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Studies on the effect of water logging stress at different Stages on cotton, maize and sunflower crops of vertisols under simulated conditions

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Abstract
A field experiment was conducted for three continuous kharif seasons of 2014, 2015 & 2016 at Regional Agricultural Research Station, Nandyal, Andhra Pradesh to study the water logging stress at different Stages on cotton, maize and sunflower crops of vertisols under simulated conditions. Studies were conducted under rain out shelters with simulated waterlogging conditions at different stages of three major kharif crops like cotton, maize and sunflower. Waterlogging decreased the cotton kapas yield significantly over the control. Imposition of waterlogging for two days and four days were significantly reduced the kapas or lint yield. Four days waterlogging decreased the kapas yield by 43.22 percent and two days waterlogging decreased the kapas yield by 34.81 percent over the control at vegetative and boll development stages. In maize crop, highest seed yield was observed in control treatment (5412 kg/ha) while lowest seed yield was observed in maize crop at vegetative stage waterlogged condition (2935kg/ha). In sunflower crop also almost similar results (Table 3) were reported as in case of cotton and maize crops through out the three years of study. Highest LAI (2.32) at 60 DAS, SLA (145.8(cm^2/g), Plant height (140 cm) at 80 DAS, SCMR (53 at 60DAS), NAR (0.917 g/m2/day), RGR (0.0226 g/m^2/day), CGR (11.113 g/m^2/day) at 80 DAS were recorded in control treatment when compared to other treatments. Highest seed yield was observed in control treatment (540 kg/ha) while lowest seed yield was observed in sunflower crop at seed filling stage (225 kg/ha).

Keywords: Abiotic stress, Ill effects, water logging condition, rain out shelters

1. Introduction
Waterlogging is a severe abiotic stress occurring when the soil profile surrounding a plant's root system becomes oversaturated with excess water. Waterlogging is part of the broader stress of flooding, which encompasses both situations where the soil profile is oversaturated and when visual ponding occurs above the soil surface (Charles Hunt Walne and K. Raja Reddy 2021) [6]. Waterlogging can occur anytime soil moisture levels rise above the field capacity. Water inputs exceed a soil's ability to move water off the soil surface and drain internally. Excessive moisture levels result in the aerated pore space filling with water. A water-filled pore space leads to soil oxygen levels rapidly depleting as the transfer of oxygen and other gasses is blocked between the soil and the atmosphere. Oxygen diffuses 10,000 times more slowly in water than in air Globally, waterlogging restricts an estimated 10–12% of all agricultural lands annually, and flooding affects over 17 million km^2 of land surface. Waterlogging ranked second to drought in the United States in terms of abiotic stress' contribution to crop production losses from 2000 to 2017.Waterlogging is serious problem which effects the crop growth and yield. Waterlogging blocks the oxygen supply to the roots thus inhibiting root respiration resulting in severe decline in energy status of root cells affecting important metabolic processes of plants. Waterlogging often results in yellowing of sunflower crop, if it persists for 7-10 days leads to mortality. Nearly 60% of the crop stand was lost when waterlogging persists for 8 days in 20days old crop (Naidu TCM and Thota AT (2011) [9]. Oxygen deficiency inhibits the root respiration of plants which results in substantial reduction in energy status of root cells. Since oxygen is a terminal electron acceptor in aerobic respiration, in its absence, Kreb's cycle and electron transport system are blocked. Therefore, plants under waterlogged conditions use alternate pathway for energy extraction.

This alternate pathway uses fermentative metabolism to produce Adenosine triphosphate (ATP), thereby, resulting in enhanced accumulation of ethanol (Muhammad Arslan Ashraf 2012) [8]. Recently Shraf *et al.* (2011) reported that exogenous application of potassium in soil and as foliar spray alleviated the adverse effects of water logging on cotton plants.

Conaty *et al.* (2008) reported that leaf SPAD readings nitrogen and potassium concentrations were reduced in waterlogged treatments compared to respective controls, and varied with cotton cultivar. Leaf phosphorous, calcium, magnesium, manganese and sulphur concentrations were reduced in waterlogged treatment compared to respective cultive controls in all cultivars. However, water logging increased the leaf total iron concentrations in all cultivars. Bange *et al.* (2003) reported that a single waterlogging event during early squaring and five events throughout growth of the same cumulative duration in cotton gave the same impact on lint yield. However, when the single event was imposed at peak green bolls, it had no significant effect on yield. Ajaz A. Lone and M.Z.K. Warsi, (2009) [9] and Olgun *et al*., (2008) [10] stated that flooding at knee height stage of the crop growth resulted in immediate wilting of plants starting from the base of the plant and subsequent loading of most of the plant. In leaves, wilting started from the tip and proceeded towards the base of the leaf. In most of the genotypes anthesis silking interval got widened even more than eight days in some cases was recorded, which subsequently resulted in barrenness of plants and reduction of overall yield (Trought, M.C.T., Drew, M.C., 1982).

In Sunflower, leaf expansion and extension were inhibited by waterlogging at 6-leaf and bud visible stage although these effects did not always persist until maturity while, with anthesis waterlogging, rapid desiccation of leaves was observed. Yield was most affected by waterlogging at anthesis but no consistent effect on seed number or 1000 seed weight was recorded (Orchard and Jessop, 1984). Measures to ameliorate the ill effects of waterlogging stress conditions will lead to enhancement of productivity of rainfed crops besides relieving distress among farmers when high rainfall situations occur (Ashraf 2009 and Ashraf M, Akram NM (2009) [3, 4].

Materials and Methods

A field experiment was conducted for three continuous kharif seasons of 2014, 2015 & 2016 at Regional Agricultural Research Station, Nandyal, Andhra Pradesh to study the water logging stress at different Stages on cotton, maize and sunflower crops of vertisols under simulated conditions. Studies were conducted under rain out shelters with simulated waterlogging conditions at different stages(Non replicated).To overcome the waterlogging situation in vertisols, we proposed this project of three continuous Kharif seasons of 2014, 2015 & 2016 with the following treatments at RARS Nandyal. Different Management Practices will be taken up whenever the crop is exposed to water logging stress (Natural/ Simulates)

Main Plots

Crop stages at which water logging stress is created

1. $M_{1:}$ Vegetative
$M_{2:}$ Pre-flowering
$M_{3:}$ Square formation
M4: Boll development
M5: Without water logging stress for cotton.

2. $M_{1:}$ Vegetative
M2: Knee high stage
M3: Flowering stage
M4: Cob filling stage
M5: Without water logging stress/Control for Maize. &

3. M1: Vegetative
M2: Star bud stage
M3: Flowering stage
M4: Seed Filling stage
M5: Without water logging stress/Control for Sunflower.

Sub Plots

S1: Cotton
S2: Maize
3: Sunflower

The three major kharif crops like Cotton, Maize and sunflower were sown under rain out shelters. The plot size was 9mx3m and spacing of 60cmx30cm. Waterlogging stress was imposed at vegetative stage i.e at 21DAS, two days for one treatment from 21-22 DAS and four days for other treatments from 21to 24 DAS and control plants were maintained under normal irrigation conditions. Waterlogging was administered by applying heavy irrigation to the plots assigned to the waterlogging treatments. Soil was kept saturated with the water above field capacity by continuous flooding, usually every day twice to create an oxygen deficiency environment. The crops were grown following the recommended package of practices and timely plant protection measures were also adapted. Sampling was done at 25, 35,45,55,65 DAS. Five plants from each treatment were dugout along with roots and separated into leaf, stem, root and pods and dried at 80^o c temperature in a hot air oven until constant weight was attained. The dry weight of leaf, stem, pods and roots of the plant was recorded separately.

Results and Discussion

The results were depicted from Table 1 to 3.

The results revealed that physiological parameters like LAI, CGR, NAR, SLA, RGR and CGR decreased with the waterlogging due to decrease in the leaf area and drymatter production.

Cotton: Significant differences were observed between waterlogging treatments and control throughout the crop growth for LAI and CGR (Table 1). Imposition of waterlogging for two days and four days significantly reduced the leaf area index (LAI) and crop growth rate (CGR) at all stages of plant growth. At 120 DAS, control plants showed highest LAI (1.68) and CGR (3.643 g m^{-2} d^{-1}), where as four days waterlogging showed lowest LAI (0.19) and CGR (1.212g m^{-2} d^{-1}). Waterlogging for two days found less detrimental to LAI and CGR as compared to waterlogging for four days. The leaf area index and CGR was decreased in all the treatments compared to control, which was due to the impairment of water absorbing ability of the plants as indicated by the reduction in leaf turgidity as well as translocation of drymatter from the squares to kapas possibly due to damage caused to the root system. Such inhibition may also be due to adverse effects of waterlogging on water and mineral uptake (Hocking *et al*., 1987). Higher LAI and CGR in control treatment was recorded due to maintaining higher physiological traits under waterlogged conditions like SCMR, higher plant height, total drymatter, leaf area, higher rate of photosynthesis and leaf growth and due to quick recovery of photosynthesis after waterlogging and leaf growth, higher photosynthetic rate as reflected through the total drymatter (Ahmed *et al*., 2002).

Similar differences in genotypes were also observed in green gram by Yadav and Saxena (1998) and in maize by Saritha and Singh (2002) [16]. Irrespective of treatments, the NAR and SLA decreased in all the growth stages of cotton crop in control and under waterlogged conditions from 25-35 DAS upto harvest (Table 1). Significant differences were observed between waterlogged treatments and controlupto150 DAS in NAR and upto harvest in RGR. Imposition of waterlogging for two days and four days were significantly reduced the NAR and RGR at all stages of plant growth. At 150 DAS, control plants showed highest NAR (3.214g/m^2/day) and RGR (0.0514 g/m^2/day) where as four days waterlogging showed lowest NAR (0.028g/m^2/day) and RGR (0.0214g/m^2/day). Waterlogging for two days was found less detrimental to the NAR and RGR compared to four days. The NAR and RGR was decreased in all treatments compared to control, which was due to decreased photosynthetic efficiency due to impaired chlorophyll content and assimilatory apparatus and decreased drymatter accumulation at growth stages and the impaired of water absorbing ability of plants. Such inhibition may be due to adverse effects of waterlogging on water and mineral uptake (Hocking *et al.*, 1987). Similar results were also reported in tobacco by Hurng and Kao (1993).

Waterlogging decreased the cotton kapas yieldsignificantly over the control. Imposition of waterlogging for two days and four days were significantly reduced the kapas or lint yield. Four days waterlogging decreased the kapas yield by 43.22 percent and two days waterlogging decreased the kapasyield by 34.81 percent over the control at vegetative and boll development stages. Reduction in kapas yield in waterlogging treatment was due to oxygen deficiency and anaerobic conditions and less mineral uptake and less root activity (Wample and Thorton, 1984). Similar results were also reported in wheat (Olgun *et al.*, 2008) [10] and blackgram (Pallavi *et al.*, 2004) [11]. Highest kapas yield in control treatment was recorded due to higher leaf area, higher total drymatter, higher LAI, higher rate of photosynthesis and leaf growth and due to quick recovery of photosynthesis after waterlogging, higher photosynthetic rate as reflected through the total drymatter (Ahmad *et al*., 2002).

From the above results it can be concluded that waterlogging decreased the Physiological parameters like LAI, SLA, SCMR, NAR CGR and RGR are considered to possess submergence tolerance among the five genotypes studied. Prasanna Y.L. and Ramarao G. 2014, were also reported similar results in Green gram crop.

Table 1: Impact of waterlogging stress on Cotton crop growth at different growth stages (3 years pooled mean data).

S. No.	Treatment	LAI	SLA (cm^2/g)	Plant height(cm)	SCMR	NAR g/m2/day	RGR g/g/day	CGR g/m2/day
Stress at vegetative growth								
1	30DAS	0.19	32.5	28	28.6	-	-	-
2	60DAS	0.21	34.1	44	32.2	2.31	0.0214	1.212
3	90DAS	0.68	16.2	85	40	7.84	0.0253	1.468
4	120DAS	0.88	10.8	125	37	10.6	0.0312	2.363
5	150DAS	0.81	4.2	132	38	16.4	0.0371	2.439
Stress at square formation								
1	30 DAS	0.21	41	31	41	-	-	-
2	60DAS	0.26	31	45	37	2.8	0.0243	1.416
3	90DAS	0.72	38	85	41	8.9	0.0211	1.729
4	120DAS	0.81	17	120	34	14.2	0.0236	2.673
5	150DAS	0.94	6	137	35	19.4	0.0285	2.835
Stress at flowering stage								
1	30 DAS	0.23	28	32	42	-	-	-
2	60DAS	0.96	38.2	55	44	3.7	0.0284	1.524
3	90DAS	0.98	38	87	39	10.8	0.0214	1.664
4	120DAS	1.2	26	120	40	18.2	0.0331	3.485
5	150DAS	1.09	7	147	39	26	0.0382	3.113
Stress at Boll development								
1	30 DAS	0.2	43.5	33	37	-	-	-
2	60DAS	0.91	45	70	42	4.1	0.0326	1.446
3	90DAS	0.88	41	107	46	12.2	0.0331	2.861
4	120DAS	1.1	39	135	40	20.6	0.0314	3.384
5	150DAS	1.08	7	147	41	24	0.0385	3.036
Control								
1	30 DAS	0.23	42.1	36	43	-		
2	60 DAS	0.93	36	72	46	4.1	0.0323	1.933
3	90 DAS	1.32	30	108	43	13.2	0.0301	1.864
4	120 DAS	1.68	15	142	38	23.7	0.0326	3.643
5	150DAS	1.02	9	162	37	32	0.0514	3.243

Kapas Yield (Kg/ha)				
Vegetative stage	**Square formation stage**	**Flowering stage**	**Boll Development stage**	**Control**
1380	1482	1645	1903	1922

Maize crop: Significant differences were observed between waterlogging treatments and control throughout the crop growth for LAI and CGR (Table 2). Imposition of waterlogging for two days and four days significantly reduced the leaf area index (LAI) and crop growth rate (CGR) at all stages of plant growth. At 75 DAS, control plants showed highest LAI (2.72) and CGR (2.764 g m^{-2} d^{-1}), where as four days waterlogging showed lowest LAI (0.56) and CGR (1.120 g m^{-2} d^{-1}). In Maize crop Similar results were also reported in maize by Yadav and Srivastava (2010) [20], in cotton by Naidu and Thota (2012) [9]. Waterlogging decreased the maizeseed yield significantly over the control. Imposition of waterlogging for two days and four days were significantly reduced the seed yield. Highest seed yield was observed in control treatment (5412 kg/ha) while lowest seed yield was observed in maize crop at vegetative stage waterlogged condition (2935kg/ha).

Table 2: Impact of waterlogging stress on maize crop growth at different growth stages. (3years pooled mean data).

S. No.	Treatment	LAI	SLA (cm^2/g)	Plant height(cm)	SCMR	NAR g/m2/day	RGR g/g/day	CGR g/m2/day
Stress at vegetative growth								
1	25DAS	0.56	42.5	40	38	-	-	-
2	50DAS	1.22	54.1	70	42	0.531	0.0314	1.120
3	75DAS	2.61	36.2	115	54	0.684	0.0353	2.168
4	100DAS	1.08	12.8	165	46	0.426	0.0412	1.263
Stress at knee height stage								
1	25DAS	0.62	39.1	41	36	-	-	-
2	50DAS	0.99	50.1	75	41	0.518	0.0313	1.316
3	75DAS	1.98	32.2	115	56	0.621	0.0331	2.429
4	100DAS	0.78	11.2	160	44	0.411	0.0436	1.473
Stress at Cob filling stage								
1	25DAS	0.73	48.2	42	36	-	-	-
2	50DAS	1.96	61.8	85	43	0.557	0.0294	1.577
3	75DAS	2.48	28.7	117	54	0.711	0.0314	2.254
4	100DAS	1.02	10.7	160	43	0.498	0.0231	1.685
Control								
1	25DAS	0.73	42.1	56	37	-		
2	50DAS	1.93	62.6	80	46	0.598	0.0383	1.833
3	75DAS	2.72	30.2	118	54	0.781	0.0401	2.764
4	100DAS	1.48	15.7	162	44	0.503	0.0346	2.051

Seed yield (Kg/ha)			
Vegetative stage	**knee height stage**	**Cob Filling stage**	**Control**
2935	3124	3225	5412

Sunflower crop: In sunflower crop also almost similar results (Table 3) were reported as in case of cotton and maize crops through out the three years of study. Highest LAI (2.32) at 60 DAS, SLA (145.8(cm^2/g), Plant height (140 cm) at 80 DAS, SCMR (53 at 60DAS), NAR (0.917 g/m2/day), RGR (0.0226 g/m^2/day), CGR (11.113 g/m^2/day) at 80 DAS were recorded in control treatment when compared to other treatments. Highest seed yield was observed in control treatment (540 kg/ha) while lowest seed yield was observed in sunflower crop at seed filling stage (225 kg/ha) followed by flowering stage (296 kg/ha) when crop is in waterlogged condition.

Table 3: Impact of waterlogging stress on sunflower crop growth at different growth stages. (3years pooled mean data).

S. No.	Treatment	LAI	SLA (cm^2/g)	Plant height(cm)	SCMR	NAR g/m2/day	RGR g/g/day	CGR g/m2/day
Stress at vegetative growth								
1	20DAS	0.49	38.5	25	36	-	-	-
2	40DAS	1.21	74.1	45	48	0.221	0.0114	2.012
3	60DAS	2.18	125.2	85	50	0.544	0.0157	3.968
4	80DAS	0.88	150.8	125	40	0.816	0.0222	7.363
Stress at Star bud stage								
1	20DAS	0.41	43.2	31	40	-	-	-
2	40DAS	1.36	71.5	50	44	0.228	0.0143	2.022
3	60DAS	2.22	128.5	90	52	0.512	0.0191	4.729
4	80DAS	0.81	147.2	127	38	0.727	0.0206	8.673
Stress at flowering stage								
1	20DAS	0.43	38.7	32	42	-	-	-
2	40DAS	1.16	68.2	55	48	0.312	0.0184	1.964
3	60DAS	2.08	118.8	91	54	0.625	0.0214	2.864
4	80DAS	0.92	136.2	134	40	0.882	0.0281	7.665
Stress at Seed Filling								
1	20DAS	0.46	37.5	34	41	-	-	-
2	40DAS	1.51	75.4	59	44	0.411	0.0126	2.115
3	60DAS	2.28	124.4	107	52	0.592	0.0191	4.861
4	80DAS	0.88	100.4	135	40	0.876	0.0214	9.384
Control								
1	20DAS	0.53	40.2	38	43	-		
2	40DAS	1.52	76.2	68	46	0.391	0.0123	2.433
3	60DAS	2.32	123.5	118	53	0.624	0.0181	5.864

4	80DAS	0.99	145.8	140	38	0.917	0.0226	11.113

Seed yield (Kg/ha)				
Vegetative stage	**Star bud stage**	**Flowering stage**	**Seed Filling stage**	**Control**
312	345	296	225	540

Conclusion

Measures to ameliorate the ill effects of waterlogging stress conditions will lead to enhancement of productivity of rainfed crops besides relieving distress among farmers when high rainfall situations occur.

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