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Forage Yield and Quality Evaluation in Intercropping of Kochia, Sesbania and Guar under Saline Irrigation

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ABSTRACT

Salinity is one of the most important factors limiting plants growth and production in irrigated agriculture. The natural potential of salt tolerant plants like Kochia could be exploited through legume-containing intercropping systems as an effective strategy in mitigating the increasing salinity crisis.This experiment used split plots based on a randomized complete block design with three replications, in 2016 and 2017, at the Iranian National Salinity Research Center, Yazd, Iran. Water salinity was considered as the main factor (EC= 4, 9, and 14 dS m^{-1}) and the cropping system was considered as subfactor with seven levels including sole cropping of Kochia (*Kochia scoparia*), Sesbania (*Sesbania aculeate*), and Guar (*Cyamopsiste tragonoliba*) and their possible dual and triple intercropping systems. The highest absorbed light was observed in triple intercropping and the total forage yield in triple intercropping was increased by 5% and 4.1% at 4 and 9 dS m^{-1} salinity, respectively, compared to that in Kochia sole cropping, while it decreased by 1.5% at 14 dS m^{-1}.The Land Equivalent Ratio (LER) values ranged from 0.99 to 1.33. The total crude protein yield in triple intercropping was increased by 55.8 to 66.3% as compared to Kochia sole cropping. The NDF (Neutral Detergent Fiber) and ADF (Acid Detergent Fiber) were decreased by 7 to 22% in various intercropping systems. Considering increased forage quantity and quality, mainly through decreasing NDF and increasing Dry Matter Intake (DMI) levels, cultivation of Kochia within triple intercropping systems can be recommended instead of Kochia sole cropping.

Keywords: Acid detergent fiber, Crude protein, Dry matter intake, Neutral detergent fiber, Salinity**.**

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INTRODUCTION

Gradual salinization of agricultural soil is one of the most important challenges in many parts of the world, particularly arid and semi-arid regions, (Hernández *et al*., 2017). Almost 20% of the world's irrigated agricultural lands producing one-third of the world's food are under saline stress (Slama *et al*., 2015), which increases every year. Of the total 15 million hectares of cropped lands in Iran, approximately 6 million (30%) are under irrigated cultivation, out of which 1.7 million hectares are impacted by various degrees of salinity (Zamani *et al*., 2011). Yazd province, Iran, is located mainly in arid and desert regions with severe rainfall shortage. This entails more challenging salinity stress and imposes more restrictions on cultivation management, particularly concerning the selection of agronomically useful and economical crops. The paucity of adequate water resources is a threat to

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sustainable agriculture. Under water shortage conditions, it is inevitable to exploit unconventional water resources such as saline waters for agricultural production. On the other hand, the harmful impacts of salinity on plant growth and development caused by the disturbance in the photo-assimilate supply inhibit the leaf cell proliferation and reduce the number and size of leaves, shoot growth, and the number of tillers and secondary branches (Chaves *et al*., 2009). This possibly leads to reduced dry matter and yield loss in crop plants. High sodium content in saline soils causes deficiency of essential elements required for plant metabolism (Mansour *et al*., 2005). Salinity stress has been frequently reported to reduce vegetative growth in various plant species (De Lacerda *et al*, 2003; Yadav *et al*., 2019); meanwhile, owing to its high foliage production capacity, Kochia is recommended for cultivation under harsh environmental conditions such as severe salinity and water stress (Kafi *et al*., 2010). Reduced dry matter and leaf area in various plants under salinity stress have also been reported (Zhao *et al*., 2007; Jamali *et al*., 2019). As regards Kochia, salinity stress acts through reducing the plant height, which leads to the reduced contribution of lignin to the total harvest. This in turn results in enhanced forage quality, mainly via reducing the NDF and increasing the digestibility of different plants such as Kochia (Salehi *et al*., 2009) and cereals (Yensen and Biel, 2008).

An effective strategy for coping with soil salinity issue is to cultivate plants with a high salinity tolerance. Kochia is a salt-tolerant plant with a deep taproot system mainly known for producing palatable forage for livestock (Mengistu and Messersmith, 2002). Belonging to fabaceae family, Sesbania (Kurdali and Al-Ain, 2002) and Guar (Rao and Shahid, 2011) are two other salt-tolerant plant species with semi-deep taproot systems and high ability to establish symbiosis with nitrogen-fixing microorganisms.

In arid and semi-arid areas, intercropping is a common practice for preventing yield loss and achieving production sustainability, particularly under environmental stress condition. In addition, the use of an intercropping system involving salt-tolerant species is an effective approach to increasing forage yield under salinity stress conditions (Mashhadi *et al*., 2016). Selection of suitable forage crops for yield improvement in intercropping systems under salt stress may also contribute to obtaining higher goals in sustainable agriculture. Among these objective, mention can be made of more efficient exploitation of natural resources (Vrignon-Brenas *et al*., 2016), increased efficiency in radiation use (Mahallati *et al*., 2015), elevated food productivity (Abusuwar and Al-Solimani, 2013), augmented nutrient uptake efficiency (Nyasasi and Kisetu, 2014), increased protein yield (Contreras-Govea *et al*., 2009), and enhanced forage quality for livestock. Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), Crude Protein (CP) and ash have been reported as the most applicable indicators in assessing forage quality (Yilmaz *et al*., 2008). In intercropping systems, forage quality indices tend to improve as a result of the beneficial changes in ecological niches and the involvement of legumes with higher protein content, ultimately leading to increased forage quality (Ross *et al*., 2005).

Providing high quality forage for livestock in arid and semi-arid regions of central Iran is of particular importance concerning the goals of sustainable agriculture. However, very few studies have evaluated the quantitative and qualitative yield of Kochia, Sesbania and Guar forages within intercropping systems under salinity conditions. Accordingly, this study was carried out to (i) Specify the dry yield, (ii) Assess certain qualitative traits of the forage produced by these species in dual and triple intercropping systems, and (iii) Select the most optimal system for application under salinity stress.

MATERIALS AND METHODS

Experimental Set Up

The field experiments were carried out at the research farm of the Iranian National Salinity Research Center (54° 14´ 11´´ E, 32° 03 ´ 11 ´´ N; Altitude= 1,136 m above meansea level) Yazd, Iran, during two growing seasons of 2016 and 2017. The experiments were designed as split plot based on a randomized complete block with three replications. Irrigation water salinity in three levels (4, 9 and 14 dS m^{-1}) was considered as the main factor and the cropping systems in sub-plots included Kochia sole cropping (K), Sesbania sole cropping (S), Guar sole cropping (G), Kochia-Sesbania intercropping (K:S), Kochia-Guar intercropping (K:G), Sesbania-Guar intercropping (S:G), and Kochia-Sesbania-Guarinter cropping (K:S:G). Intercropping was performed by replacement method (50%:50%). In three species intercropping; Kochia was placed in the rows between Sesbania and Guar, by 33% of proportion for each species.

The soil texture was loamy-clay-sand with sand, silt and clay percentages of 51:26:23 ratios in 30 cm upper soil layer and 53:25:22 ratios in 30-60 cm depth. Fertilizers were applied at110 kg ha^{-1} of urea (46% N), and 43 kg ha^{-1} triple super-phosphate. Weed-control practice was done manually.

Primary tillage operations consisted of ploughing, disking and bed preparation. Then, plots with dimensions of 4.5×3 meter containing 9 rows with 50 cm row spacing were prepared. Seeds were sown manually as piles with 20 cm intra-row distance (each seed pile consisting of 2, 3 and 3 seeds for Kochia, Sesbania, and Guar, respectively) at 5th April. In intercropping systems, the species were sown in alternate rows.

In order to have uniform density, all plants were irrigated (4 dS m^{-1}) immediately after planting and before full establishment (30 days after). Then, salinity treatments were applied through third irrigation till the end of crop growth period. Irrigation was performed once every 10 days with a constant regime considering additional water needed for leaching. The 4 and 9 dS m^{-1} saline waters were prepared by mixing water from two natural wells (EC= 2 and 14 dS m^{-1}) by a system installed in the farm prior to entering the main plots through piping network.

Determination of Absorbed Light

A photometer device (SunScan, Delta-T model, England) was used to measure light on a sunny day between 11:00 AM and 14:00 PM at the start of Kochia budding stage. Light was measured on each plot at the top and bottom of the canopy (three replications perpendicular to the crop rows). The final percent of light absorbed by the sole and intercropping canopies was calculated by Equation 1 (Tesfaye *et al*., 2006).

$$\text{Absorbed light (\%)} = [(I_a - I_b)/I_a] \times 100 \qquad (1)$$

Where, I_a and I_b are measured light in top and bottom of canopy, respectively.

Forage Yield Determination

The plants in the middle rows (3 m^2) were harvested at the beginning of the Kochia blooming stage. Dry forage yield was measured after drying fresh materials in oven at 65°C for 72 hours.

Forage Quality Determination

In order to determine the qualitative characteristics, dried forage samples were milled and sieved. Total nitrogen percentage was determined using Kejeldahl device. Crude protein percentage was determined by multiplying nitrogen percentage by 6.25 (Strydhorst *et al*., 2008). Crude protein yield was obtained by multiplying the crude protein percentage of each plant by its dry

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matter yield (Yin and Vyn, 2005). Crude protein yield in intercropping system was calculated separately for each involved species, and the mean total crude protein yield in dual and triple intercropping was then obtained based on the yield ratio of each plant in unit area. NDF (Neutral Detergent Fiber) and ADF (Acid Detergent Fiber) were measured using a Fiber Tec Device according to the method of Van Soest (1994).

The ground samples of each plant were kept for 5 hours in a furnace at 600°C and ash content were measured.

Total Digestible Nutrients (TDN), Dry Matter Intake (DMI) and Net Energy for Lactation (NEL) were calculated according to Equations (2), (3) and (4), proposed by Lithourgidis *et al*., (2006).

$$TDN= (-1.291\times ADF)+101.35 \quad (2)$$

$$DMI\ (\%)= 120/NDF \text{ dry matter basis} \quad (3)$$

$$NEL= [1.044-(0.0119\times ADF\ \%)]\times 2.205 \quad (4)$$

Analysis of Yield Advantage and Competition Indices in Intercropping

The Land Equivalent Ratio (LER) was used as an indicator of land productivity and was calculated by Equations (5) and (6) (Zhang *et al*., 2011). The Relative Crowding Coefficients (RCC) was used to measure the relative dominance of one component crop over another in intercropping and the Actual Yield Loss (AYL) was calculated to show the competition between and within the component crops (Zhang *et al*., 2011; Dhima *et al*., 2007). RCC and AYL were calculated according to Banik (1996) and De Wit (1960).

$$LER_{(Double\ cropping)}= LER_1+LER_2= (Y_{ab}/Y_{aa})+(Y_{ba}/Y_{bb}) \quad (5)$$

$$LER_{(Triple\ cropping)}= LER_1+LER_2+LER_3= (Y_{abc}/Y_{aaa})+(Y_{bac}/Y_{bbb})+(Y_{cab}/Y_{ccc}) \quad (6)$$

$$RCC_{(Double\ cropping)}= RCC_1\times RCC_2 = [(Y_{ab}\times Z_{ba})/((Y_{aa}-Y_{ab})\times Z_{ab})]\times[(Y_{ba}\times Z_{ab})/((Y_{bb}-Y_{ba})\times Z_{ba})] \quad (7)$$

$$RCC_{(Triple\ cropping)}= RCC_1 \times RCC_2 \times RCC_3 = [(Y_{abc}\times(Z_{bac}+Z_{cab}))/((Y_{aaa}-Y_{abc})\times Z_{abc})]\times[(Y_{bac}\times(Z_{abc}+Z_{112}))/((Y_{bbb}-Y_{bac})\times Z_{bac})]\times[(Y_{cab}\times(Z_{abc}+Z_{bac}))/((Y_{ccc}-Y_{cab})\times Z_{cab})] \quad (8)$$

$$AYL_{(Double\ cropping)}= [(Y_{ab}/Z_{ab})/(Y_{aa}/Z_{aa})]-1 \quad (9)$$

$$AYL_{(Triple\ cropping)}= [(Y_{abc}/Z_{abc})/(Y_{aaa}/Z_{aaa})]-1 \quad (10)$$

Where, Y_{ab} and Y_{ba} are the forage Yields of two different crops in intercropping and Y_{aa} and Y_{bb} are the Yields of those of these crops in sole cultures; Y_{abc}, Y_{bac} and Y_{cab} are the forage Yields of three different crops in intercropping, Y_{aaa}, Y_{bbb} and Y_{ccc} are the forage Yields of those of these crops in sole cultures, and Z_{aa}, Z_{aaa} and Z_{ab}, Z_{abc} are the sown row proportions in sole cropping and intercropping, respectively.

Statistical Analysis

Combined analysis of variance for the data was performed by SAS statistical software, version 9.4. The uniformity of variances was tested using Bartlett's test and it was found not significant for any of the measured traits. Thus the combined analysis was performed. Means were compared by using Duncan method at 5% level, and if the interaction effects were significant, the physical slicing was performed using proc sort procedure (Hallahan, 1995).

RESULTS AND DISCUSSION

Crude Protein

Crude protein percentage and total crude protein yield of forage were significantly influenced by salinity, cropping system, and their interaction effects (Table 1). Previous studies have shown that the crude protein content of legume forages is higher than that of many other plant species (Ross *et al*., 2005; Bingol *et al*., 2007). Among the salinity levels in all experimental treatments, the highest and the lowest crude protein percentage belonged to Guar sole cropping and Kochia sole cropping, respectively

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(Table 4). In intercropping systems, the presence of Guar and Sesbania, both pertaining to the legumes, resulted in enhanced crude protein content. On the contrary, the existence of Kochia in intercropping systems reduced the crude protein content. Therefore, it may be concluded that the Guar and Sesbania in triple intercropping systems possibly mitigates the decreasing effects of Kochia on this trait, resulting in an acceptable crude protein percentage.

Comparison of the mean interaction effects of the irrigation water salinity and the cropping system on total crude protein yield (Table 4) showed that at all three salinity levels, the highest and the lowest total crude protein yield was obtained by the triple intercropping and the Kochia sole cropping systems, respectively.

Furthermore, the triple intercropping system and Kochia sole cropping showed the highest crude protein contents. In addition, the triple system was only slightly different from superior systems (Guar and Sesbania) in terms of crude protein percentage. The total crude protein yield value is obtained via multiplying the crude protein percentage by the forage yield value, possibly explaining the higher total crude protein yield resulting from this intercropping system. Additionally, despite its high forage yield, Kochia sole cropping system had the least total crude protein yield, which might be due to the very low crude protein percentage of this crop.

Comparison of the mean interaction effects of year and cropping system (Table 2) indicated significant differences among the cropping systems concerning the total crude protein yields over the two years of experiment. In both years, the highest mean of total crude protein yield (with a significant difference) was observed in triple intercropping system. In this system, the total crude protein yield was (1.51 and 1.71), (1.28 and 1.44) and (1.43 and 1.47) times more than Kochia sole cropping ,Guar sole cropping, and Sesbania sole cropping systems in the first and second year, respectively.

The higher total crude protein yield in the triple intercropping compared to Kochia sole cropping in the second year was due to the increased forage yield in the intercropping system (Table 2). The crude protein yield was obtained by the crude protein percentage multiplied by the forage yield, which seemingly explains the improvement in the total crude protein yield.

NDF and ADF

Analysis of variance (Table 1) showed that the NDF and ADF contents were significantly influenced by the main effects of irrigation water salinity and cropping system, as well as their interaction effects. Mean comparison of the interaction effects of irrigation water salinity and cropping system showed that at different salinity levels, the highest NDF pertained to Kochia sole cropping, which had a significant difference with other cropping systems. Also, the lowest NDF content was found in Sesbania sole cropping system (Table 4). In Kochia sole cropping and every dual intercropping system where Kochia was one of the crops, NDF tended to decrease with increasing the irrigation water salinity. On the contrary, in both Guar and Sesbania sole cropping systems, increased salinity elevated the cell wall concentration. It was further observed that in triple intercropping, this trait was not significantly different among various salinity levels, possibly due to the higher compensation effects of Kochia compared to Guar and Sesbania. The increased NDF content can be attributed to the higher nitrogen uptake, higher growth rate of the vegetative organs (Cox *et al*., 2001), more stem percentage (Kume *et al*., 2001), lower contribution of reproductive organs, and plant environmental conditions (Buxton *et al*., 1996).

NDF value at salinity levels of (4, 9 and 14 dS m^{-1}) decreased by (13, 12, and 7%) in the Kochia and Guar dual intercropping, (19,

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Table 1. Combined analysis of variance for the effect of different salinity levels and different cropping systems on forage yield component and some forage qualitative characteristics in a two-year experiment.

Source of variation	DF	Mean squares[a]									
		Absorbed light	Yield	CP	CPY	NDF	ADF	TDN	DMI	NEL	ASH
Year (Y)	1	1.88^{ns}	543457.3^{ns}	2.58^{ns}	39165.4^{ns}	0.58^{ns}	6.96^{ns}	11.62^{ns}	0.09^{ns}	0.004^{ns}	12.95^{ns}
Rep×Y	4	159.67	160671.6	319.55	908639.8	867.24	477.43	795.71	5.67	0.32	347.96
Salinity (S)	2	37.10**	3211871.6*	40.35**	608904.7**	2.91^{ns}	20.52*	34.19*	0.07^{ns}	0.01*	1.37^{ns}
Y×S	2	0.03^{ns}	41192.2^{ns}	0.21^{ns}	2943.8^{ns}	0.69^{ns}	0.49^{ns}	0.83^{ns}	0.01^{ns}	0.0003^{ns}	0.34^{ns}
Error a	8	31.89	28271.7	7.12	289667	4.37	0.63	1.06	0.03	0.0004	0.92
Cropping system(C)	6	890.86**	26387711.8**	431.89**	531177.4**	766.33**	384.07**	640.05**	4.59**	0.26**	37.33**
Y×C	6	4.16^{ns}	80718.0*	1.25**	13084.5**	4.20*	1.48^{ns}	2.46^{ns}	0.04**	0.001^{ns}	0.44^{ns}
S×C	12	3.54^{ns}	466934.2**	2.84**	17876.5**	8.97**	11.62**	19.37**	0.05**	0.007**	2.89**
Y×S×C	12	1.79^{ns}	19011.7^{ns}	0.23^{ns}	2445.8^{ns}	0.91^{ns}	0.54^{ns}	0.91^{ns}	0.006^{ns}	0.0003^{ns}	0.20^{ns}
Error	72	32.98	30131.9	5.54	16791.6	2.39	1.03	1.72	0.05	0.0007	5.22
CV %		9.77	3.28	11.77	12.72	3.77	3.80	1.96	7.36	7.81	15.90

[a] Crude Protein (CP), Crude Protein Yield (CPY), Neutral Detergent Fibers (NDF), Acid Detergent Fibers (ADF), Total Digestible Nutrient (TDN), Dry Matter Intake (DMI), Net Energy for lactation (NEL). ns, *and**: indicate non-significant and significant at the 5 and 1% levels of probability, respectively.

Table 2. Mean comparison of the interaction effects of year ×cropping systems on forage yield and some measured quality indices.

Year	Cropping system	Forage yield (kg ha^{-1})	CP[b] (%)	CPY (kg ha^{-1})	NDF (g kg^{-1})	DMI (g kg^{-1})
2016	K	6444.8 a[a]	13.109 f	841.78 c	51.01 a	2.38 e
	G	3557.6 d	27.567 a	991.19 bc	37.86 d	3.21 c
	S	4248.7 c	20.800 c	887.83 c	32.58 e	3.75 a
	K:G	6170.4 a	17.488 ed	1083.35 b	45.31 b	2.69 e
	K:S	5222.7 b	16.646 e	872.98 c	42.69 c	2.84 d
	S:G	4447.7 c	23.734 b	1054.60 b	36.22 f	3.39 b
	K:S:G	6459.6 a	19.660 cd	1270.69 a	41.39 c	2.94 d
2017	K	6491.4 a	12.424 e	807.17 c	52.00 a	2.32 e
	G	3468.9 d	27.722 a	957.82 c	37.97 d	3.29 b
	S	4297.3 c	21.794 c	935.85 c	31.50 f	3.94 a
	K:G	6382.3 a	17.821 d	1139.89 b	46.52 b	2.62 d
	K:S	5345.1 b	16.790 d	898.92 c	42.01 c	2.89 c
	S:G	4682.2 c	24.075 b	1128.34 b	34.96 e	3.52 b
	K:S:G	6771.0 a	20.382 c	1381.25 a	41.14 c	2.99 c

[a] Means indicated with different letters are significantly different, based on LSD test at $P< 0.05$. [b] Crude Protein (CP), Crude Protein Yield (CPY), Neutral Detergent Fibers (NDF), Acid Detergent Fibers (ADF), Total Digestible Nutrient (TDN), Dry Matter Intake (DMI), Net Energy for lactation (NEL)

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19, and 15%) in Kochia and Sesbania dual intercropping, and (22, 21, and 17%) in triple intercropping systems, respectively, in comparison to Kochia sole cropping (Table 4). Mean comparison of the interaction effects of water salinity and cropping system on the ADF content (Table 4) revealed that at 4 dS m^{-1} salinity level, the highest ADF was obtained in Kochia sole cropping, which showed a significant difference with other cropping systems. At 9 dS m-1 salinity level, the Kochia sole cropping had the highest NDF but showed no significant difference with Guar sole cropping. Nevertheless, at the salinity level of 14 dS m^{-1}, the highest ADF belonged to Guar sole cropping, which had significant differences with all other cropping systems (Table 4). As shown in Table 4, at 4 and 9 dS m^{-1} salinity levels, Kochia produced in intercropping systems revealed a lower ADF content in comparison to that in sole cropping. Similar results indicating reduction of NDF and ADF in forages obtained by legume-containing intercropping systems have been reported (Ross *et al*., 2005; Lithourgidis *et al*., 2006; Bingol *et al*., 2007; Strydhorst *et al*., 2008; Contreras-Govea *et al*., 2009). Reduction in NDF and ADF has been reported to improve the forage quality obtained by intercropping systems (Assefa and Ledin, 2001) compared to Kochia sole cropping, possibly due to the presence of Sesbania and Guar legumes. Furthermore, reduced NDF content has been reported to be associated with a lower foragefeeding capacity (Van Soest, 1994); therefore, the forage production in intercropping systems is able to reduce the dry matter consumption in animal feeding.

Mean comparison of the interaction effects of year×cropping system (Table 2) showed that, over the two years of experiment, there was a significant difference among the mean NDF contents of different cropping systems. In both years, Kochia sole cropping had the highest mean NDF and showed a significant difference with other treatments. In the first and second year, the mean NDF in triple intercropping system compared to that in Kochia sole cropping was reduced by 18.86% and 20.88%, respectively. It seems that the leaf contribution from photosynthetic material tends to augment with increasing salinity level (Salehi *et al*., 2009), resulting in a higher leaf growth rate and enhanced forage quality (Everitt *et al*., 1983). According to the forage quality standard (Table 3), it can be concluded that, in terms of protein percentage, the Kochia sole cropping system ranked second (good) at 4 dS m^{-1} salinity level and third (fair) at 9 and 14 dS m^{-1} salinity levels, whereas other systems ranked prime and premium. However, concerning total NDF, all Kochia-containing intercropping systems ranked premium at different levels of salinity, indicating the improved forage quality as a result of mixing with legumes. Regarding total ADF, the most optimal performances was observed in intercropping Sesbania sole cropping systems.

As an important criterion for the true contribution of forage consumed by animals (Bingol *et al*., 2007; Lithourgidis *et al*., 2006), NDF content is known to have an inverse association with dry matter intake

Table 3. Forage qualitative standard table for legume-grass intercropping systems (Lithourgidis *et al*., 2006).

Standard type	Qualitative attributes[a] (%)			
	DMI	NDF	ADF	CP
Prime	> 3	< 40	< 30	> 19
1 (Premium)	2.6-2.9	40-46	31-35	17-19
2 (Good)	2.1-2.5	47-53	36-40	11-16
3 (Fair)	1.7-2	54-60	41-42	11-13
4 (Poor)	1.3-1.6	61.65	43-45	8-10
5 (Reject)	< 1.2	> 65	> 45	< 8

[a] Dry Matter Intake (DMI), Neutral Detergent Fibers (NDF), Acid Detergent Fibers (ADF), Crude Protein (CP).

Table 4. Mean comparison of some measured yield indices in different intercropping systems and salinity levels.

Irrigation water salinity (dS m^{-1})	Cropping system	Forage yield (kg ha^{-1})	CP [b] (%)	CPY (kg ha^{-1})	NDF (g kg^{-1} DM)	ADF (g kg^{-1} DM)	TDN (g kg^{-1} DM)	DMI (g kg^{-1} of body weight)	NEL (Mcal kg^{-1})	Ash (%)
4	K	6510.33 b [a]	13.93 e	906.16 c	52.99 a	31.78 a	60.31 e	2.28 d	0.21 e	17.31 a
	G	4385.00 e	27.44 a	1205.97 b	35.46 d	28.96 b	63.95 d	3.47 b	0.28 d	14.65 bc
	S	4438.17 e	22.56 c	1007.14 c	31.32 e	17.71 c	78.47 a	3.95 a	0.57 a	11.18 d
	K:G	6574.00 b	18.98 d	1248.27 b	45.88 b	29.67 b	63.03 d	2.68 c	0.26 d	15.81 ab
	K:S	5433.33 c	18.75 d	1021.40 c	42.94 c	25.87 c	67.94 c	2.82 c	0.36 c	14.98 abc
	S:G	4789.00 d	24.72 b	1185.38 b	34.92 d	22.81 d	71.90 b	3.55 b	0.44 b	13.05 cd
	K:S:G	6833.50 a	21.25 c	1451.37 a	41.20 c	26.58 c	67.03 c	2.97 c	0.34 c	15.03 abc
9	K	6409.83 b	12.52 e	803.29 d	52.08 a	31.55 a	60.62 e	2.31 f	0.21 e	15.80 a
	G	3527.50 f	27.24 a	966.64 bc	38.82 d	30.98 a	61.35 e	3.14 c	0.23 e	15.33 a
	S	4239.20 e	20.98 c	886.84 cd	31.80 f	17.51 e	78.73 a	3.84 a	0.58 a	11.98 b
	K:G	6233.00 b	17.26 d	1078.41 b	46.07 b	29.57 b	63.17 d	2.63 e	0.26 d	14.81 a
	K:S	5266.50 c	15.96 d	841.35 cd	42.27 c	25.72 c	68.13 c	2.88 d	0.36 c	13.80 ab
	S:G	4529.50 d	23.99 b	1084.38 b	35.97 e	24.04 d	70.31 b	3.39 b	0.41 b	13.43 ab
	K:S:G	6671.17 a	20.05 c	1336.06 a	41.40 c	26.17 c	67.56 c	2.95 d	0.35 c	14.78 a
14	K	6435.50 a	11.85 f	763.98 c	49.44 a	29.51 c	63.24 d	2.45 f	0.26 d	15.11 a
	G	2627.20 e	28.25 a	750.90 c	39.48 d	34.23 a	57.15 e	3.13 c	0.14 e	16.01 a
	S	4141.67 d	20.34 bc	841.55 bc	32.99 f	19.01 e	76.80 a	3.76 a	0.54 a	11.88 b
	K:G	6022.17 b	16.71 de	1088.17 b	45.79 b	29.90 b	62.73 d	2.65 ef	0.25 d	14.33 ab
	K:S	5151.83 c	15.44 e	795.09 c	41.8 c	25.93 d	67.87 b	2.90 cd	0.36 b	14.25 ab
	S:G	4376.33 d	23.01 b	1004.66 b	35.88 e	27.39 c	65.97 c	3.42 b	0.32 c	13.81 ab
	K:S:G	6341.17 a	18.77 cd	1190.49 a	41.20 cd	26.75 cd	66.81 bc	2.98 c	0.34 bc	14.33 ab

[a] Means indicated with different letters are significantly different based on LSD test at $P<0.05$. [b] Crude Protein (CP), Crude Protein Yield (CPY), Neutral Detergent Fibers (NDF), Acid Detergent Fibers (ADF), Total Digestible Nutrient (TDN), Dry Matter Intake (DMI), Net Energy for lactation (NEL).

Table 5. Mean squares resulting from the analysis of variance for the effects of salinity and cropping system on LER, RCC and AYL in two experimental years.[a]

Source of variation	Df	Mean squares	Df	Mean squares					
				Kochia		Sesbania		Guar	
		LER		RCC_K	AYL_K	RCC_S	AYL_S	RCC_G	AYL_G
Year (Y)	1	0.032 ns	1	0.037 ns	0.006 ns	0.003 ns	0.0003 ns	0.96 ns	0.16 ns
Rep×Y	4	0.003	4	0.014	0.002	0.01	0.002	0.14	0.01
Salinity (S)	2	0.002 ns	2	0.04*	0.005**	0.007 ns	0.001 ns	0.03 ns	0.007 ns
Y×S	2	0.003 ns	2	0.02 ns	0.002 ns	0.0001 ns	0.00001 ns	0.06 ns	0.007 ns
Error a	8	0.0005	8	0.005	0.0006	0.001	0.0003	0.02	0.003
Cropping system (C)	3	0.327**	2	3.97**	1.06**	1.20 ns	0.44**	0.13 ns	0.10**
Y×C	3	0.003*	4	0.003 ns	0.0009 ns	0.002 ns	0.0005 ns	0.11 ns	0.007 ns
S×C	6	0.005**	2	0.005 ns	0.0002 ns	0.005 ns	0.001 ns	0.16*	0.02*
Y×S×C	6	0.0005 ns	4	0.004 ns	0.0001 ns	0.0001 ns	0.00001 ns	0.03 ns	0.003 ns
Error	36	0.001	24	0.008	0.0009	0.002	0.0005	0.04	0.005
CV		3.29		6.54	15.73	3.60	13.01	16.35	17.98

[a] Df: Degree of freedom; LER: Land Equivalent Ratio; RCC_K, RCC_S, and RCC_G: Relative Crowding Coefficient of Kochia, Sesbania and Guar; AYL_K, AYL_S and AYL_G: Actual Yield Loss of Kochia, Sesbania and Guar. ns, * and **: Indicate non-significant and significant at the 5 and 1% levels of probability, respectively.

(Van Soest, 1994). Therefore, the nutritive value and intake capability of the forage produced in Kochia sole cropping system, which had the highest NDF and ADF values (Table 4), might be significantly enhanced via its intercropping with Sesbania and Guar.

Total Digestible Nutrients (TDN), Dry Matter Intake (DMI), and Net Energy for Lactation (NEL)

The results of the analysis of variance (Table 1) showed that TDN, DMI and NEL were significantly affected by irrigation water salinity, cropping system, and their interactions. The mean comparison of the interaction effect of water salinity×cropping system showed that at different salinity levels, the highest TDN, DMI and NEL belonged to Sesbania sole cropping system, which showed a significant difference with other systems. Moreover, the lowest TDN, DMI and NEL at salinity levels of 4 and 9 dS m^{-1}were associated to Kochia sole cropping system. At salinity level of 14 dS m^{-1}, the lowest TDN and NEL values belonged to Guar sole cropping, but the least DMI was obtained from Kochia sole cropping (Table 4). TDN indicates the available nutrients for livestock, and its amount depends on the ADF concentration in forage. Therefore, for every cropping system in which ADF increased, the TDN value tended to decrease, in turn slightly reducing the use efficiency of forage nutrients in livestock (Lithourgidis *et al*., 2006). NDF is also used to predict DMI value and there is a significant negative correlation between DMI and NDF (Contreras-Govea *et al*., 2009). Therefore, in systems with increased forage NDF, the content and quality of DMI decreased (Kume *et al*., 2001).

In this two-year study, dual and triple intercropping of Kochia with legumes (particularly Sesbania) led to an increased TDI, DMI and NEL values in Kochia forage. Accordingly, when the Kochia is intercropped with legumes under water salinity condition, the forage quality is expected to improve owing to the reduced NDF and DMI. In addition, with the reduction in NDF values at different salinity levels, the NEL values were observed to increase in comparison to Kochia sole cropping. Mean comparison of year×cropping system interactions (Table 2) showed that the cropping systems were significantly different in terms of the total digestible nutrients over the two years of experiment. In both years, Sesbania sole cropping had the highest mean of the total digestible nutrient content and showed a significant difference with other treatments. Compared to Kochia sole cropping, the total digestible nutrients in triple intercropping system were increased by 19.04 and 22.41% in the first and second years, respectively.

Ash Content

The results of analysis of variance (Table 1) showed that ash content was significantly affected by water salinity, cropping system, and their interactions effects. Comparing the mean interactions of salinity and cropping system, Kochia sole cropping had the highest ash content at 4 and 9 dS m^{-1} water salinity levels and showed a significant difference with other cropping systems. However, at the salinity level of 14 dS m^{-1}, the maximum ash content was found in Guar sole cropping, which had a significant difference only with Sesbania sole cropping system. At all three salinity levels, the lowest ash content was in Sesbania sole cropping system (Table 4). The ash content of Kochia in intercropping systems decreased from 2.5 to 13.5% in comparison with its sole cropping systems. Application of Sesbania to intercropping with Kochia enhanced the forage quality mainly through reducing the ash content, as compared to Kochia sole cropping.

Absorbed Light

The results of analysis of variance (Table 1) showed that the absorbed light was

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significantly influenced by water salinity in the cropping system. The mean comparison analysis showed that with increasing the salinity levels from 4 to 9 and 14 dS m^{-1}, the mean absorbed light decreased by 1.5 and 3.2%, respectively (Table 6). Triple intercropping had the highest absorbed light and showed a significant difference with other cropping systems. The average amount of absorbed light in triple intercropping was higher by 7.2, 32.4, and 38.2% compared to the sole cropping systems of Kochia, Sesbania, and Guar, respectively. The quantity and quality of absorbed light have been reported to increase in intercropping systems compared to the sole cropping systems (Awal *et al*., 2006). In intercropping systems, owing to the reduced light reflection (Sinoquet and Bonhomme, 1992), modified canopy shape, and foliage arrangement of the involved plants (Tsubo *et al*., 2005) the photosynthesis radiation losses decreased and radiation use efficiency increased (Agegnehu *et al*., 2006). On the other hand, the mean absorbed radiation in the triple intercropping was higher than that in other systems, therefore, it seems that this system provides a different ecological niche in which the dense occupancy increases the received radiation (Tsubo *et al*., 2001).

Forage yield

The results of the analysis of variance (Table 1) showed that the main effects of irrigation water salinity and cropping system as well as the interaction effects of water salinity ×cropping system and year ×cropping system had a statistically significant impact on the forage yield. In all surveyed cropping systems, the mean total forage decreased with the increase in the salinity level of the irrigation water.

The highest decrease in mean total forage yield due to increased salinity was seen in Guar sole cropping, where the increase in the salinity level from 4 to 9 and 14 dS m^{-1} resulted in 19.5 and 40.1% reductions, respectively (Table 4). At 4 and 9 dS m^{-1} salinity levels, the highest mean total forage yield was obtained by three-species intercropping, whereas at 14 dS m^{-1} salinity, Kochia sole cropping yielded the highest. Additionally, at 14 dS m^{-1} salinity level, there were no statistically significant differences between Kochia sole cropping and three-species intercropping concerning the mean total forage yield. Meanwhile, at all three levels of salinity, the least mean total forage yield pertained to Guar sole cropping system.

Mean comparison of the year×cropping system interaction (Table 2) showed that in the two years of experiment, the cropping systems were significantly different in terms of forage yields. In both years, the highest yield belonged to three-species intercropping system, which, contrary to

Table 6. Absorbed light comparison in different water salinity treatments and cropping systems.

Salinity (dS m^{-1})	Light absorbed (%)
4	59.66 a [b]
9	58.78 b
14	57.78 c
Cropping system [a]	
K	65.10 b
G	50.48 e
S	52.69 d
K:G	59.85 c
K:S	59.79 c
S:G	53.49 d
K:S:G	69.78 a

[a] K: Sole cropping of Kochia; S: Sole cropping of Sesbania; G: Sole cropping of Guar; K:S: Intercropping of Kochia-Sesbania; S:G: Intercropping of Sesbania-Guar; K:G: Intercropping of Kochia-Guar; K:S:G: intercropping of Kochia-Sesbania-Guar. [b] Similar letters in each column indicate non-significant difference according to LSD test at the 5% level.

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other cropping systems, was not significantly different from Kochia sole cropping and Kochia-Guar intercropping systems. Kochia has a deeply extended taproot system and both Sesbania and Guar have vertically grown semi-deep roots, therefore, the improved photo-assimilate accumulation and the resulting increased dry weight observed in the plants grown in intercropping systems under saline conditions might be related to their more efficient uptake, mobilization, and use of water and soil nutrients (Larocque *et al*., 2012). In addition, the morphological changes in plant aerial parts such as plant height, leaf area, and leaf angles may improve the penetration of light into the canopy, thereby increasing the light use efficiency and photosynthesis rate in these plants (Larocque *et al*., 2012).

The denser canopy formed in triple intercropping system allows the plants use radiation more efficiently than monoculture system (Awal *et al*., 2006). In the triple system, the light transmitted from the higher canopy of Kochia can be received by Sesbania and Guar plants. Furthermore, the higher mean total yield observed in superior intercropping systems may be associated with the reduced interspecific competition and the increased supplementary effects of species in these systems (Helenius and Jokinen, 1994). However, the reduction in the mean total forage yield in the intercropping of Kochia with Sesbania is ascribed to the increased competition between the two species for light absorbing in this cropping system (Mahfouz and Migawer, 2004). With increase in the salinity level, the least reduction in the mean total forage yield was observed in the Kochia sole cropping. Mean comparison of the salinity ×cropping system interaction (Table 4) revealed that the application of triple intercropping system along with the intercropping of Kochia and Guar reduced the rate of forage yield loss caused by salinity in all studied species.

Land Equivalent Ratio (LER)

Analysis of variance for LER showed that the main effect of cropping system and interaction effects of salinity and cropping system were significant (Table 5). The mean comparison of the interaction effects of salinity and cropping system indicated significant differences in the mean LER among the cropping systems at various salinity levels (Table 7). The lowest mean LER at all three salinity levels (0.99) belonged to the intercropping of Sesbania with Kochia. Meanwhile, the highest LER was observed in the triple intercropping, which was significantly different with other systems. At salinity levels of 4, 9, and 14 dS m^{-1}, the mean LER pertaining to the triple intercropping was higher than the dual intercropping of Kochia with Guar by 9.8, 12.8, and 16%, respectively, higher than the dual intercropping of Kochia with Sesbania by 24.2, 25.6, and 25.2%, and higher than dual intercropping of Sesbania with Gaur by 18.18, 15.03, and 13.74%, respectively (Table7).

Morphological differences of plants play a major role in achieving higher LER values and increased effectiveness in intercropping systems (Monti *et al*., 2016). Within an intercropping system, where both involved species compete for the nutrient uptake, the availability of an additional nutrient source, such as nitrogen fixation nodules in legume species, may reduce the pressure of competition for nitrogen uptake (Vandermeer, 1992). Therefore, LERs of higher than 1 in intercropping systems could be explained by these factors. The advantage of triple intercropping in LER indicates that the involved species have efficiently benefited from the advantageous intercropping condition, resulting in increased total yield (Mohsenabadi *et al*., 2008). Given the relative superiority of the triple intercropping system and its significantly increased total yield at various salinity levels, it can be deduced that this system may be highly applicable under

Table 7. Land Equivalent Ratio (LER) comparison in different water salinity treatments and intercropping systems.

Salinity (dS m^{-1})	Cropping system [b]	LER
4	K:G	1.20 b [a]
	K:S	1.00 d
	S:G	1.09 c
	K:S:G	1.32 a
9	K:G	1.17 b
	K:S	1.00 c
	S:G	1.14 b
	K:S:G	1.33 a
14	K:G	1.10 b
	K:S	0.99 c
	S:G	1.13 b
	K:S:G	1.31 a

[a] Similar letters in each column and salinity level indicate non-significant difference according to LSD test at the 5% level. [b] K: Sole cropping of Kochia; S: Sole cropping of Sesbania; G: Sole cropping of Guar; K:S: Intercropping of Kochia-Sesbania; S:G: Intercropping of Sesbania-Guar; K:G: Intercropping of Kochia-Guar; K:S:G: intercropping of Kochia-Sesbania-Guar.

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extreme salinity conditions. The lowest LER amount was observed in the dual intercropping of Kochia and Sesbania, most probably due to their intense competition for light absorption and nutrient uptake (except for nitrogen) from the soil.

Relative Crowding Coefficients (RCC) and Actual Yield Loss (AYL)

The effect of irrigation water salinity on RCC of Kochia was significant. The cultivation system had also a significant effect on RCC of Kochia and Sesbania. Also, interaction of irrigation water salinity and cropping system had significant effect on Guar RCC (Table 6). On average, the intercropped Kochia (without Kochia with Sesbania) had higher RCC (1.77) values than the intercropped Sesbania (1.62) and Guar (1.40), indicating that Kochia was more competitive than Sesbania and Guar (Tables 8 and 9).The greater competitiveness of Kochia might be attributed to shading by the Kochia crop. Indeed, the tall-growing Kochia or the high Kochia proportion in the mixtures could affect light interception by Sesbani and Guar (Oroka, 2012). Increasing salinity levels decreased the RCC of Kochia. The lowest RCC of Kochia was observed at 14 dS m^{-1} salinity level, which decreased by 6.8% compared to 4 dS m^{-1} treatment (Table 8). The highest increase in RCC of Kochia and Sesbania was obtained in intercropping of three species (Table 8). Also in Guar plant, Sesbani:Guar, and three species intercropping system showed good ability to increase RCC at salinity levels of 9 and 14 dS m^{-1} (Table 9).

The trend observed for the AYL was similar to that obtained with the RCC. Analysis of variance showed that the effect of salinity on AYL of Kochia, cropping system on AYL of Kochia, Sesbania and Guar was significant at 1% probability level. Also, interaction of irrigation water salinity and cropping system had significant effect on Guar AYL (Table 5). The best value of partial AYL was found in three species intercropping system (AYL_{Kochia}= 0.42, $AYL_{Sesbania}$= 0.35, AYL_{Guar}= 0.23), indicating the best combination and planting pattern (Tables 8 and 9). AYL of Kochia (Kochia:Sesbania) and Guar (Guar:Kochia

Table 8. Partial RCC and AYL of Kochia and Sesbania plant comparison in different water salinity treatments and cropping systems.

Salinity (dS m^{-1})	RCC_K	AYL_K	Salinity (dS m^{-1})	RCC_S	AYL_S
4	1.47 a [a]	0.21 a	4	1.33 a	0.17 a
9	1.42 ab	0.19 ab	9	1.35 a	0.18 a
14	1.37 b	0.18 b	14	1.37 a	0.19 a
Cropping system			Cropping system		
K:G	1.61 b	0.23 b	S:G	1.33 b	0.14 b
K:S	0.89 c	-0.06 c	K:S	1.10 c	0.05 c
K:S:G	1.77 a	0.42 a	K:S:G	1.62 a	0.35 a

[a] Similar letters in each column indicate non-significant difference according to LSD test at the 5% level.

Table 9. Mean comparison of partial RCC and AYL of Guar plant in different intercropping systems and salinity levels.

Salinity (dS m^{-1})	Cropping system	RCC_G	AYL_G
4	K:G	1.32 a [a]	0.13 b
	S:G	1.07 b	0.03 c
	K:S:G	1.37 a	0.23 a
9	K:G	1.22 b	0.09 b
	S:G	1.40 a	0.13 b
	K:S:G	1.36 a	0.22 a
14	K:G	1.01 b	-0.001 c
	S:G	1.40 a	0.13 b
	K:S:G	1.33 a	0.21 a

[a] Similar letters in each column indicate non-significant difference according to LSD test at the 5% level.

at 14 dS m^{-1} salinity level) were negative, which indicated a yield disadvantage for Kochia and Guar, probably due to the exhaustive effect of Sesbania and Kochia and shading in the early growth stage of Kochia crop (Banik *et al*., 2000). Although intensification of irrigation water salinity had no significant effect on AYL in Sesbania and Guar, it caused an increase in AYL in Kochia plant (Table 8). On the other hand, at different salinity levels, using three species intercropping system increased the AYL of Guar (Table 9).

CONCLUSIONS

Generally, the highest light absorption percentage, maximum forage yield, and the highest LER belonged to Kochia, Sesbania, and Guartriple intercropping system. Higher LER indicates the advantage of intercropping system over sole cropping in terms of forage yield. According to the RCC values, Kochia was the dominant species only when it was planted with the Guar and three species intercropping system. Additionally, forage quality indicators including mean total crude protein yield, neutral detergent fibre, acid detergent fiber, total digestible nutrient, and dry matter intake in Kochia were found to be ameliorated via its intercropping with legumes. The highest mean total crude protein yield was observed in triple intercropping system comprising three species. At all salinity levels, the measured NDF and ADF values of Kochia intercropping systems decreased in comparison to Kochia sole cropping. The reduced NDF and ADF may elevate the nutritive value of forage (Contreras-Govea

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et al., 2009); therefore, the forage produced in triple intercropping systems may be of a higher nutritive value and feeding capacity compared with that generated in Kochia sole cropping system. The fibre digestibility further increased with the reduction in NDF contents. Based on the forage quantitative and qualitative measures, it can be concluded that the triple intercropping of the three studied species is able to (i) Maintain the forage yield, (ii) Improve the forage quality at high salinity levels as compared to Kochia sole cropping, and (iii) Reduce the need for protein supplements in livestock nutrition. Accordingly, it is recommended that Kochia sole cropping be replaced by triple intercropping system in order to produce higher quality forage in areas exposed to irrigation water with high salinity.

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ارزیابی عملکرد و کیفیت علوفه کوشیا، سسبانیا و گوار تحت شرایط شوری آب آبیاری

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چکیده

شوری یکی از مهم‌ترین فاکتورهای محدود کننده رشد و عملکرد در کشاورزی فاریاب است. پتانسیل طبیعی گیاه متحمل به شوری کوشیا در کنار لگوم‌ها در کشت مخلوط می‌تواند به عنوان استراتژی مناسب در کاهش بحران شوری که در حال افزایش است، مورد استفاده قرار گیرد. این آزمایش به صورت اسپلت پلات در قالب طرح بلوک‌های کامل تصادفی با سه تکرار و در سال‌های ۱۳۹۵ و ۱۳۹۶ در مزرعه تحقیقاتی مرکز ملی تحقیقات شوری ایران- یزد، انجام شد. شوری به عنوان عامل اصلی (آبیاری با آب دارای هدایت الکتریکی ۴، ۹ و ۱۴ دسی‌زیمنس‌برمتر) و سامانه‌های کشت به عنوان عامل فرعی و در هفت سطح شامل سه تیمار کشت خالص کوشیا، سسبانیا و گوار و کشت‌های مخلوط دو و سه گونه‌ای آنها در نظر گرفته شد. کل عملکرد علوفه در کشت مخلوط سه گونه نسبت به تک‌کشتی کوشیا در سطح شوری ۴ و ۹ دسی‌زیمنس‌برمتر به ترتیب ۵ و ۴/۱ درصد افزایش معنی‌دار و در شوری ۱۴ دسی‌زیمنس‌برمتر ۱/۵ درصد کاهش غیرمعنی‌داری داشت. نسبت برابری زمین (LER) بین ۰/۹۹ تا ۱/۳۳ بود. عملکرد پروتئین خام کل در مخلوط سه گونه نسبت به تک‌کشتی کوشیا ۵۵/۸ تا ۶۶/۳ درصد افزایش نشان داد. فیبر شوینده خنثی (NDF) و فیبر شوینده اسیدی (ADF) در سیستم‌های کشت مخلوط ۷ تا ۲۲ درصد کاهش یافت. با توجه به افزایش کمی و کیفی علوفه که از طریق کاهش میزان NDF و افزایش DMI حاصل شد، می‌توان کشت مخلوط سه گونه را بجای تک‌کشتی کوشیا توصیه نمود.

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