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Limited Irrigation and Phosphorus Fertilizer Effects on Yield and Yield Components of Grain Sorghum (*Sorghum bicolor L.var. Kimia*)

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Abstract: Prevailing drought stress is one of the main agricultural problems in arid and semi-arid regions of the world. To evaluate the effect of limited irrigation systems and phosphorus fertilizer on yield and yield components of grain sorghum (Kimia), the crop was sown in the Research Farm of College of Agriculture, University of Tehran in Karaj/Iran. The treatments comprised of different limited irrigation regimes applied at different vegetative and generative growth stages of sorghum along with different levels of phosphouors fertilizer viz: contol (no fertizer application); sole chemical phosphorus fertilizer of ammonium phosphate (250 kg/ha) and a mixture of 50% ammonium phosphate (125 kg/ha)+ phosphorus sulobilizing bacteria. The highest grain yield of 7 t/ha was obtained from the control irrigation treatment (no drought stress) when biological phosphorous fertilizer was applied along with 50% of the required chemical fertilizer (ammonium phosphate). Severe drought stress at generative growth stage along with sole ammonium phosphate application led to the least grain yield of less than 0.5 t/ha. Severe limited irrigation during vegetative growth stage and moderately limited irrigation during generative stage (despite 30% grain loss) could produce a reasonable crop with a tremendous water saving with high water use efficiency.

Key words: Limited irrigation % Phosphorus fertilizer % Grain sorghum % Grain yield % Yield components

INTRODUCTION

Drought stress is one of the most important and effective factors in agricultural practices in arid and semi-arid regions of the world. The arid and semi-arid regions comprise more than 70% of the total area of Iran. The over dominant calcareous soil in the cultivated lands along with extended dry climatic conditions minimizes the absorbance and availability of phosphorus to the crop plants. To achieve the sustainable agricultural goals, it is necessary to reduce the application of chemical phosphorus fertilizers and provide the required phosphorous by other means. In this regard the investigation on efficiency of biological fertilizers (phosphorus solublizing bacteria) to provide with the required amount of phosphorous for different crops is of especial importance.

One of the main problems to produce protein and dairy products in dry regions is the shortage of sufficient quality feed and forage for the livestock. Over grazing along with over dominated drought stress have caused that the Iranian rangelands with an area of more than 90 million hectares could only produce about 10 million tons of dry forage per year. This could supply enough feed for only 16 millions animal units which is only 22% of the total livestock population in the country. A significant amount of dry forage (3-5 MT) is imported to feed the livestock in Iran every year.

Sorghum (*Sorghum bicolor L.*) is an important forage crop in arid and semi-arid regions of the world. Because of its excellent adaptability to the dry climatic conditions and high water use efficiency, this crop can produce good yield in areas with water deficiency problem [1]. Berenguer and Faci [2] working on grain sorghum under various sowing densities and water availabilities, concluded that by decreasing the available water or under higher drought stresses, the evapotranspiration, yield, harvest index and total dry matter production will decrease. Carsky *et al*. [3] tested sorghum in a dry faming system by applying the supplemental irrigation

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and phosphorous fertilizer. They concluded that supplementary irrigation during growing season significantly increased the yield while the yield reaction to phosphorus fertilizer was not considerable.

Application of different phosphorous fertilizers is considered as of one of the main sources to provide with the requirements of plants in arid and semi-arid areas of the world. However, the adverse effects of chemical phosphorous fertilizers have restricted their application, especially in dry regions. A significant increase in yield production of *Phaseolus mango* was obtained by applying a mixed animal manure and phosphorus solubilizing bacteria fertilizer [4]. Prabhakar and Saraf [5] by testing the effects of different irrigation regimes along with different phosphorus fertilizer sources (Super phosphate and phosphate stone+phosphorus solubilizing bacteria) on chickpea, reported that the application of phosphorus fertilizer in moderate drought stress had an increasing effect on biomass production and water use efficiency. They also indicated that the application of chemical phosphorous fertilizer along with phosphorus solubilizing bacteria had a better effect on yield production compared to sole chemical phosphorous fertilizer application. Jisha and Alagawadi [6] reported that the inoculation of seeds by both Tricoderma and Pseudomonas bacteria have a more efficient effect on nitrogen and phosphorus absorption, kernel weight, floret in kernel, stem weight and sorghum grain yield in a vertisoils. The inoculated seed by *Pseudomonas* produced only 6 to 8% higher yield compared to control while inoculation by *Tricoderma* resulted in 28 to 30% increment in grain production. However, the inoculation by both microorganisms because of their synergic effects was recommended to achieve higher grain yields in sorghum. The combined inoculation of seed by fungi and bacteria along with application of phosphorus fertilizer will result in a better nutrient absorption for plants in poor and infertile soils [7]. The effect of inoculation by phosphorus sulobilizing bacteria (*Pseudomonas* type) and *mycohrriza* fungi on nitrogen and phosphorus absorption and sorghum grain yield was studied. The inoculation by combination of both microorganisms led to 6-8% increase in grain yield, N and P absorption over the inoculation by sole bacteria and 28-30% increment over sole fungi inoculation [8].

The present experiment was conducted to evaluate the effect of chemical and biological phosphorus fertilizers (phosphorus sulobilizing bacteria) at various limited irrigation regimes on yield and yield components of grain sorghum (*Sorghum bicolor L. var. Kimia*).

MATERIALS AND METHODS

The experiment was initiated in Research Farm of College of Agriculture, University of Tehran located in Karaj/Iran during summer 2004. Karaj is classified among the temperate climatic regions in the country with average rainfall of 256mm per year. The soil physical and chemical characteristics of the experimental site is presented in Table 1.

The experimental treatments were arranged as split plots based on a randomized complete block design with four replications. The main plots were allocated to five different irrigation regimes which applied drought stress on sorghum (soil moisture approached wilting point before the next irrigation) at different vegetative and generative growth stages. The irrigation regimes comprised of:

Full irrigation (IR1) (control): The plots in this treatment were irrigated at weekly intervals up to the end of the growing period.

Moderate drought stress in both vegetative and generative stages (IR2): The plots allocated to this treatment were irrigated on weekly basis until the plants reached well establishment at 6 to 8-leaf growth stage and then the irrigation was ceased until 10 to 12-leaf stage where the plots received irrigation. Re-irrigation was ceased until the early flowering stage (5 to 10% flowering) when the plants received another irrigation. The next irrigation was applied when the plants were in early milky grain stage and since then no irrigation was applied until the plants reached the physiological maturity.

Moderate drought stress in vegetative stage (after 6-8 leaf stage) and severe drought stress in generative stage (IR3): Irrigation treatment was identical to IR2 up to early flowering stage and then no irrigation was applied until plants reached the physiological maturity.

Severe drought stress at vegetative stage and moderate stress at generative stage (IR_4): At vegetative growth stage the irrigation treatment was similar to IR2 except that no irrigation was applied at 10 to 12- leaf growth stage. However, the irrigation treatment followed exactly the same as IR2 in generative part of the plant growth.

Severe drought stress in both vegetative and generative growth stages (IR5): The Irrigation treatment followed the same trend as IR4 at vegetative and IR3 at generative stages of plant growth.

Table 1: The results of the soil chemical and physical analysis of the experimental site

Soil texture	Sand (%)	Silt (%)	Clay (%)	pH	EC (ds/m)	N(%)	K(%)	P(mg/kg)
loamy clay	34.6	36.2	29.2	8.2	0.81	0.07	142	4.6

Table 2: Schedule table of limited irrigation treatments at sensitive phenological growth stages of sorghum

	Phenological stages of plant growth				
Irrigation regimes	6-8 leaf Growth stage	10-12 leaf Growth stage	Early flowering stage	Early milky grain stage	No. of irrigations
(IR_1) Full irrigation (control) †					18
(IR_2) Moderate drought stress in vegetative and generative growth stages	*	*	*	*	10
(IR_3) Moderate drought stress in vegetative and severe drought stress in generative stage	*	*	*	-	9
(IR_4) Severe drought stress in vegetative and Moderate drought stress in generative growth stage	*	-	*	*	9
(IR_5) Severe drought stress in both vegetative and generative growth stages	*	-	*	-	8

Irrigated*

Not Irrigated -

† Plots were irrigated on weekly intervals to the end of the growing season (physiological plant maturity)

*Irrigation was applied only when the soil water potential reached -15 bars (wilting point)

Soil moisture content up to the 60 cm of soil depth was measured in all irrigation treatments before re-applying any amount of water to make sure that the soil water potential was around wilting point (-15 bars). The irrigation schedule of limited irrigation treatments at sensitive phenological growth stages of sorghum is presented in Table 2.

The subplots were allocated to three fertilizer treatments of F1 (control, no fertilizer application), F2 (chemical phosphorus fertilizer of ammonium phosphate, 250 kg/ha) and F3 [50% ammonium phosphate (125 kg/ha)+biological phosphorous fertilizer (phosphorus sulobilizing bacteria)].

The applied biological fertilizer was in the type of the bacteria which release the phosphorus from soil components and neutralize the soil pH. The commercial name of the biologic fertilizer is Barvar-2. The effective gradients of the biological phosphorus fertilizer is comprised of two bacteria strains of p^{5} *(Bacillus lentus)* and P^{13} (*Pseudomonas potida*) with 108 cfu (colony forming units) which have been screened from soil bacteria populations. The medium of the fertilizer is some kind of sugarcane perlite. The bacteria strain p^{5} (*Bacillus lentus*) dissolves P from soil mineral compounds while p^{13} (*Pseudomonas potida*) separates P from soil organic compounds by exerting a variety of phosphotase enzymes. The synergic effect of these two bacteria reduces the soil pH along with increasing of P availability which tends to increase the crop yield by 10 to 54% compared to control [9]. In case of the availability of sufficient P by chemical fertilizer application, the activity of these bacteria would be limited and less P will be released. This phenomenon indicates that the environmental conditions play a significant role in the performance of this biological fertilizer [9].

To evaluate the grain yield and yield components, after the plant physiological maturity, 16 representative plants were randomly selected from each plot (considering the border effects) to measure the panicle length, panicle weight, 1000- seed weight, grain yield, biomass dry weight, biological yield, harvest index, the number of leaves per plant and stem length.

RESULTS AND DISCUSSIONS

The statistical analysis of the data showed that there was a significant difference ($p<0.01$) in grain yield production due to different irrigation regimes (Table 3). The highest grain yield of 5871 kg/ha was obtained from control plots while the lowest grain yield of 500 kg/ha (less than ten times) was produced in severe drought stress both in vegetative and generative growth stages (Fig. 1). As the drought stress in generative stage of the plant was increased, grain yield followed a decreasing trend. Nowa [10] explained that the significant difference in grain sorghum yield at different limited irrigation regimes was due to different irrigation intervals. In the severe drought stress regime in generative stage (IR3),

Table 3: The analysis of variance (mean squares) of measured parameters

Sources of variation	df	Mean squares Grain yield	1000-seed weight	Panicle weight	Panicle length	Biomass weight	Biological yield	Harvest index
Limited irrigation regimes	2	**53666126.00	**629.37	**14.30	**66.25	**38.14	**171.122	**1270
Phosphorous fertilizer	4	**2535720.80	**238.06	**8.05	**354.5	**4.73	**13.998	*16/73
Limited irrigation regimes phosphorous fertilizer	8	**645585.20	**248.13	**1.24	0.742^{ns}	*1.18	**3.247	ns4/81
CV%		13.98	9.96	10.85	4.71	5.87	5.18	11/79

Significant at 0.05 level *, significant in 0.01 level **, ns no significant difference

Table 4: Sorghum grain yield as affected by different irrigation regimes and phosphorus fertilizer treatments

Irrigation regimes	Fertilizer treatments	Biomass weight (leaves and branches) (T/ha)	Biological yield (T/ha)	Grain yield (kg/ha)	1000-seed (g)	Panicle weight (T/ha)
IR_1	F1	11.84c	16.76c	4908.00c	35.95abcd	6.03b
	F2	13.06b	18.88b	5818.00b	38.24ab	7.63a
	F3	14.57a	21.47a	6896.00a	38.72a	8.32a
IR_2	F1	11.09cde	12.83e	1744.00efg	31.07de	2.42ef
	F2	10.85de	13.13de	2265.00ef	32.64bcde	2.84e
	F3	11.52cd	13.95de	245.002e	32.81bcde	2.47ef
IR_3	F1	8.01h	8.47i	472.06h	16.45f	0.836h
	F2	8.75	9.19hi	441.02h	28.38e	1.28gh
	F3	9.01gh	9.51ghi	504.00h	29.78e	1.487gh
IR_4	F1	9.06g	12.57de	3506.00d	38.02ab	3.94d
	F2	9.65g	13.05de	3397.00d	36.11abcd	5.01c
	F3	10.02ef	14.11d	4088.00d	37.28abc	6.36b
IR_5	F1	9.43g	10.79fg	1358.00g	31.1de	1.89fg
	F2	9.02g	10.36fgh	1344.00g	30.84de	2.05efg
	F3	9.45	11.02f	1567.00f	32.03cde	2.78c

the reduction of the panicle weight and one thousand seed weight could be accounted for grain yield decrement (Table 4). This shows the importance of water availability in generative stage of the plant growth (especially grain filling stage).

The interaction effect of limited irrigation regimes and phosphorus fertilizer was significant ($p<0.05$) on sorghum grain yield (Table 3). In control plots (full irrigation) as the application of phosphorous fertilizer increased, the grain yield increased (Table 4). Prabahakar and Saraf [5] and AL-Karaki *et al.* [11] working on the sorghum and bean achieved the similar results. In full irrigation plots (control) by application of the biological P fertilizer+50% ammonium phosphate, the grain yield reached its maximum level of about 7000 kg/ha (Table 4). The grain yield was also increased from application biological P fertilizer+50% ammonium phosphate at severe drought stress both at vegetative and generative growth (IR5) (Table 4). These results shows the buffering index effect of the Biological phosphorous fertilizer which tends to increase the drought tolerance of sorghum under severe environmental conditions. These results support findings by Gill and Dellon [12] and Vasconcelos *et al.* [13] in similar experiments.

The severe reduction of grain yield in irrigation regimes of IR2, IR3 and IR5 indicated the plant sensitivity to drought stress at different phenological stages. Grain production decreased over 50% in these treatments compared to control, however, in IR4 treatment, this reduction was only about 30%. Always the yield decrement in the biological fertilizer+50% chemical phosphorus fertilizer was less than the sole chemical fertilizer in the same limited irrigation treatments. Application of phosphorus solubilizing bacteria+50% ammonium phosphate in full irrigation treatment produced the highest grain yield and applying the same fertilizing treatment at drought stress conditions provided the least damage to sorghum grain production. Sharma *et al.* [14] by applying different phosphobacterial fertilizers and irrigation regimes on lentil concluded that the application

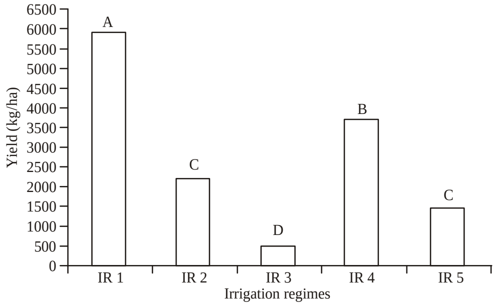

Fig. 1: The effect of different irrigation regimes on grain yield of grain sorghum var. Kimia

IR1: Full irrigation (control).

IR2: Moderate stress in both vegetative and generative growth stages

IR3: Moderate stress in vegetative stage and severe stress in generative growth stage.

IR4: Severe drought stress in vegetative stage and moderate stress in generative growth stage.

IR5: Severe drought stress in both vegetative and generative growth stages.

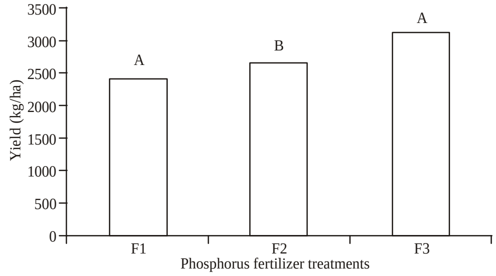

Fig. 2: The effect of different phosphorous fertilizer treatments on grain yield of sorghum var. Kimia

F1: Control (no fertilizer application)

F2: Chemical fertilizer of Ammonium phosphate (250 kg/ha)

F3: Phosphorous solubilizing bacteria+50% of Ammonium phosphate chemical fertilizer (125 kg/ha).

of these fertilizers will increase the efficiency of the soil mineral nutrients absorption (especially phosphorus) which will lead to a higher yield production. Based on the results of this experiment, application of phosphorus solubilizing bacteria+50% Ammonium phosphate, not only has synergic effect on P absorption from chemical Phosphrous fertilizer, but also increases the soil buffer index at moisture stress conditions by saving more moisture in the soil which decreases the harmful effects of over concentration of mineral elements in soil water. These results support the achievements of other researchers in similar experiments [15, 16]. Data also indicated the importance of irrigation at early flowering and milky grain stages of the plant growth which could produce not only a proper grain yield, but also contribute in significant water conservation compared to control (full irrigation). The number of irrigations in IR4 treatment was reduced by 50% (from 18 to 9) compared to control which from ecological and economical point of the views is very important in a dry country like Iran. There was statistically positive and significant correlation between parameters like panicle weight, panicle length, one thousand seed weight, biological yield and harvest index with grain yield production. By increasing of any of these parameters, the grain yield significantly increased.

Drought stress especially in generative growth stages caused a severe decrement in grain yield which could be because of decreasing of 1000- seed weight, panicle length decrement and consequently decreasing the number of grains per panicle (Table 4). Also the lowest number of grains in each panicle may be due to disordered pollination and finally decrement the number of fertilized flowers [4].

There was a significant difference ($p<0.01$) among fertilizing treatments on grain yield (Table 3). The lowest grain yield of 2398 kg/ha was obtained in F1 control plots (no fertilizer application) while the grain yield in ammonium phosphate fertilizer treatment (F2) and phosphorus solubilizing bacteria+50% ammonium phosphate fertilizer (F3) plots were 2653 and 3101 kg/ha of grain, respectively (10 and 22% increase, respectively (Fig. 2).

The results of this experiment shows that the application of biologic fertilizer along with chemical P fertilizer (phosphorus solubilizing bacteria+50% ammonium phosphate treatment) have a synergic effect on phosphorus absorption from rhizosphere which increases the soil buffer index at moisture stress conditions by moderating the harmful effects of over viscosity of mineral elements in the soil water.

By applying a regular irrigation on sorghum from germination to plant establishment stage (7-8 leaf) and then limited irrigations just at 10-12 leaf, early flowering and milky grain stages, the number of irrigations will be decreased from 18 to 9 times. Despite of 30% grain yield reduction in this system, still it is beneficial from ecological and economical point of the views for a dry country like Iran. So, it seems that by severe moisture stress at vegetative along with providing the minimum water requirements in generative growth stages, the water consumption efficiency of the plant will be improved and a reasonable grain yield is achievable.

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