general, it appears that in spite of yield reduction as result of water stress, crop residue retention and applying adequate N rate could be an effective tool in ameliorating the detrimental effects of water stress on common growth and seed yield. Future field studies are needed to evaluate the effects of the combined N fertilizer levels and crop residue treatments on soil microbial biomass and activity and common bean nitrogen fixation under water stress.

CRediT authorship contribution statement

Marziye Dianatmanesh: Conceptualization, Project administration. **Seyed A. Kazemeini:** Investigation, Methodology, Supervision, Writing – original draft. **Mohammad J. Bahrani:** Data curation, Investigation, Methodology, Supervision, Writing – original draft. **Ehsan Shakeri:** Data curation, Formal analysis, Investigation, Writing – original draft. **Mozhgan Alinia:** Investigation, Methodology, Project administration Writing – original draft. **Syeda F. Amjad:** Supervision, Writing – original draft, Writing – review & editing. **Nida Mansoora:** Formal analysis. **Peter Poczai:** Data curation, Funding acquisition, Writing – original draft. **Irfana Lalarukh:** Writing – review & editing. **Mohamed H.H. Abbas:** Writing – review & editing. **Ahmed A. Abdelhafez:** Data curation, Supervision, Writing – review & editing. **Mahdy H. Hamed:** Formal analysis, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material (Appendix A) related to this article can be found online at https://doi.org/10.1016/j.eti.2022.102549.

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