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Direct and Indirect Effects of Physiological and Yield Parameters under Stagnant Flooding on Grain Yield in Rice (Oryza sativa L.)

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ABSTRACT

Rice crop is the only crop that can be cultivated even under low land where water stagnant from 30 to 50 cm water depth for prolonged period of more than one month. Rice productivity under stagnant flooding is hampered by poor tillering, lodging of the crop. Yield improvement under stagnant flooding is a herculain task as it is complex trait controlled by polygenes. Keeping this in view present study is aimed to study direct and indirect effects of 19 traits comprising of various physiological, lodging related and yield parameters on grain yield under stagnant flooding at Regional Agricultural Research Station, Maruteru. Path analysis revealed that all the yield parameters exhibited positive direct effect on grain yield, all the physiological traits except kneeing ability showed negative direct effect on grain yield and all the lodging related parameters except per cent of lodging expressed negative direct effect on grain yield. Positive association with grain yield per plant were caused by positive indirect effects of yield traits by nullifying negative direct effects of physiological and lodging related parameters on grain yield. This indicated that careful selection of traits, plant survival %, moderate elongation, strong culm by considering yield parameters is important for yield enhancement under stagnant flooding.

Key words: *Heritability and genetic advance, Rice and variability.*

Rice crop is often affected by different types of floods (flash floods, stagnant flooding, deep water flooding, anaerobic germination). Submergence is one of the major abiotic stresses that affect productivity of rice. In the world, the average yield from flooded area is only 1.5 t/ha. In south and south east Asia, 20 million hectares area is prone to stagnant flood and deep water flooding (Sandhya *et al.,* 2017). Floods are largely caused by incessant rainfall during the monsoon season from mid-June to early October, often causing transient flash floods for 2 weeks or prolonged stagnant flooding (30 – 50 cm water depth) for one month in areas with poor drainage, resulting in huge financial losses. *Sub 1* introgressed lines showed tolerance to flash flooding but not to stagnant flooding. *Sub1* lines expressed lower plant survival % and lower yields under stagnant flooding.

Several varieties were developed conventionally for stagnant flooding but not of realizing potential yields. The yield reduction under stagnant flooding is due to smaller panicles, poor spikelet fertility, poor tillering ability and excessive lodging. Yield reduction up to 47 % under stagnant flooding was reported by (Kato *et al.,* 2014). Grain yield is a complex trait particularly under stagnant flooding depending on many physiological, lodging and yield related traits.

Path coefficient analysis splits the correlation coefficient in to direct and indirect effects and helps the plant breeder in selection of component characters associated with grain yield. Present srudy aimed to identify direct and indirect effects of physiological, lodging related and yield parameters on grain yield under stagnant flooding.

MATERIAL AND METHODS

The experimental material was evaluated at Regional Agricultural Research Station (RARS), Maruteru, West Godavari district of Acharya N. G. Ranga Agricultural University (ANGRAU) during *Kharif,* 2018-19. The experimental material comprises of 167 F_7 Recombinant Inbred Lines (RILs) developed at RARS, Maruteru using susceptible parent Indra (MTU 1061) and resistant donor AC 39416A for flood tolerance by Single Seed Descent method. Each RIL was transplanted in 2 rows at spacing of 20 x 15 cm and with a row length of 6.6 m. Augmented design is used with 6 blocks where three checks Indra, AC 39416A and Bheema were repeated in each block. The water depth was maintained at 30 – 53 cm from vegetative stage to flowering stage. Data was recorded for different yield parameters like days to 50 % Flowering (DFF), plant height(PH), ear bearing tillers plant^{-1} (EBT), panicle length (PL) , number of grains panicle^{-1}(NGP), spikelet fertility % (SF), 1000 grain weight(T.WT), grain yield plant^{-1} (GY). Data on Physiological traits like plant survival % (P.S%), Stem elongation at 30 days after transplanting(SE1), stem elongation at 60 days after transplanting(SE2), flag leaf length(FLL), flag leaf width(FLW), kneeing

Table 1. Direct and indirect effects of physiological, lodging related and yield traits on grain yield of RILs

	P. S %	SE1	SE2	FLL	FLW	BIL	CD	CT	CS	% L	KA	PH	DFF	EBT	NGP	PL	SF	T.WT	GY
P. S %	-0.106	-0.099	-0.047	-0.065	-0.033	-0.095	-0.219	-0.003	-0.080	-0.030	-0.003	0.227	0.026	0.010	0.105	0.449	0.076	0.025	0.138
SE1	-0.070	-0.149	-0.078	-0.086	-0.045	-0.114	-0.304	-0.004	-0.087	-0.027	-0.002	0.283	0.041	0.081	0.135	0.611	0.11	0.035	0.329
SE2	-0.038	-0.089	-0.131	-0.084	-0.044	-0.103	-0.283	-0.005	-0.080	-0.021	-0.001	0.272	0.045	0.123	0.145	0.59	0.111	0.033	0.440**
FLL	-0.061	-0.112	-0.096	-0.115	-0.056	-0.124	-0.370	-0.007	-0.095	-0.013	-0.002	0.318	0.053	0.132	0.184	0.739	0.137	0.042	0.556*
FLW	-0.057	-0.109	-0.093	-0.105	-0.062	-0.124	-0.372	-0.004	-0.089	-0.008	-0.001	0.319	0.056	0.141	0.19	0.753	0.15	0.042	0.628*
BIL	-0.068	-0.114	-0.090	-0.095	-0.051	-0.150	-0.326	-0.005	-0.091	-0.029	-0.002	0.310	0.048	0.108	0.168	0.677	0.128	0.038	0.459*
CD	-0.058	-0.112	-0.092	-0.105	-0.057	-0.121	-0.404	-0.004	-0.091	-0.013	-0.002	0.318	0.054	0.139	0.184	0.741	0.147	0.043	0.568*
CT	-0.004	-0.008	-0.009	-0.011	-0.004	-0.010	-0.024	-0.071	-0.004	0.001	0.000	0.025	0.006	0.005	0.015	0.07	0.015	0.004	-0.004
CS	-0.070	-0.106	-0.086	-0.089	-0.045	-0.111	-0.301	-0.002	-0.122	-0.033	-0.002	0.291	0.044	0.080	0.14	0.61	0.121	0.037	0.355
% L	-0.040	-0.051	-0.035	-0.018	-0.006	-0.055	-0.069	0.001	-0.051	-0.078	-0.004	0.116	0.006	-0.021	0.014	0.131	0.005	0.008	-0.147
KA	-0.044	-0.053	-0.022	-0.026	-0.012	-0.048	-0.097	0.002	-0.039	-0.045	-0.007	0.088	0.005	-0.006	0.02	0.147	0.011	0.009	-0.116
PH	-0.069	-0.121	-0.102	-0.104	-0.057	-0.133	-0.369	-0.005	-0.102	-0.026	-0.002	0.349	0.055	0.126	0.186	0.751	0.146	0.042	0.564*
DFF	-0.046	-0.103	-0.098	-0.101	-0.057	-0.119	-0.366	-0.007	-0.089	-0.008	-0.001	0.320	0.060	0.152	0.191	0.748	0.156	0.042	0.675*
EBT	-0.005	-0.058	-0.078	-0.073	-0.042	-0.079	-0.271	-0.002	-0.047	0.008	0.000	0.212	0.044	0.207	0.146	0.543	0.12	0.03	0.655*
NGP	-0.052	-0.092	-0.087	-0.097	-0.054	-0.116	-0.343	-0.005	-0.078	-0.005	-0.001	0.298	0.053	0.139	0.217	0.704	0.131	0.037	0.649*
PL	-0.061	-0.116	-0.098	-0.108	-0.059	-0.129	-0.380	-0.006	-0.094	-0.013	-0.001	0.332	0.057	0.142	0.194	0.788	0.15	0.043	0.643*
SF	-0.046	-0.094	-0.084	-0.090	-0.053	-0.110	-0.342	-0.006	-0.085	-0.002	0.000	0.292	0.054	0.142	0.164	0.681	0.174	0.04	0.633*
T.WT	-0.055	-0.110	-0.092	-0.101	-0.055	-0.120	-0.366	-0.005	-0.094	-0.013	-0.001	0.312	0.053	0.132	0.17	0.713	0.145	0.047	0.558*

*, ** Significant 5 % and 1 % level, respectively

ability (KA) were recorded. Observations on lodging related parameters like culm diameter(CD), culm thickness(CT), basal internodal length(BIL), culm strength(CS), per cent of lodging (%L) were recorded. Correlation & Path analysis was conducted using software R Version 3.6.2.

RESULTS AND DISCUSSION

Plant survival % exhibited negative direct effect on grain yield and negative indirect effects for stem elongation at 30 days after transplanting (DAT), stem elongation at 60 DAT, basal internodal length, culm diameter, culm strength, per cent of lodging. Positive correlation of plant survival % with grain yield (0.138) under stagnant flooding was caused by positive indirect effects of plant height, ear bearing tillers plant^{-1}, panicle length. Selection of genotypes with higher plant survival % giving priority to moderate plant height and long panicles would be rewarding to realize higher yields under stagnant flooding. Similar pattern of results were expressed by Kumari *et al.* (2019) under flash floods for plant height, panicle length, ear bearing tillers plant^{-1}.

Stem elongation at 30 DAT and at 60DAT showed negative direct effect on grain yield and negative indirect effects for physiological parameters like plant survival %, and for lodging related parameters basal internodal length, culm diameter, culm thickness, culm strength, per cent of lodging and where as negative indirect effects are noticed for plant height, days to 50 % flowering, ear bearing tillers plant^{-1} and panicle length resulting in positive correlation with grain yield plant^{-1} under stagnant flooding. Above pattern of results were in compliance with earlier reports of Kumari *et al.* (2019) and for plant height, panicle length, ear bearing tillers plant^{-1} under flash floods.

Flag leaf length and flag leaf width exhibited negative direct effect on grain yield plant^{-1} and negative indirect effects manifested through plant survival %, stem elongation at 30 DAT, stem elongation at 60 DAT, flag leaf width, basal internodal length, culm diameter, culm thickness, culm strength and per cent of lodging. Flag leaf length and width expressed positive indirect effects *via* plant height, days to 50 % flowering, panicle length, spikelet fertility % and 1000 grain weight. This resulted in positive significant association of flag leaf length and flag leaf width with grain yield per plant under stagnant flooding. Hence, direct selection for flag leaf length and width giving weightage to causal factors showing higher positive effects such as plant height and panicle length would be effective in getting higher yields under stagnant flooding. Similar trend of results were reported by Ramesh *et al.* (2018) and Akhter *et al.* (2018)

Negative direct effect of basal internodal length on grain yield plant^{-1} resulted with negative indirect effects of plant survival %, stem elongation at 30 DAT, stem elongation at 60 DAT, culm diameter, culm thickness, culm strength and per cent of lodging. This trait displayed positive indirect effects *via* plant height, days to 50 % flowering, ear bearing tillers plant^{-1}, number of grains panicle^{-1} and 1000 grain weight resulting positive significant association of basal internodal length with grain yield per plant. Careful selection of genotypes possessing minimal basal internodal length by considering positive effect of yield parameters is necessary to realize potential yield under stagnant flooding. Earlier work of Ganapati *et al.* (2014) confirms identical results for plant height, number of grains panicle^{-1}, 1000 grain weight under normal conditions.

Positive significant phenotypic association of culm diameter with grain yield plant^{-1} was due to the positive indirect effects of plant height, ear bearing tillers plant^{-1}, panicle length, spikelet fertility % and 1000 grain weight. This trait exhibited negative direct effect on grain yield plant^{-1} and negative indirect effects *via* plant survival %, stem elongation at 30 DAT, stem elongation at 60 DAT, flag leaf length, flag leaf width, basal internodal length, culm strength, per cent of lodging and kneeing ability. Genotypes with wider culms possessing moderate stem elongation reduce lodging risk under stagnant flooding to get higher yields. Above trend of results were in accordance with earlier reports of Akhtar *et al.* (2018) and Akhtar *et al.* (2018) for plant height, ear bearing tillers plant^{-1}, panicle length, 1000 grain weight, flag leaf length and flag leaf width under normal situations.

Culm thickness recorded negative non-significant association with grain yield plant^{-1}. This was caused by negative direct effect on grain yield plant^{-1} and negative indirect effects of stem elongation at 30 DAT, stem elongation at 60 DAT, basal internodal length, culm diameter, culm strength, per cent of lodging. Culm thickness explained positive indirect effects *via* plant height, days to 50 % flowering, ear bearing tillers plant^{-1}, panicle length, spikelet fertility % and 1000 grain weight. Characters explaining positive indirect effects with culm thickness would be considered as a criterion during selection process which helps in improvement of grain yield.

Culm strength recorded negative direct effect on grain yield plant^{-1} through indirect effects of stem elongation at 30 DAT, stem elongation at 60 DAT, basal internodal length, culm diameter, culm thickness and per cent of lodging. Culm strength recorded positive indirect effects of plant height, ear bearing tillers plant^{-1}, number of grains panicle^{-1}, panicle length and 1000 grain weight. Lower values of culm strength are required to minimize lodging risk under stagnant flooding. Therefore Lower values of culm strength along with yield parameters are taken in to consideration as selection criterion for yield improvement under stagnant flooding.

Per cent of lodging displayed negative non-significant association with grain yield plant^{-1} manifested through negative direct effect on grain yield plant^{-1} and negative indirect effects of plant survival %, stem elongation at 30 DAT, stem elongation at 60 DAT, basal internodal length, culm diameter and culm strength. Per cent of lodging showed positive indirect effects *via* culm thickness, plant height, days to 50 % flowering, number of grains panicle^{-1}, spikelet fertility % and 1000 grain weight. Lower per cent of lodging is prerequisite to achieve better yields under stagnant flooding. Therefore selection of genotypes with lower percent of lodging coupled with moderate elongation, lower basal internode length, lower values of culm strength and kneeing ability along with yield parameters would be rewarding for yield enhancement under stagnant flooding.

Kneeing ability recorded negative non-significant phenotypic association with grain yield plant^{-1}. This was caused by negative direct effect on grain yield plant^{-1} and indirect effects of stem elongation at 30 DAT, stem elongation at 60 DAT, flag leaf width, basal internodal length, culm diameter, culm strength and per cent of lodging. Kneeing ability displayed positive indirect effects *via* culm thickness, plant height, number of grains panicle^{-1}, panicle length, spikelet fertility % and 1000 grain weight. Lower values of kneeing ability are essential to attain better yields under stagnant flooding. Hence, selection of genotypes with lower values of kneeing ability giving consideration to strong culm traits, yield parameters would be useful for yield improvement under stagnant flooding.

Plant height exhibited positive significant phenotypic association with grain yield plant^{-1}. This trait expressed positive direct effect on grain yield plant^{-1} manifested through indirect effects of days to 50 % flowering, panicle length, spikelet fertility % and 1000 grain weight. Plant height recorded negative indirect effects *via* plant survival %, stem elongation at 30 DAT, stem elongation at 60 DAT, flag leaf length, flag leaf width, basal internodal length, culm diameter, culm strength, per cent of lodging. Exercising selection of genotypes with moderate plant height is essential by considering positive direct effects of the yield for getting higher yields. Days to 50 % flowering displayed positive significant phenotypic association with grain yield plant^{-1} (0.675). This trait expressed positive direct effect on grain yield plant^{-1} manifested through positive indirect effects of plant height, number of grains panicle^{-1}, panicle length and 1000 grain weight. Days to 50% flowering observed negative indirect effects *via* plant survival %, stem elongation at 30 DAT, stem elongation at 60 DAT, flag leaf length, flag leaf width, basal internodal length, culm strength, per cent of lodging and kneeing ability. Selection of medium to long duration genotypes would sustain adverse effects of stagnant flooding by accommodating positive effects of yield components. Above pattern of results were reported by Muthuvijayaragavan *et al.* (2017) under flash floods for plant height, number of grains per panicle, 1000 grain weight under flash floods.

Ear bearing tillers plant^{-1} exhibited positive significant phenotypic association with grain yield plant^{-1} caused by positive direct effect on grain yield and indirect effects of per cent of lodging, plant height, days to 50 % flowering, spikelet fertility % and 1000 grain weight. Ear bearing tillers plant^{-1} exhibited negative indirect effects *via* plant survival %, stem elongation at 60 DAT, basal internodal length, culm diameter, culm thickness, culm strength. As positive association of ear bearing tillers plant^{-1} with grain yield is required, characters showing positive indirect effects with ear bearing tillers plant^{-1} are to be considered during selection for yield improvement under stagnant flooding. The above results are in complaince with earlier reports of Pandey *et al.* (2018) for days to 50 % flowering, spikelet fertility % and 1000 grain weight in normal conditions.

Number of grains panicle^{-1} exhibited positive significant association with grain yield plant^{-1} was manifested by positive direct effect on grain yield plant^{-1} and indirect effects of plant height, panicle length, spikelet fertility % and 1000 grain weight. Number of grains panicle^{-1} expressed negative indirect effects *via* plant survival %, stem elongation at 30 DAT, stem elongation at 60 DAT, flag leaf length, flag leaf width, basal internodal length, culm strength, per cent of lodging and kneeing ability. Positive association of number of grains panicle^{-1} with grain yield is required, hence characters explaining positive indirect effects with number of grains panicle^{-1} are to be considered in the selection process for enhancement of yield under stagnant flooding. Similar pattern of results were reported by Muthuvijayaragavan *et al.* (2017), for spikelet fertility % under flash floods.

Panicle length recorded positive significant phenotypic association with grain yield plant^{-1}. This trait showed positive direct effect on grain yield plant^{-1}. Panicle length explained positive indirect effects *via* plant height, days to 50 % flowering, ear bearing tillers plant^{-1}, number of grains panicle^{-1}, spikelet fertility % and 1000 grain weight. Panicle length expressed negative indirect effects *via* plant survival %, stem elongation at 30 DAT, stem elongation at 60 DAT, basal internodal length, culm diameter, culm strength, per cent of lodging and kneeing ability. Selection of genotypes with longer panicles giving importance to yield components and non lodging panicles is essential under stagnant flooding. Above pattern of results were similar to earlier reports of Pandey *et al.* (2018) for plant height, days to 50 % flowering, 1000 grain weight in normal conditions.

Positive significant association of spikelet fertility % with grain yield plant^{-1} is manifested through positive direct effect on grain yield and indirect effects of plant height, days to 50 % flowering, ear bearing tillers plant^{-1}, panicle length. Spikelet fertility exhibited negative indirect effects *via* plant survival %, stem elongation at 30 DAT, stem elongation at 60 DAT, basal internodal length, culm diameter, culm thickness and per cent of lodging. Direct selection of genotypes with higher spikelet fertility % giving importance to lodging resistant panicles and yield parameters is essential to get higher yields under stagnant flooding. Similar trend of results were reported by Pandey *et al.* (2018) and Ramesh *et al.* (2018) for days to 50 % flowering, ear bearing tillers plant^{-1}, panicle length and under normal conditions.

1000 grain weight exhibited positive significant phenotypic association with grain yield plant^{-1}. This trait expressed positive direct effect on grain yield plant^{-1}. 1000 grain weight exhibited positive indirect effects *via* plant height, days to 50 % flowering, ear bearing tillers plant^{-1}, number of grains panicle^{-1}, panicle length and spikelet fertility %. 1000 grain weight exhibited negative indirect effects *via* plant survival %, stem elongation at 30 DAT, stem elongation at 60 DAT, flag leaf length, flag leaf width, basal internodal length, culm diameter, culm thickness, culm strength, per cent of lodging and kneeing ability. Positive association of 1000 grain weight with grain yield manifested through positive indirect effects is to be considered in selection of genotypes for realizing higher yields under stagnant flooding. Above pattern of results were similar to earlier reports of Reddy *et al.* (2018) for days to 50 % flowering, flag leaf length and flag leaf width, Pandey *et al.* (2018) for plant height, spikelet fertility under normal conditions.

CONCLUSION

Yield improvement under stagnant flooding can be achieved by careful selection of genotypes possessing physiological traits higher plant survival %, moderate elongation, broad and larger flag leaves along with tillering ability to compensate adverse effect of floods, larger panicles and higher spikelet fertility with strong culm and minimal lodging risk.

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