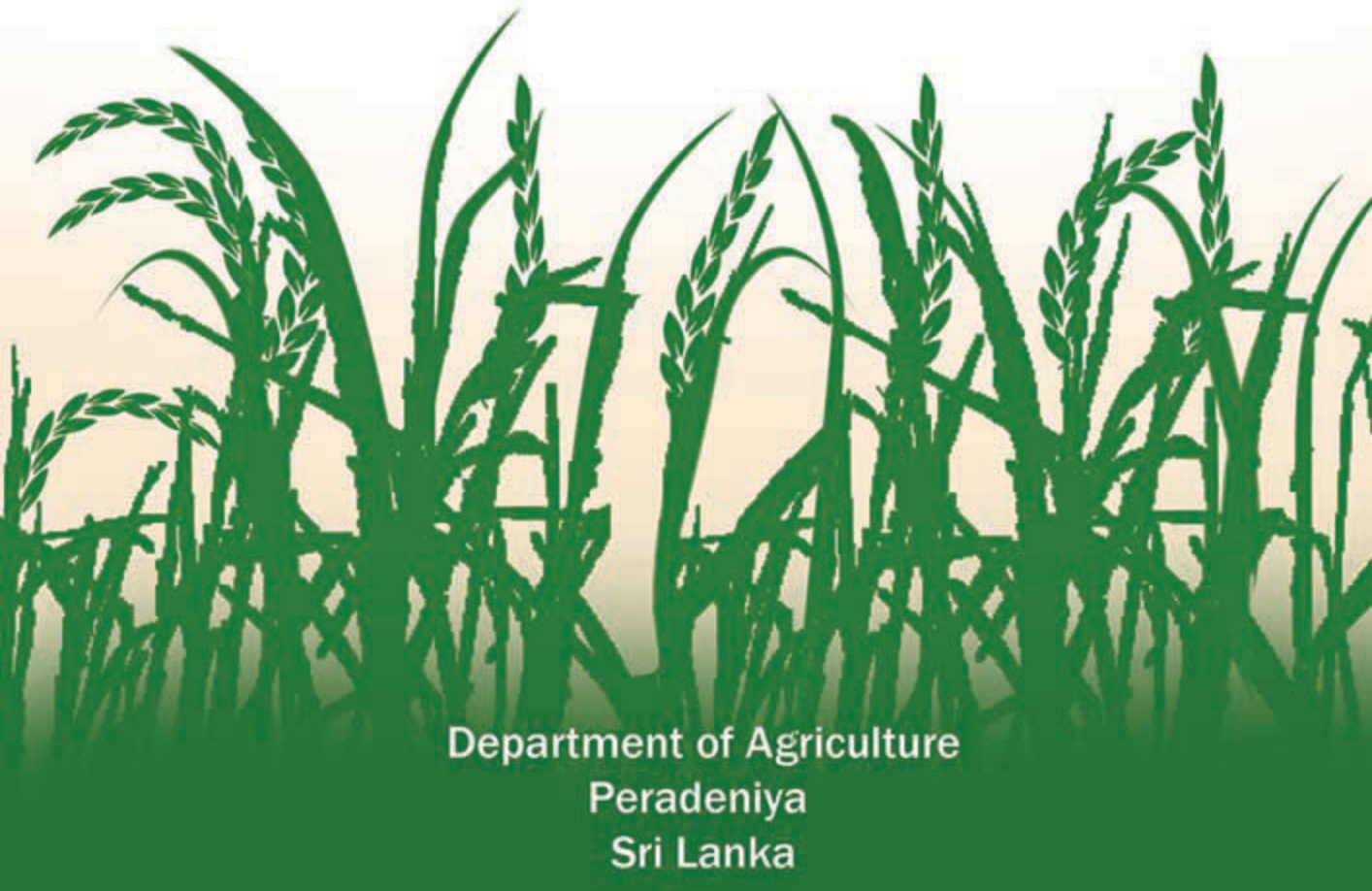
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RECENT TRENDS OF EXTREME POSITIVE RAINFALL ANOMALIES IN THE DRY ZONE OF SRI LANKA

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ABSTRACT

A study was conducted in the Dry zone of Sri Lanka, to identify the trends in occurrence of positive extreme rainfall anomalies, using daily rainfall time series from 1990-2014 collected at 13 rain gauge stations scattered in all major agro-ecological regions of the Dry zone. A trend analysis was carried out, by considering the 95th and 99th percentile of daily time series of annual and seasonal rainfall *viz,* First Inter Monsoon (FIM), South West Monsoon (SWM), Second Inter Monsoon (SIM) and North East Monsoon (NEM) as the cut-off values to designate Heavy and Very Heavy rainfall events of positive anomalies, respectively. The base period to calculate the cut-off values was taken as the 30-year period from 1960-1989. Even though no significant trend in occurrence of Heavy Rainfall (HRF) events or Very Heavy Rainfall (VHRF) events has been observed during last 25-year period from 1990-2014, annually or seasonally, it is revealed that an apparent trend of these extreme positive rainfall anomalies is discernible, especially during SWM and NEM rainfall seasons. This trend has been clearly evident during last 5-year period from 2010-2014. It may likely to inflict significant implications on the agricultural production in the region in terms of both quantity and quality, as SWM and NEM seasons coincide with the reproductive phase of the crops grown in both *Yala* and *Maha* cultivation seasons in the Dry zone. As the climate change is likely to exacerbate extreme rainfall events in future, these apparent trends may even become obvious thus, excess soil moisture stress in rainfed upland crops, flood damages in lowland paddy fields and rapid drying out in cascade of tanks in long-run will be a serious threat to agricultural productivity in the Dry zone of Sri Lanka.

Key Words: Dry Zone, Extreme Rainfall, Heavy Events, Very Heavy Events, Climate Change

INTRODUCTION

The Dry zone covers about 70 % of the total land extent in Sri Lanka. It is the major agricultural region of the country since the earliest historical times of the island; the dry zone of Sri Lanka consist of thousands of man-made small and large tanks without which human existence in the Dry zone would be difficult as described by Abeyratne (1956) and Ievers (1899). Village tank settlements have always been the back-bone of our Hydraulic Civilization since ancient times. It is also perceived as one of the most appropriate adaptation strategy for climate variability and change in the Dry zone. The annual average rainfall of the Dry zone is less than 1,750 mm with a distinct dry period from May to September coupled with high daily evaporation rates of between 5 to 8 mm due to warm and desiccating winds. Thus, very often annual rainfall represents only a fraction of the water requirements for double-cropped rice and therefore, heavily dependent on supplementary irrigation from aforesaid tanks and reservoirs.

Among the various issues and the threats faced by these tanks, high siltation is of special significance. Continually shrinking catchment area of respective tanks due to encroachment of forests and irrational land use practices on upstream lands, result in more soil erosion leading to rapid siltation of tanks in the Dry zone. Moreover, high-intense rains receiving during convectional rainy periods (March – April and September – October) also increase the soil erosion rate of the Dry zone landscape.

Siltation of tanks not only causes reduction of storage capacity but also leads to alter the tank geometry and ecology. Subsequent rehabilitation works, if any, where the capacity would be increased by raising the spill and tank bund would create a shallow water body spreading over a large surface area. This makes the situation more complicated creating several other problems such as inundation of upstream paddy lands in the cascade, development of salinity conditions in the upper area, increase of tank water losses by evaporation due to increased surface/depth ratio, disappearance of the tree strips in the high flood region (*Gasgommana*) and the grass cover (*Perahana*) and disappearance of

some indigenous fish species, which cannot survive in shallow water or do not find a favourable breeding environment. In addition, reduction of capacity of village tanks in the Dry zone also pose additional threats to livelihood, ecosystem services, health and infrastructure, both directly and indirectly resulting web of negative impacts on socio-economic conditions of the Dry zone's peasant community (Anon, 1993).

Global warming is expected to lead to a more vigorous hydrological cycle, including more total rainfall and more frequent high intensity rainfall events (IPCC, 2013), which in turn increases the soil erosion and subsequent siltation of tanks. Climate model simulations (Hennessey *et al*., 1997) and empirical evidences confirm that warmer climates, owing to increased water vapour, will lead to more intense precipitation events in the future (IPCC, 2007). Recent studies conducted in Central India have confirmed that there are significant rising trends in the frequency and the magnitude of extreme rainfall events (Rajeevan *et al.*, 2008; Goswami *et al.*, 2006). High intense rains were used to be a common feature of the rainfall climatology of the Dry zone only during convectional rainy periods. However, it has been observed in recent times that such rains have become a regular event at any rainy season irrespective of the nature of origin, which may further aggravate the problem of siltation of tank cascade systems in the Dry zone.

Therefore, this study was undertaken to identify whether there is a change in occurrence of extreme rainfall events in the Dry zone enabling policy makers to formulate appropriate risk reduction strategies to conserve the village tank eco-systems in the Dry zone.

METHODOLOGY

To study the recent trends of positive extreme rainfall events, a 25 year daily time series was taken from 1990 to 2014 from 13 rain gauge stations scattered throughout the Dry zone, representing different Agro Ecological Regions (AER) (Table 1). The base period was considered from 1960 to 1989 as against to the common standard base period of 1961-1990 due to the availability of data. Even though there are some more rain gauge stations in other agro-ecological regions of

the Dry zone, it was unable to employ all of them in the analysis due to presence of large number of missing data and/or being only a short time series. This was particularly true for stations in northern and eastern provinces where data has not been recorded continuously during the period of civil disturbances. The locations of rainfall observation stations in the Dry zone used in the study and their latitude and longitude are shown in Table 1.

Table 1. Geographical details of rainfall observation stations used in the study.

District	Station	AEZ	Latitude (N)	Longitude (E)
Anuradhapura	Anuradhapura	DL 1b	8º 35’	80º 38’
Matale	Pelwehera	DL 1b	7º 90’	80º 68’
Anuradhapura	MahaIlluppallama	DL 1b	8º 12’	80º 47’
Trincomalee	Kantalai	DL 1c	8º 38’	81º 05’
Ampara	Ampara	DL 2a	7º 28’	81º 67’
Trincomalee	Trincomalee	DL 2b	8º 58’	81º 25’
Batticaloa	Batticaloa	DL 2b	7º 72’	81º 70’
Jaffna	Jaffna	DL 3	9º 68’	80º 03’
Puttlam	Puttlam	DL 3	8º 03’	79º 83’
Mannar	Mannar	DL 4	8º 98’	79º 92’
Mannar	Murunkan	DL 4	8º 83’	80º 05’
Hambantota	Hambantota	DL 5	6º 12’	81º 13’
Hambantota	Weerawila	DL 5	6º 28’	81º 23’

In this study, it was an important step to decide an appropriate definition or cut-off value to identify the extreme rainfall events in a time series of daily rainfall data. Even though review of literature revealed that there is no unique definition or method to determine the cut-off value, as quoted by Punyawardena and Premalal (2013) and Shin-Chu *et al*. (2008) have shown that there are three approaches which have been extensively used in identifying extreme positive rainfall anomalies of a data series. The first method is based on the actual rainfall amounts with an arbitrary threshold value. Karl *et al*. (1996) and Groisman (1999) constructed a mean annual number of days which 24-hour accumulation exceeds 50.8 mm (2 inches) as a Heavy Rainfall (HRF) event over the mainland United

States. Similarly, Very Heavy Rainfall (VHRF) climatology is derived when daily precipitation exceeds 101.6 mm (4 inches).

The second way to define extreme positive anomalies is to use specific thresholds such as the 95th and 99th percentiles of daily rainfall values to define HRF and VHRF events, respectively. The third way of defining extreme positive rainfall events is to calculate return periods of the event based on the annual maximum 24- hour precipitation series (Kunkel *et al*., 1999). However, cursory analysis of rainfall data in the Dry zone of Sri Lanka has revealed that HRF events are more common in recent past and it could be probably attributed to the climate change. Therefore, the return period approach may lead to erroneous conclusions (Punyawardena and Premalal, 2013). The first approach of using an arbitrary threshold value is not appropriate for local conditions as it has been based on empirical evidences of another country where the rainfall climatology is different from the Dry zone's environment. The second method, percentile based approach gives a proper estimation of extreme values with a strong statistical foundation even with recent data. Punyawardena and Premalal (2013) have successfully employed the same approach to identify the trends in extreme rainfall events in the Central Highlands of Sri Lanka. The same approach has been adopted by Shahid (2011) to study the pattern of extreme positive rainfall events in Bangladesh.

The base period for the analysis was taken as the 1960-1989 to capture a period of 30 years to determine the 95th and 99th percentiles in annual and seasonal time series of each station. These two values were then considered as the cut-off values for HRF and VHRF events, respectively. The 25-year period from 1990 to 2014 was taken to determine the trends of HRF and VHRF events by annually as well as rainfall season wise, *viz*, First Inter Monsoon (FIM), South West Monsoon (SWM), Second Inter Monsoon (SIM) and North East Monsoon (NEM). A trend analysis was carried out on extreme positive rainfall events, namely, HRF and VHRF events for annual daily rainfall and each rainfall season, based on the above time periods as the independent variable. Furthermore, the number of days that received positive extreme rainfall events - HRF and VHRF events - were categorized independently in to 5 year time periods (pentad) from 1990 to 2014, namely, 1990-1994, 1995-1999, 2000-2004, 2005-2009 and 2010-2014 to determine whether there is any recent occurrence of such rainfall events.

However, the first pentad period (1990-1994) of stations located in DL_4 region, namely, Murunkan and Mannar was dropped from the analysis due to presence of excessive number of missing values. The same remains true with Jaffna data for the period of 1995-1999. The observed apparent increasing trends of HRF and VHRF during last pentad of 2010-2014 in most locations were tested for significance using "CATMOD" procedure in SAS statistical software as these data were not normally distributed.

RESULTS AND DISCUSSION

Table 2 shows the cut-off values for HRF and VHRF rainfall events for annual time series using 1960-1989 base period. A similar calculation was carried out for all four rainfall seasons independently using the same base period (Values are not shown in the text).

Table 2.Cut-off values for 95th and 99th percentiles of selected locations of the study for annual time series

Station	AEZ	95th percentile(mm)	99th percentile(mm)
Anuradhapura	DL_{1b}	21.5	57.2
Pelwehera	DL_{1b}	25.4	67.6
MahaIlluppallama	DL_{1b}	24.1	61.7
Kantalai	DL_{1c}	24.1	62.4
Ampara	DL_{2a}	28.7	71.3
Trincomalee	DL_{2b}	25.9	70.4
Batticaloa	DL_{2b}	27.6	70.0
Jaffna	DL_3	21.5	58.6
Puttlam	DL_3	20.3	52.0
Mannar	DL_4	17.3	50.9
Murunkan	DL_4	19.1	50.8
Hambantota	DL_5	17.0	46.0
Weerawila	DL_5	14.4	41.3

Table 3 and 4 show the trends of HRF and VHRF events, respectively at study locations for annual daily rainfall time series and four rainfall seasons *viz*, FIM, SWM, SIM and NEM seasons independently. Even though there is an apparent increasing trend of HRF events in annual daily time series in all study locations except Murunkan none of them were statistically significant. However, the increasing trend at Kantalai was significant with a fairly strong relationship ($r^2 = 0.22$). VHRF events in daily time series reveal both apparent increasing and decreasing trends at different locations where the increasing trend at both Anuradhapura ($r^2 = 0.32$) and Kantalai ($r^2 = 0.27$) is significant with a strong correlation (Table 3 and 4).

Comparison among the seasons

HRF events during FIM season reveal an apparent increasing trend in all study locations except Pelwehera and Murunkan with a significant relationship at Anuradhapura, Kantalai and Trincomalee. Interestingly, VHRF events during FIM season too show an apparent increasing trend at all study locations even though none of them are significant except Trincomalee. Generally, HRF events during SWM season show a decreasing trend at most of the locations except Ampara and Jaffna. However, this decreasing trend was significant only at Weerawila ($r^2 = 0.22$). There was a mixed trend of relationship in VHRF events during SWM season at different locations, but none of them were significant (Table 3 and 4). During SIM season, both HRF and VHRF events show a mixed trend with both positive and negative apparent trends, but it was significant only at Kantalai, Pelwehera and Hambantota with VHRF events (Table 4). Similarly during FIM season, HRF events during NEM season also reveal an apparent increasing trend at all study locations except Ampara and Murunkan. But none of these trends were significant except Kantalai. VHRF events during NEM season too show an apparent increasing trend in all study locations except Hambantota, but the trend was significant only at Anuradhapura ($r^2 = 0.17$).

Table 3. Trend and significance of Heavy rainfall events in the Dry zone of Sri Lanka

Station	AEZ	Annual	FIM	SWM	SIM	NEM
Anuradhapura	DL_{1b}	y = 0.352x - 684.8	y = 0.120x - 236.5	y = -0.041x + 89.4	y = 0.073x - 144.6	y = 0.190x - 374.6
		(0.16, 0.050)	(0.25, 0.011)	(0.01, 0.683)	(0.07, 0.185)	(0.12, 0.095)
Pelwehera	DL_{1b}	y = 0.141x - 263.9	y = -0.001x + 4.7	y = -0.048x + 103.6	y = -0.054x + 110.7	y = 0.079x - 153.3
		(0.04, 0.331)	(0.00, 0.989)	(0.01, 0.667)	(0.07, 0.229)	(0.03, 0.433)
MahaIlluppallama	DL_{1b}	y = 0.154x - 291.1	y = 0.056x - 111.3	y = -0.108x + 223.7	y = -0.006x + 15.4	y = 0.092x - 179.5
		(0.07, 0.189)	(0.06, 0.236)	(0.05, 0.276)	(0.00, 0.898)	(0.04, 0.306)
Kantalai	DL_{1c}	y = 0.504x - 984.8	y = 0.121x - 240.0	y = -0.063x + 134.8	y = 0.108x - 212.7	y = 0.278x - 550.4
		(0.22, 0.019)	(0.18, 0.033)	(0.03, 0.399)	(0.05, 0.303)	(0.19, 0.031)
Ampara	DL_{2a}	y = 0.352x - 684.8	y = 0.086x - 171.2	y = 0.003x - 0.9	y = 0.026x - 50.3	y = -0.020x + 46.6
		(0.16, 0.072)	(0.05, 0.256)	(0.00, 0.961)	(0.01, 0.676)	(0.00, 0.796)
Trincomalee	DL_{2b}	y = 0.169x - 318.8	y = 0.145x - 288.6	y = -0.181x + 370.2	y = -0.017x + 37.6	y = 0.156x - 307.0
		(0.04, 0.314)	(0.16, 0.046)	(0.15, 0.057)	(0.00, 0.806)	(0.07, 0.192)
Batticaloa	DL_{2b}	y = 0.226x - 430.4	y = 0.079x - 156.1	y = -0.114x + 236.9	y = -0.019x + 42.2	y = 0.185x - 365.1
		(0.07, 0.191)	(0.05, 0.259)	(0.07, 0.198)	(0.00, 0.765)	(0.14, 0.064)
Jaffna	DL_{3}	y = 0.117x - 215.7	y = 0.120x - 237.0	y = 0.114x - 222.5	y = -0.085x + 174.9	y = 0.002x - 0.3
		(0.02, 0.525)	(0.10, 0.162)	(0.04, 0.419)	(0.13, 0.115)	(0.00, 0.980)
Puttlam	DL_{3}	y = 0.352x - 684.8	y = 0.112x - 222.3	y = -0.011x + 29.1	y = 0.045x - 88.1	y = 0.064x - 123.0
		(0.16, 0.072)	(0.12, 0.087)	(0.00, 0.906)	(0.04, 0.352)	(0.02, 0.478)
Mannar	DL_{4}	y = 0.114x - 209.3	y = 0.017x - 31.8	y = -0.083x + 174.5	y = -0.026x + 56.2	y = 0.072x - 141.3
		(0.02, 0.502)	(0.00, 0.873)	(0.01, 0.638)	(0.01, 0.696)	(0.02, 0.554)
Murunkan	DL_{4}	y = -0.113x + 248.0	y = -0.014x + 32.3	y = -0.054x + 116.1	y = -0.075x + 154.6	y = -0.072x + 149.4
		(0.01, 0.633)	(0.00, 0.909)	(0.00, 0.780)	(0.05, 0.345)	(0.01, 0.619)
Hambantota	DL_{5}	y = 0.031x - 44.3	y = 0.044x - 86.8	y = -0.080x + 169.1	y = 0.036x - 70.4	y = 0.047x - 90.2
		(0.00, 0.774)	(0.03, 0.402)	(0.05, 0.303)	(0.01, 0.556)	(0.01, 0.631)
Weerawila	DL_{5}	y = 0.014x - 5.5	y = 0.074x - 144.1	y = -0.303x + 616.9	y = 0.058x – 112.0	y = 0.031x - 55.2
		(0.00, 0.896)	(0.06, 0.252)	(0.21, 0.019)	(0.02, 0.480)	(0.00, 0.737)

Note: Equation used; $y=mx \pm c$, values given in parenthesis represent r^2 and p-value, respectively

Table 4. Trend and significance of Very heavy rainfall events in the Dry zone of Sri Lanka

Station	AEZ	Annual	FIM	SWM	SIM	NEM
Anuradhapura	DL_{1b}	y = 0.217x - 429.9	y = 0.069x - 137.4	y = -0.010x + 22.8	y = -0.001x + 3.7	y = 0.089x - 177.5
		(0.32, 0.003)	(0.24, 0.012)	(0.00, 0.790)	(0.00, 0.933)	(0.17, 0.040)
Pelwehera	DL_{1b}	y = 0.015x - 26.9	y = 0.005x - 8.6	y = -0.005x + 12.1	y = -0.034x + 69.6	y = 0.061x - 122.1
		(0.00, 0.811)	(0.00, 0.865)	(0.00, 0.887)	(0.21, 0.021)	(0.09, 0.145)
MahaIlupallama	DL_{1b}	y = -0.018x + 40.4	y = 0.007x - 15.2	y = -0.023x + 49.2	y = -0.017x + 35.9	y = 0.027x - 54.3
		(0.00, 0.761)	(0.01, 0.606)	(0.02, 0.507)	(0.03, 0.383)	(0.03, 0.418)
Kantalai	DL_{1c}	y = 0.284x - 564.3	y = 0.060x - 118.8	y = 0.042x - 82.1	y = 0.070x - 140.7	y = 0.049x - 97.0
		(0.27, 0.008)	(0.15, 0.053)	(0.03, 0.369)	(0.16, 0.045)	(0.04, 0.309)
Ampara	DL_{2a}	y = 0.217x - 429.9	y = 0.032x – 64.0	y = 0.031x - 61.2	y = 0.001x - 2.5	y = 0.026x - 51.7
		(0.32, 0.191)	(0.05, 0.267)	(0.03, 0.432)	(0.00, 0.948)	(0.05, 0.282)
Trincomalee	DL_{2b}	y = 0.011x - 19.1	y = 0.075x - 150.0	y = -0.051x + 103.3	y = -0.015x + 29.9	y = 0.052x - 103.4
		(0.01, 0.854)	(0.17, 0.039)	(0.05, 0.293)	(0.01, 0.605)	(0.06, 0.230)
Batticaloa	DL_{2b}	y = 0.106x - 206.8	y = 0.027x - 54.5	y = -0.004x + 10.7	y = -0.002x + 5.3	y = 0.058x - 115.6
		(0.08, 0.181)	(0.04, 0.347)	(0.00, 0.896)	(0.00, 0.913)	(0.07, 0.210)
Jaffna	DL_{3}	y = -0.101x + 208.2	y = 0.050x - 100.7	y = 0.016x - 31.7	y = -0.030x + 60.7	y = 0.8
		(0.12, 0.141)	(0.10, 0.179)	(0.01, 0.728)	(0.11, 0.142)	(0.00, 1.000)
Puttlam	DL_{3}	y = 0.217x - 429.9	y = 0.025x - 48.9	y = -0.031x + 64.6	y = -0.026x + 52.7	y = 0.031x - 61.9
		(0.32, 0.930)	(0.10, 0.127)	(0.03, 0.391)	(0.091, 0.143)	(0.03, 0.433)
Mannar	DL_{4}	y = 0.030x - 58.3	y = 0.001x - 1.8	y = -0.029x + 60.4	y = -0.021x + 42.8	y = 0.048x - 97.4
		(0.02, 0.583)	(0.00, 0.981)	(0.01, 0.609)	(0.03, 0.486)	(0.14, 0.098)
Murunkan	DL_{4}	y = -0.008x + 21.1	y = 0.015x - 29.3	y = 0.017x - 33.0	y = 0.002x - 3.3	y = 0.039x - 77.5
		(0.00, 0.934)	(0.00, 0.784)	(0.00, 0.810)	(0.00, 0.958)	(0.04, 0.382)
Hambantota	DL_{5}	y = 0.045x - 86.7	y = 0.021x - 42.6	y = 0.003x - 6.4	y = -0.066x + 134.9	y = -0.005x + 12.1
		(0.02, 0.482)	(0.04, 0.324)	(0.00, 0.909)	(0.18, 0.033)	(0.00, 0.873)
Weerawila	DL_{5}	y = 0.151x - 297.5	y = 0.019x - 37.9	y = -0.035x + 70.9	y = 0.880	y = 0.068x - 133.7
		(0.18, 0.032)	(0.03, 0.404)	(0.03, 0.379)	(0, 1.000)	(0.09, 0.138)

Note: Equation used; $y=mx \pm c$, values given in parenthesis represent r^2 and p-value, respectively

Variation among the pentad time series

To further explore the apparent increasing trend of extreme positive rainfall events during the last 25- year period, total number of respective HRF and VHRF events occurred during recent 5-year time slots, namely, 1990-1994, 1995-1999, 2000-2004, 2005-2009 and 2010-2014 have depicted in Figure 1 to 10 representing major agro-ecological regions of the Dry zone, namely, DL_1, DL_2, DL_3, DL_4 and DL_5. It clearly shows that in all major agro-ecological regions of the Dry zone, occurrence of HRF events during NEM season has dramatically increased during the most recent pentad, 2010-2014 at almost all locations of the study. The same is true for the occurrence VHRF events too, except a few instances. The SWM also shows a similar pattern of increasing occurrence of extreme positive rainfall anomalies during most recent pentad at most locations except Ampara and Weerawila.

The increasing trends of extreme positive rainfall anomalies during SWM and NEM seasons at the fifth pentad during 2010-2014 is significant for both HRF ($p<0.0006$) and VHRF ($p<0.0207$) events. It is also pertinent to note that in general, there is no any decreasing trend in either event during most recent pentad of SIM season especially in DL_1 and DL_2 regions. However, occurrence of both events in the most recent pentad (2010-2014) has decreased during FIM season across all major agro-ecological regions except DL_1 region. Even in DL_1 region, its neighbouring region to DL_2 (Kantalai – DL_{1c}) follows the same trend. This trend of FIM is quite contrary to the trend observed in long term data analysis from 1990-2014 (Table 3 and 4) DL_1, DL_2, DL_3, DL_4 and DL_5 where an apparent increasing trend was observed. The observed spatial variability of trends in different AERs does not reveal any spatial pattern as per the statistical analysis of "CATMOD" procedure in SAS software.

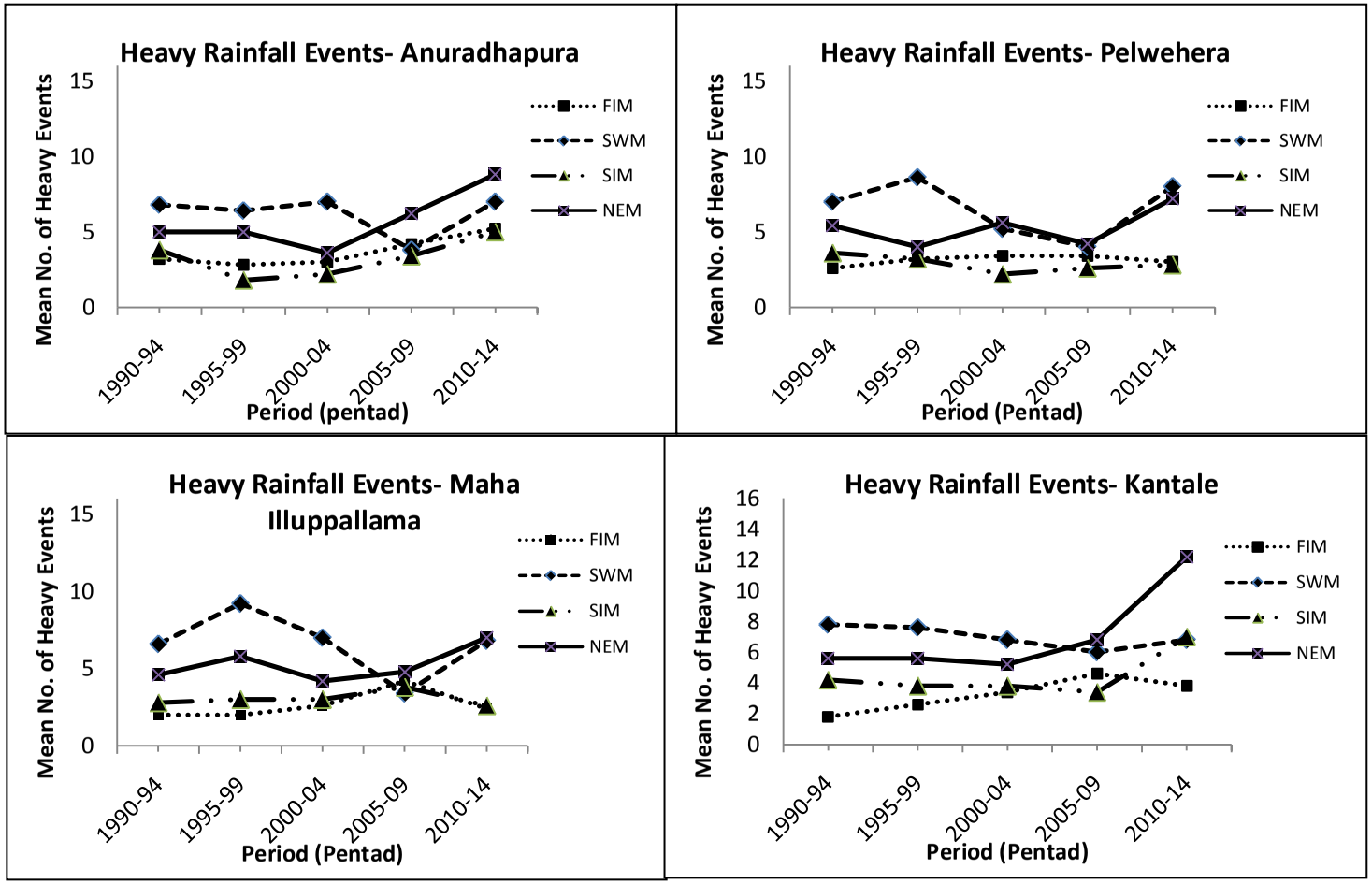


Figure 1: Occurrence of extreme positive rainfall anomalies in the DL_1 agro-ecological region of the Dry zone in Sri Lanka – Heavy events

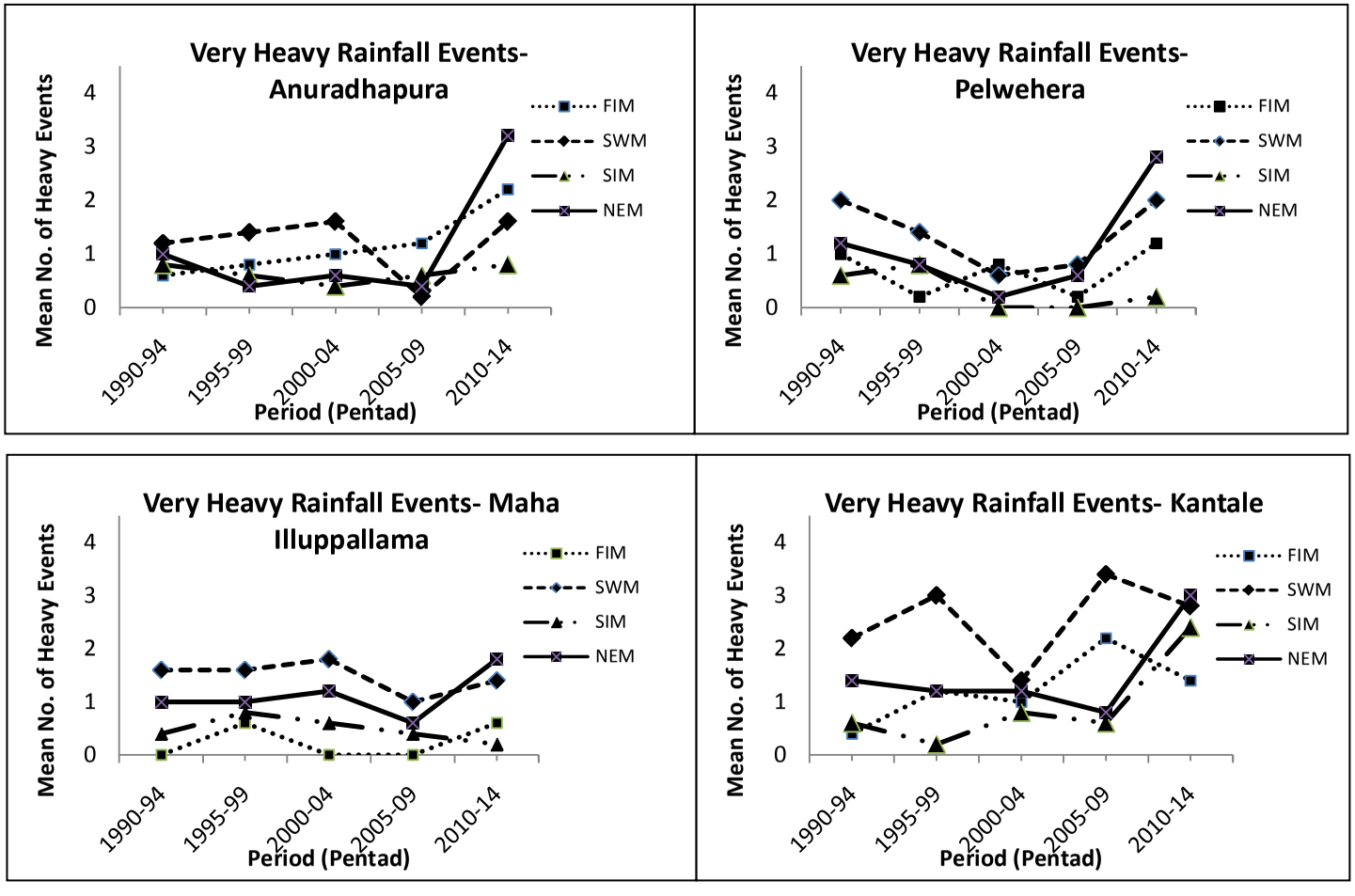


Figure 2: Occurrence of extreme positive rainfall anomalies in the DL_1 agro-ecological region of the Dry zone in Sri Lanka – Very Heavy events

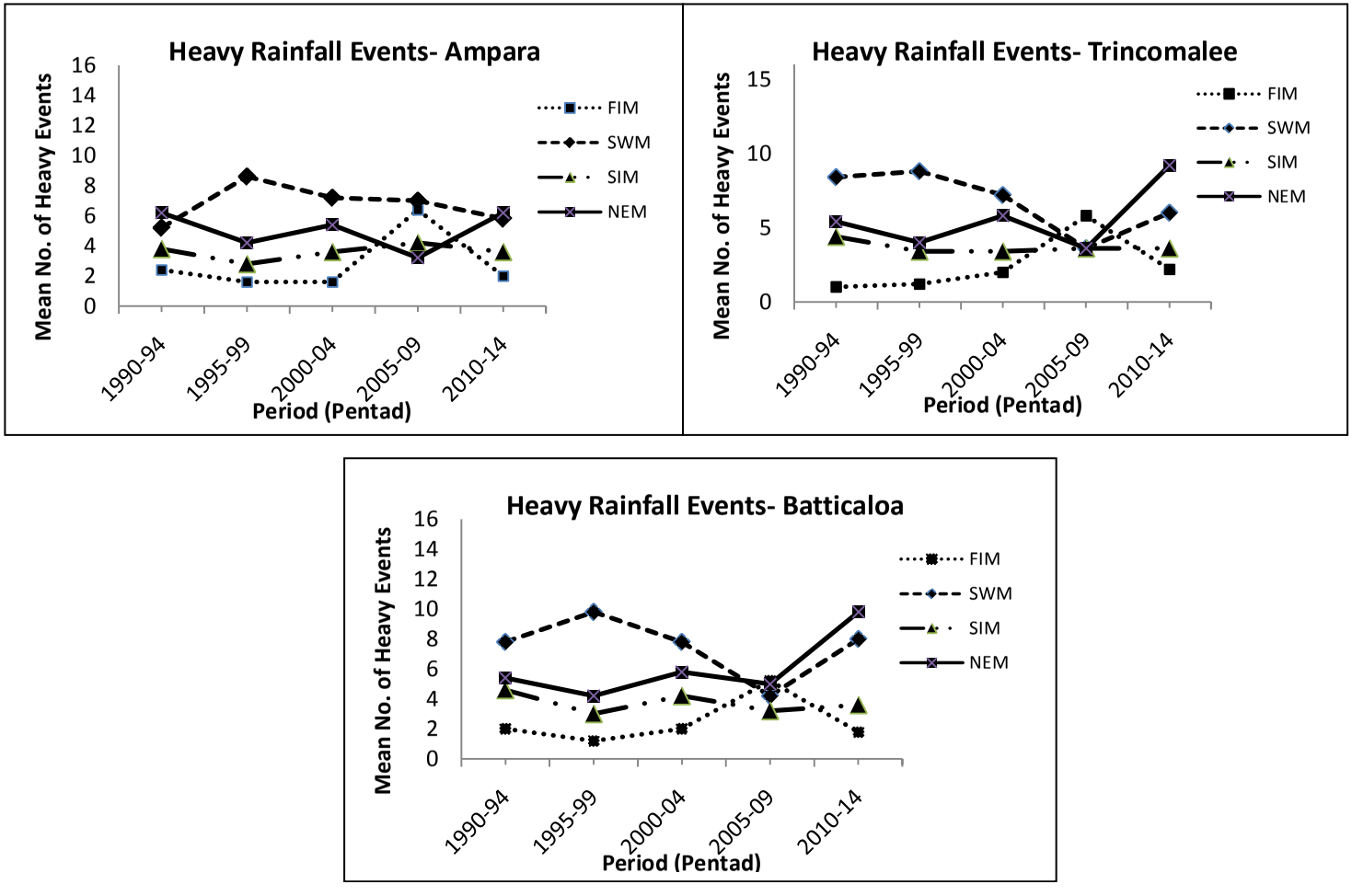


Figure 3: Occurrence of extreme positive rainfall anomalies in the DL_2 agro-ecological region of the Dry zone in Sri Lanka – Heavy events

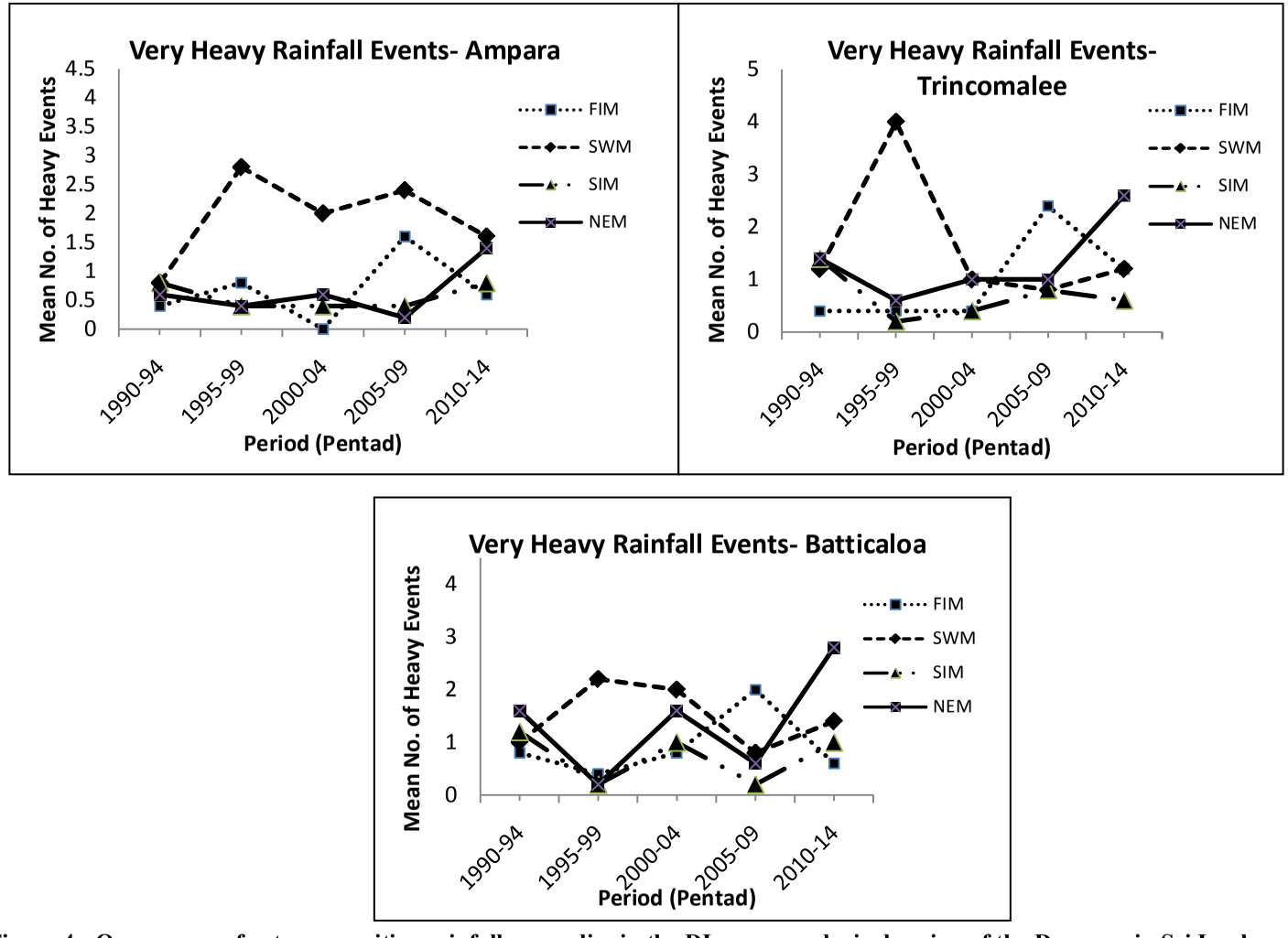


Figure 4: Occurrence of extreme positive rainfall anomalies in the DL_2 agro-ecological region of the Dry zone in Sri Lanka – Very Heavy events

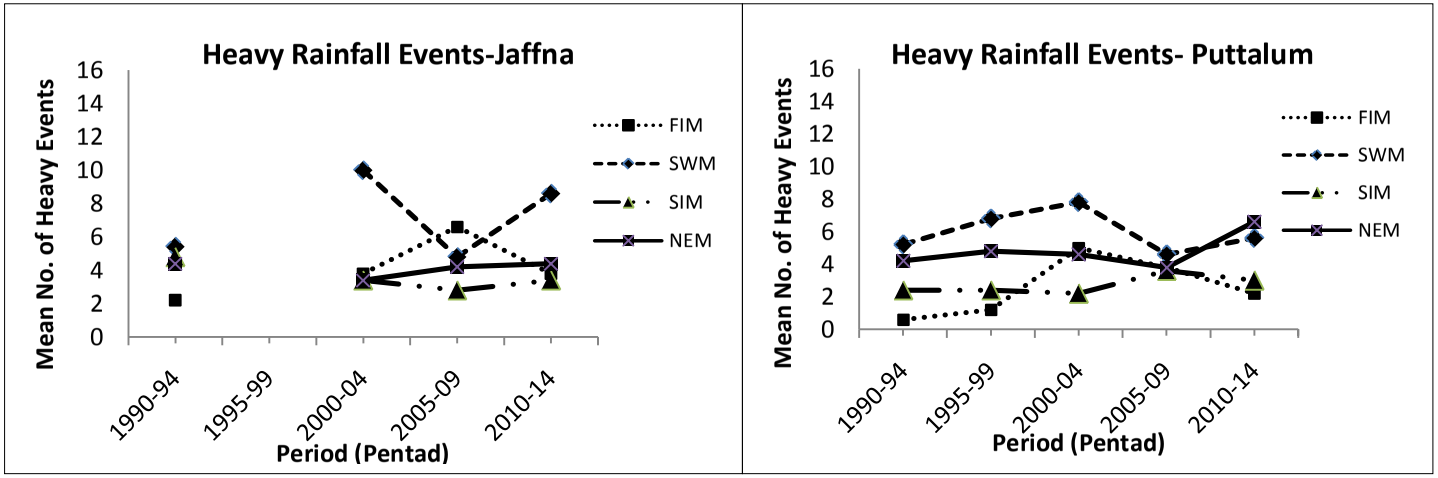


Figure 5: Occurrence of extreme positive rainfall anomaliesin the DL_3 agro-ecological region of the Dry zone in Sri Lanka – Heavy events

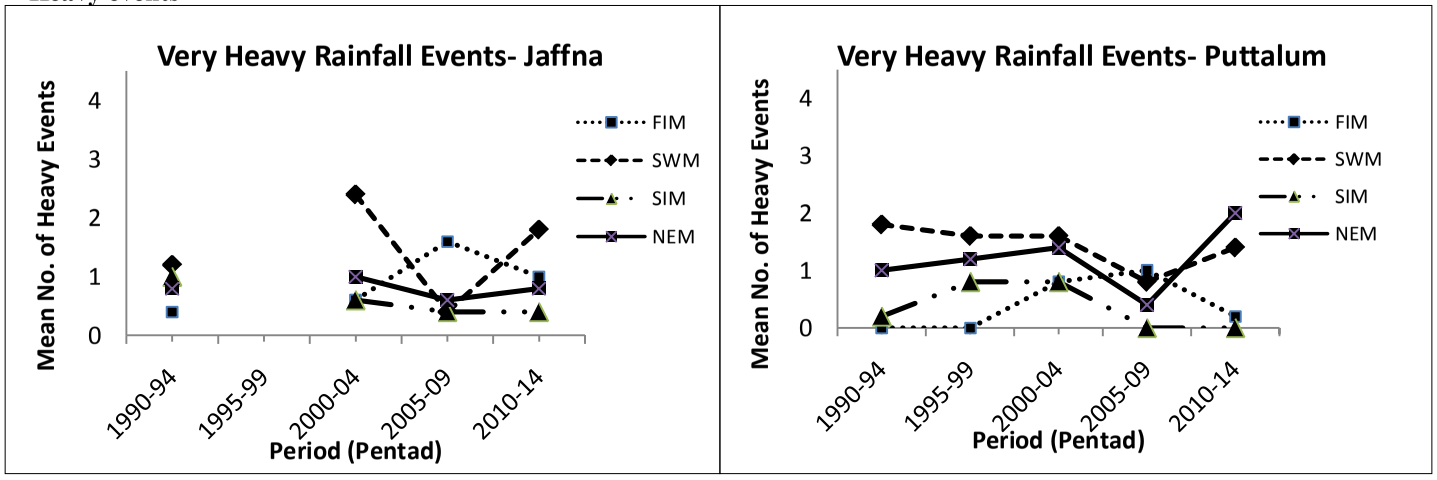


Figure 6: Occurrence of extreme positive rainfall anomaliesin the DL_3 agro-ecological region of the Dry zone in Sri Lanka – Very Heavy events

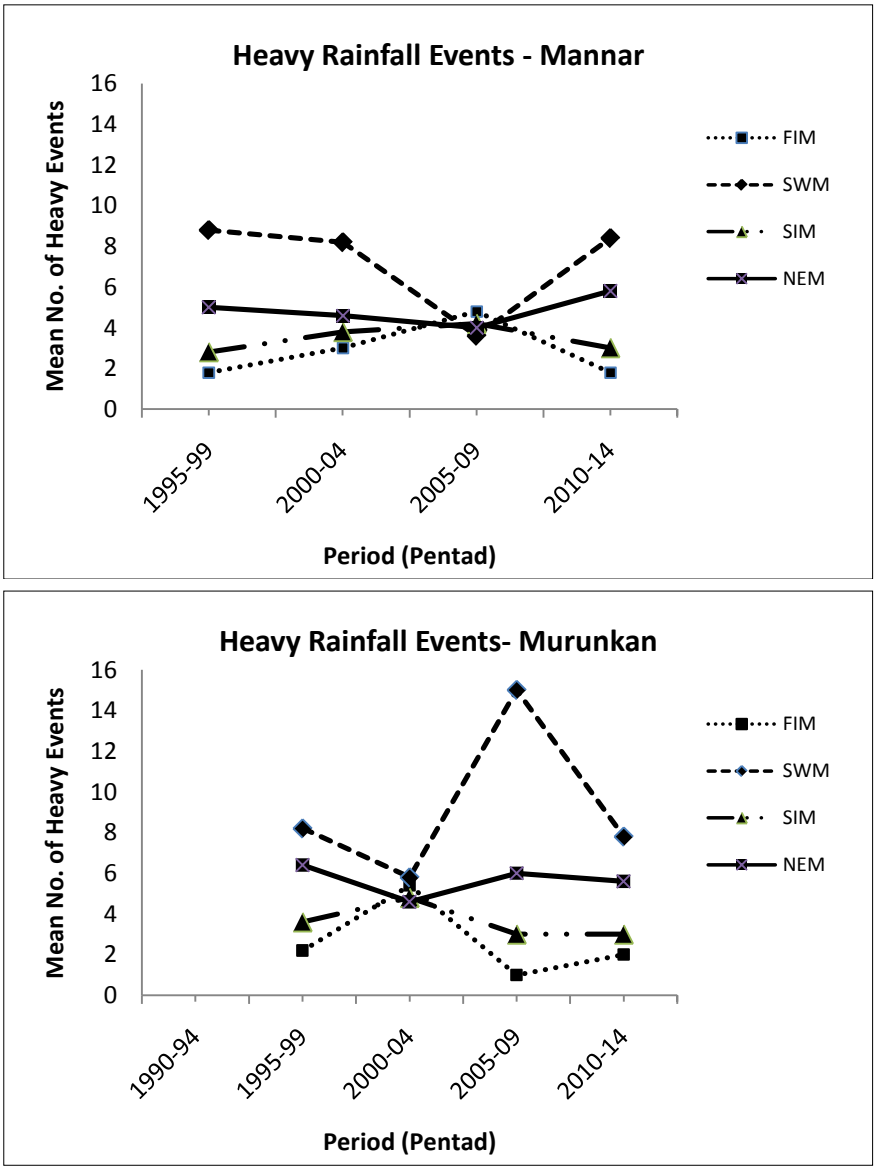
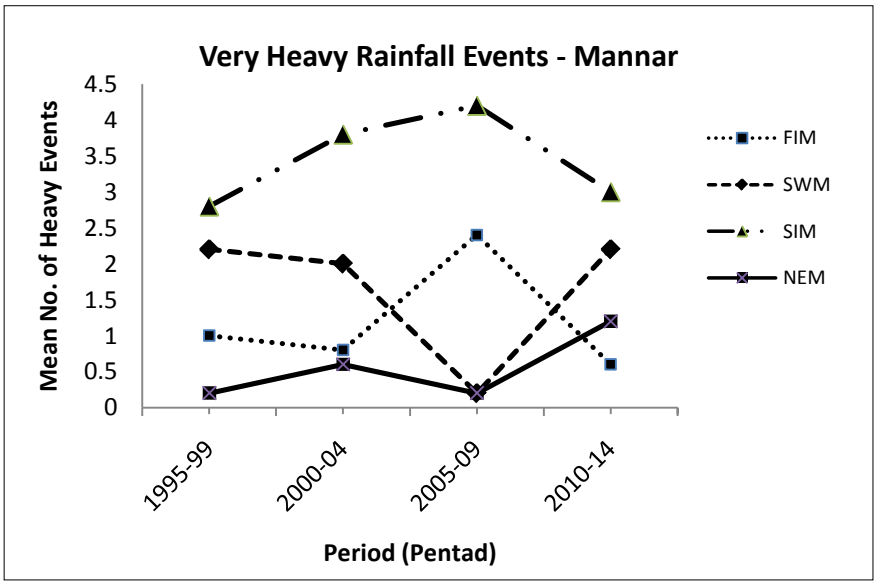


Figure 7: Occurrence of extreme positive rainfall anomalies in the DL_4 agro-ecological region of the Dry zone in Sri Lanka – Heavy events



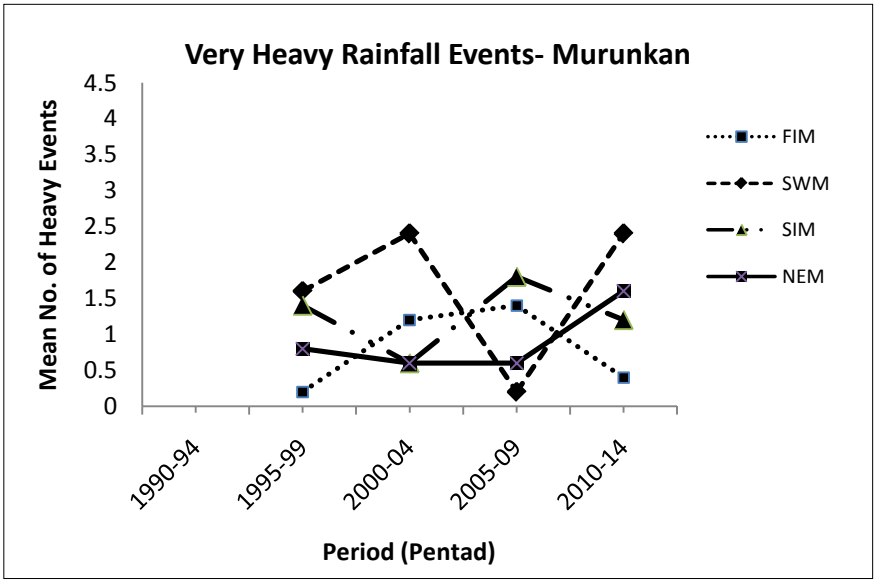


Figure 8: Occurrence of extreme positive rainfall anomalies in the DL_4 agro-ecological region of the Dry zone in Sri Lanka – Very Heavy events

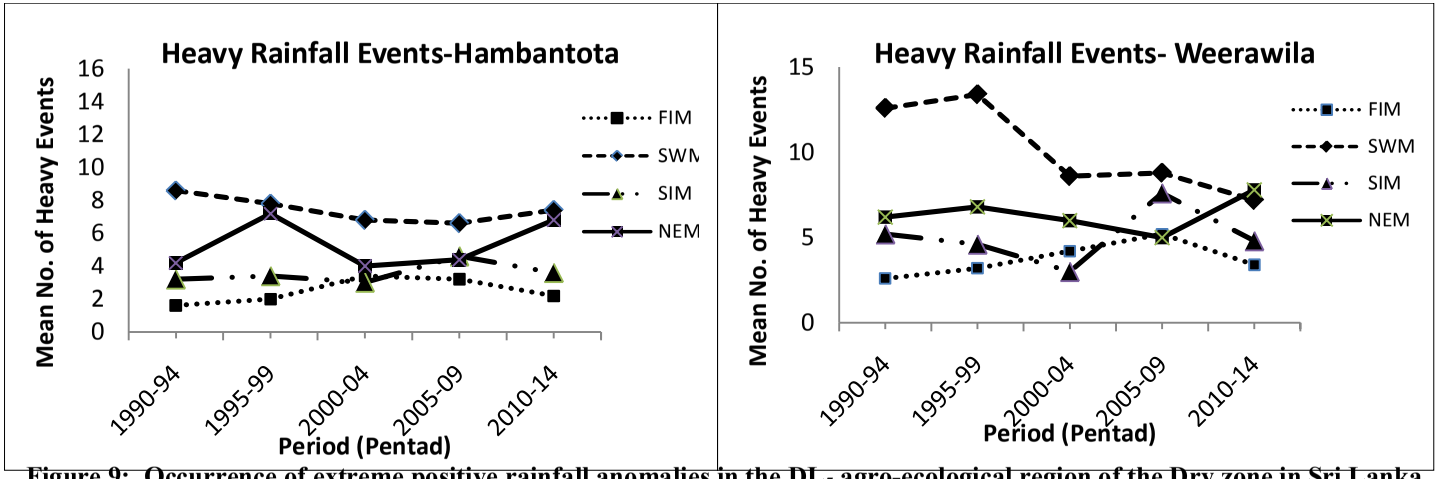


Figure 9: Occurrence of extreme positive rainfall anomalies in the DL_5 agro-ecological region of the Dry zone in Sri Lanka – Heavy events

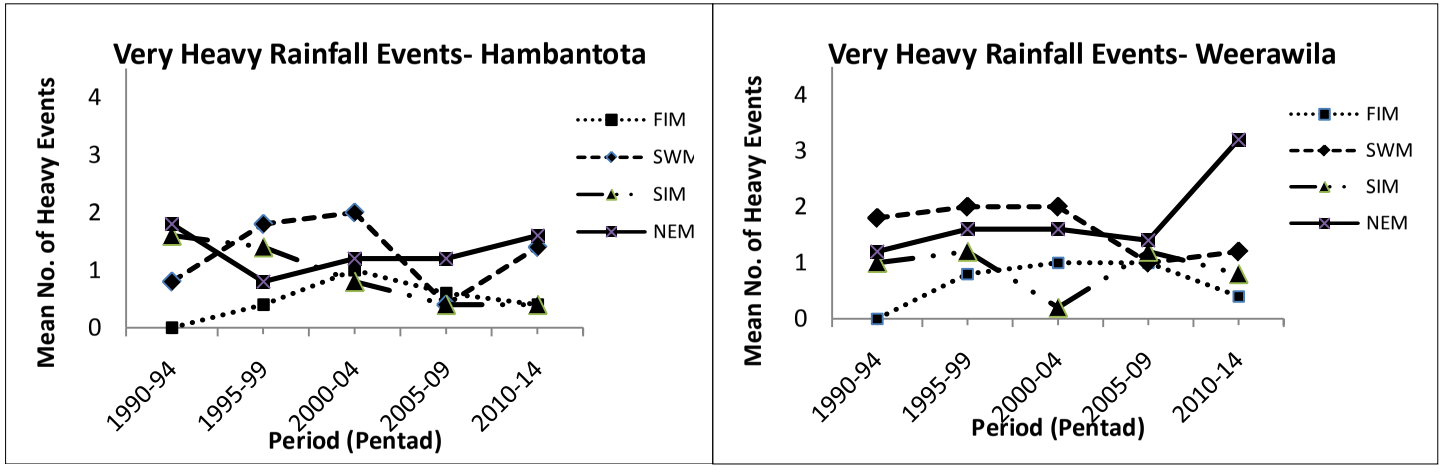


Figure 10: Occurrence of extreme positive rainfall anomaliesin the DL_5 agro-ecological region of the Dry zone in Sri Lanka – Very Heavy events

The above results suggest that even though trends in occurrence of HRF and VHRF events during most recent 25-year period of 1990-2014 is not significant, an apparent increasing trend of these extreme events during last 25 year period, last five years in particular signals a change in usual rhythm of rainfall climatology in the Dry zone of Sri Lanka that could be probably attributed to the climate change. With continuing global warming, these extreme events are expected to increase in the future (IPCC, 2013) and thus, current apparent trends could become obvious events in the future. The impacts of these frequent positive extreme rainfall events are already manifested in the Dry zone agriculture during recent times. Meanwhile, increasing trends of extreme positive rainfall anomalies during SWM and NEM seasons during most recent pentad (2010-2014) is quite important aspect to pay attention in the context of crop production in the Dry zone. These SWM and NEM seasons mark the latter half of the two major cultivation seasons in the region namely, *Yala* and *Maha*, respectively. Thus, increasing positive rainfall anomalies in SWM and NEM seasons result in frequent excess moisture conditions in rainfed upland crops and flooding in lowland paddy fields during reproductive phase of both aforesaid cropping systems with subsequent loss of yield both quantitatively and qualitatively.

Implications of the trend

Moreover, the decreasing trend of extreme rainfall events during FIM season in most places of the Dry zone poses additional threat to crop production under cascade of minor tank systems in the Dry zone. During *Yala* season, these minor tanks are usually fed by ephemeral streams in respective catchments. With the arrival FIM season, aforesaid ephemeral streams become live and feed the downstream tank. Whenever, upstream catchment receives HRF events frequently in a season tanks will come to the full-supply level in a short period of time and therefore, farmers can start the cultivation on-time. Hence, this apparent decreasing trend of heavy rains during FIM season in the Dry zone may lead to frequent insufficient water storage conditions of tanks during *Yala* season for cultivation, drinking, household use and environmental purposes.

Furthermore, the apparent increasing trend of HRF and VHRF events in the Dry zone landscape is detrimental to the existence of the tank cascade

system of the Dry zone. If any rainfall event exceeds its intensity greater than 25 mm/hr, such rains result in soil erosion in many landscape of Sri Lanka except closed canopy forests or vegetation with similar ground cover. Thus, increasing trend of HRF and VHRF events in the Dry zone suggests that such erosive rains are becoming more and more frequent in its landscape resulting accelerated soil erosion in already degraded catchments and consequently rapid siltation of downstream cascade of tanks. Siltation of tanks does not only reduce the tank's storage capacity, but also increases the risk of rapid drying out even under a minor dry weather condition. This phenomenon is likely to be aggravated in the future due to climate change. Increased surface to depth ratio of a tank morphology resulted from silting, will increase the evaporative losses from the tank with continually increasing temperature regime of the Dry zone. Punyawardena *et al.* (2013) have shown that average temperature regime of the Dry zone could be in the range of 2 ^{o}C to 3 ^{o}C higher than that of today at the turn of the 21st century

Future studies

It is logical to hypothesize that evaporative flux from the Indian Ocean around Sri Lanka should have a direct link with the increased occurrence of extreme positive rainfall anomalies of Sri Lanka. As the evaporative flux from the ocean is a function of Sea Surface Temperature (SST), any ocean-atmospheric phenomenon such as Indian Ocean Di-pole (IOD) and *El Nino* events which alter the SST dynamic around Sri Lanka likely to have a teleconnection with the occurrence of HRF and VHRF events in Sri Lanka. Therefore, further studies are required to establish such teleconnections, if any. So that reliable forecasts on these events could be made with a reasonable lead-time enabling farmers and policy makers to take appropriate risk reduction strategies for such events in approaching rainy seasons.

CONCLUSIONS

This study was undertaken to ascertain the trends of positive extreme rainfall anomalies in the Dry zone of Sri Lanka where dynamics of seasonal rainfall is an important determinant in agriculture, water resources and livelihood of the people. Even though no significant trend in occurrence of HRF or VHRF

events has been observed during last 25-year period from 1990-2014, it is revealed that an apparent trend of these extreme positive rainfall anomalies is discernible, especially during South West Monsoon (SWM) and North East Monsoon (NEM) rainfall seasons. This trend has been clearly evident during last 5-year period from 2010-2014. As these two rainy periods coincide with the reproductive phase of the crops grown in both *Yala* and *Maha* cultivation seasons in the Dry zone, it may likely to inflict significant implications on the agricultural production in the region in terms of both quantity and quality. As the climate change is likely to exacerbate extreme rainfall events in future, these apparent trends could even become obvious thus, excess soil moisture stress in rainfed upland crops, flood damages in lowland paddy fields and rapid drying out in cascade of tanks in long-run will be a serious threat to agricultural productivity in the Dry zone of Sri Lanka.

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CONSTRUCTION AND VALIDATION OF MIR159A BASED SILENCING SUPPRESSOR GENE CONSTRUCTS FOR CONTROLLING *POTATO VIRUS Y* AND *POTATO VIRUS X*

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ABSTRACT

Potato (*Solonum tuberosum* L.) is an important food crop grown throughout the world. The crop is affected with many plant viruses. *Potato virus Y* (PVY) and *Potato virus X* (PVX) are two major viruses that infect potato in single and mixed ways causing considerable yield losses. Unavailability of resistant genes and the tetraploid nature of the crop make it difficult for breeders to generate resistance to these two viruses. siRNA based and miRNA based approaches have been attempted by researches to give resistance to these viruses. In this study, two gene constructs were made using siRNA sequences that had been selected through *insilico* analysis of two suppressor genes, HC-Pro of PVY-Del66 and *p*25 of PVX-ptDel9 strains on a miR 159a backbone. The effectiveness of these two constructs in controlling PVY and PVX were evaluated transiently through agroinfiltrations in *Nicotiana benthamiana* L. and potato through post inoculations. The same constructs were also evaluated in potato plants, which had already got natural infections of PVY and PVX viruses. Results showed that the two constructs were effective in reducing PVY and PVX virus concentrations in *N. benthamiana* and potato in post inoculations. It was also observed that the two constructs were able to control the virus load in plants that had already been infected with PVY and PVX. These two constructs can be used to generate transgenic resistance against PVY and PVX.

Key words: *Potato virus Y*, *Potato Virus X*, siRNA, miRNA, gene constructs

INTRODUCTION

Potato (*Solanum tuberosm* L.) is an important food crop grown throughout the world. It is a tetraploid crop with 48 chromosomes. A number of viruses infect the potato crop and *Potato virus Y* (PVY) and *Potato virus X* (PVX) are two major viruses that affect potato worldwide. Tetraploid nature of the crop makes it arduous to breed resistant varieties for these viruses. Pathogen derived resistance is one of the important aspects, which is used to generate resistance against virus diseases in the absence of natural resistance.

Some plant use RNA silencing mechanism, which is also known as cosuppression or RNA mediated virus resistance or gene silencing to get protected from virus infections (Baulcombe, 1996; Chellappan *et al*., 2004). RNA silencing was initially reported from *Caenorhabditis elegans* (Fire *et al.*, in 1998). In RNA silencing against plant viruses, double stranded RNA (dsRNA) of plant viruses generated during replication or by the action of plant RNA dependent RNA polymerase (RdRp) are cleaved by dsRNA-specific RNAs III (dicer), yielding 21-26 long short interfering RNAs known as siRNAs (Chapman *et al*., 2004). Next, those siRNAs are recruited to an RNA induced silencing complex (RISC) where mRNAs are degraded in a sequence specific manner. Proteins of Argonaute family, nucleases and other factors also involve in RISC. These small RNA molecules can also suppress the protein translation (Voinnet, 2001). Small interfering RNAs (siRNAs) can be of endogenous origin (miRNAs) or exogenous origin (siRNA). siRNAs are generally triggered by transgenes or invading plant viruses whereas miRNAs are of natural origin in eukaryotes. miRNA are processed from imperfect hairpin forming RNA precursors transcribed from miR genes in the same way by Dicer like proteins as siRNAs (Ambros *et al*., 2003). miRNAs act as negative regulators on target mRNAs. They involve in gene silencing either through site-specific cleavage by RISCs or translational repression (Bartel, 2004). Once the RNA silencing mechanism is started by a foreign molecule it can be triggered by any other RNA species, which bare sequence homologies (Voinnet, 2001).

To counter plants' natural antiviral defense mechanism, viruses have evolved with genes encoding for proteins that suppress naturally occurring RNA

silencing mechanism in plants. Those proteins are known as silencing suppressor proteins (Baulcombe, 2001). P1/HC-Pro of potyviruses (Anandalakshmi *et al*., 1998) and *p*25 of *Potato virus X* (Voinnet *et al*., 2000) are two earlier identified silencing suppressors and well studied silencing suppressors.

Potyvirus HC-Pro is one of the earliest known silencing suppressors (Qu and Morris, 2005). It involves in polyprotein processing, amplification of genome, long distance movement and aphid transmission of PVY (Kasschau *et al*., 1997) and acts as a pathogenecity enhancer causing increased accumulation of viral RNAs of several unrelated plant RNA viruses (Pruss *et al*., 1997). Initially, *p*25 of PVX (TGBp1) was identified as a movement protein (Baynet *et al*., 2005). It has helicase activity and interferes with plasmodesmal gating. It acts as a silencing suppressor by interfering with the mobilization of silencing signals and degrading argonaute proteins (Chiu *et al*., 2010; Voinnet *et al*., 2000).

dsRNA of plant viruses are the key targets of transgene mediated RNA silencing; i.e. generation of barley lines resistant to barley yellow dwarf virus-PAV (BYDV-PAV) (Wang *et al*., 2000), tobacco lines resistant to PVY (Zhu *et al*., 2004), Tomato yellow leaf curl complex resistance (Abhary *et al*., 2006), potato lines resistant to PVY (Missiou *et al.,* 2004) and marker free PVY and PVX resistant potato (Bai *et al*., 2009). Recently the antiviral strategy of artificial micro RNA (amiR) has been applied in achieving antiviral resistant transgenics for *Turnip yellow mosaic virus*, *Turnip mosaic virus*, *Cucumber mosaic virus*, *Plum Pox Virus* and PVY (Duan *et al*., 2008; Jiang *et al.*, 2011; Niu *et al*., 2006; Qu *et al*., 2007; Simón-Mateo *et al*., 2006). In this study miR159a based two artificial constructs were made based on two viral suppressor genes, PVY-HC-Pro and PVX-*p*25 and their performance against two potato virus isolates, PVY Del66 and PVX ptDel9 were evaluated in *Nicotiana benthamiana* L. and potato.

MATERIALS AND METHODS

Amplification of PVY-HC-Pro and PVX-*p*25 and selection of siRNA

Total plant RNA was extracted from *N. benthamiana* plants 14 days post

inoculation with PVY Del66 and PVX ptDel9 strains, which were maintained in the glass house of the Division of Plant Pathology, Indian Agricultural Research Institute, New Delhi, India using TRIzole (Life Technologies, Grand Island, NY, USA). cDNA was synthesized from 50 ng of total plant RNA, using RevertAid First Strand cDNA Synthesis Kit (Fisher Scientific-USA, Pittsburgh PA, USA) according to the manufacturer's protocol. The primers BM 270F; 5′GGGGTTATGGATTC AATGGTTC 3′, BM 271R; 5′ACCAACTCTATAATGCTTAATG3′ and BM 296F; 5′ATGGATATTCTCATCATTAG3′, BM 297R; 5′CTATGTCCCTGCGCGG3′, were designed (synthesized at Sigma Aldrich Co. India) and used to amplify PVY-HC-Pro (1395 bp) and PVX-*p*25 (681 bp) portions, respectively. cDNA synthesis and polymerase chain reaction (PCR) were carried out in a MJ-Mini Personnel Thermal Cycler Model PTC-1148C (Bio-Rad Laboratories, Hercules, CA, USA). In each amplification, the PCR mixture of 25 µl consisted of 50 ng of cDNA, 0.5 µl of 10 mM forward and 10 mM reverse primers each, 0.5 µl of *Taq* DNA Polymerase (5units/µl) (RBC Bio Science Corporation, New Taipei City, Taiwan), 1.0 µl of 10 mM dNTP mix, 2.5 µl of 10X PCR buffer (RBC Bio Science Corporation, New Taipei City, Taiwan) and sterile distil water. PCR cycles consisted of initial denaturation at 94 °C for 2 min. followed by a 30 cycles of denaturation at 94 °C for 2 min, annealing at 58 °C for 40 sec, and extension at 72 °C for 30 Sec. The final extension was carried out at 72 °C for 7 minutes. The amplified products, PVY-HC-Pro and PVX-*p*25 and were ligated to RBC TA Vector (RBC Bio Science Corporation, New Taipei City, Taiwan) as per the manufacturer's protocol. Plasmid isolation was carried out using mdi pDNA miniprep kit (mdi Membrane Technologies LLC, CA, USA) as per the manufacturer's protocol. Sequencing of DNA inserts were carried out in a high-throughput sequencer; ABI 3730 XL at Xcelris laboratory, Bangalore, India (www.xcelrislabs.com). The sequence data of PVY-HC-Pro and PVX-*p*25 were analyzed using Ambion siRNA target finder (http://www.ambion.com/ techlib/misc/siRNA_finder.html). Generated siRNA sequences were analyzed using NCBI local blast (http://blast.ncbi.nlm.nih.gov) and the best suited two siRNA portions were selected from HC-Pro and *p*25 sequences, separately based on targets matching.

Designing of miR159 precursor

Total plant RNA was isolated from leaves of *Arabidopsis thaliana* using

TRIzole (Life Technologies, Grand Island, NY, USA). cDNA was synthesized from total plant RNA using RevertAid First Strand cDNA Synthesis Kit (Fisher Scientific-USA, Pittsburgh PA, USA) according to the manufacturer's protocol. miR159a precursor was then synthesized based on this cDNA using miR159a precursor primers; (BM341F: 5′CACCACAGTTTGCTTATGTCGGATCC3′ and BM342R: 5′TGAGTCGACA TGTAGAGCTCCCTTCAATCC3') described by Niu *et al*. (2006). (The primers were synthesized at Sigma Aldrich Co. India). cDNA synthesis and follow up PCRs were carried out in a MJ-Mini Personnel Thermal Cycler Model PTC-1148C (Bio-Rad Laboratories, Hercules, CA, USA). The PCR reaction mixture consisted of 50 ng of cDNA as template, 5 µl of 10Xreaction buffer, 4 µl of 2.5mMdNTP mix, 2 µl each of forward and reverse primers (10 picomole), 1.25 U of Ex Taq DNA polymerase (Takara, Japan) and autoclaved water to makeup 50 µl of total volume. The PCR cycle consisted of initial denaturation of 98 °C for 30 seconds followed by 40 PCR cycles, each consisting of denaturation at 98 °C for 10 seconds, primer annealing at 57 °C for 45 seconds, and extension at 72 °C for 1 minute. The final extension was done at 72 °C for 10 minutes. The amplified product was purified using Nucleospin gel and PCR clean-up kit (Macherey-Nagel Inc., PA, USA) as per manufacturer's protocol and ligated to RBC TA Vector (RBC Bio Science Corporation, New Taipei City, Taiwan) according to the manufacturer's protocol. Sequencing was done in a high-throughput sequencer; ABI 3730 XL at Xcelris laboratory, Bangalore, India (www.xcelrislabs.com).

Preparation of miR constructs (amiR159a)

The primers indicated in the Table 1 were designed (synthesized at Sigma Aldrich Co. India) and used to amplify HC-PromiR and *p*25miR constructs replacing the naturally occurring siRNA portions of the miR159a backbone with already identified siRNA portions from PVY-HC-Pro and PVX-*p*25 gene sequences. Restriction sites; *Kpn*1 at 5′and Sal1 at 3′ were also incorporated along with primers for downstream ligation to pBinAR vector. PCRs were carried out in a MJ-Mini Personnel Thermal Cycler (Model PTC-1148C, Bio-Rad Laboratories, Hercules, CA, USA).

The PCR reaction mixture consisted of 50 ng of RBC TA vector containing miR159a backbone as the template, 5 µl of 10Xreaction buffer, 4 µl of 2.5mMdNTP mix, 2 µl each of forward and reverse primers (10 picomole), 1.25 U of Ex *Taq* DNA polymerase (Takara, Japan) and autoclaved water to makeup 50 µl of total volume.

Table 1. The primers designed for developing artificial micro RNA constructs based on PVY HC-Pro and PVX *p*25 genes

Primer Name	Primer sequence (5´ to 3´)	Annealing Temperature (°C)	Construct name	Amplicon size (bp)
BM361F	caggtacctgatctgacgatggaagaaacgcag acatgccatgtggcatgagttgagcagggta	64	HC-PromiR	219
BM362R	tgagtcgacatgaaacgcagacatgccatgtgg gaagagtaaaagccatta			
BM 367F	caggtacctgatctgacgatggaagaatagaggaaat tggccagtccatgagttgagcagggta	64	*p*25miR	219
BM368R	tgagtcgacatgaatagaggaaattggccagt cgaagagtaaaagccatta			

The PCR cycle consisted of an initial denaturation at 98 °C for 30 seconds followed by 40 PCR cycles, each consisting of denaturation at 98 °C for 10 seconds, primer annealing at 64 °C for 45 seconds, and extension at 72 °C for 1 minute. The final extension was done at 72 °C for 10 minutes. The amplified products were purified using Nucleospin gel and PCR clean up kit (Macherey-Nagel Inc., Bethlehem, PA, USA) as per manufacturer's protocol and ligated to RBC TA Vector (RBC Bio Science Corporation, New Taipei City, Taiwan) according to the manufacturer's protocol. Sequencing was done in high-throughput sequencer; ABI 3730 XL at Xcelris laboratory, Bangalore, India (www.xcelrislabs.com). The constructs were named as HC-PromiR and *p*25miR

Transformation of constructs to binary vector

miR159a constructs were released from TA vector using endonucleases,

*Kpn*1 and *Sal*1. Then the constructs were purified from 1% Agarose gel using Nucleospin gel and PCR clean up kit (Macherey-Nagel Inc., Bethlehem, PA, USA) as per manufacturer's protocol and ligated to pBinAR vector (~12kb) that had already been restricted with *Kpn*1 and *Sal*1 endonucleases. The ligation reaction was carried out using Fermentas T4DNA ligase and ligase buffers (Fermentas, Glen Burnie, MD, USA). The ligation reaction consisted of 3 µl of 50 ng DNA insert, 1 µl of 50 ng vector, 1 µl of T4DNA ligase and 2 µl of 10X ligase buffer. Ligated vectors were transformed to *Escherichia coli* DH5α competent cells. The plasmids were isolated using mdi pDNA miniprep kit (mdi Membrane Technologies LLC CA, USA) as per the manufacturer's protocol and the inserts were confirmed through PCR.

Transient assays
Agroinfiltration studies with *Nicotiana benthamiana*

pBinAR plasmids carrying HC-PromiR and *p*25miR constructs were transformed to *Agrobacterium tumefaciencs* (strain: EHA 105) with helper component PRK2013 using triparental mating method as described by Goldberg and Ohman (1984). *N. benthamiana* plants, which were negative to PVY and PVX in Direct Antigen Coating-Enzyme Linked Immunosorbent Assay (DAC-ELISA) (Clark and Adams, 1977) were selected as healthy plants for the assay. The Agroinfiltration was carried out in *N. benthamiana* as per the method described by de Felippes and Weigel (2010). Well expanded three to four leaves of each plant were used for agroinfiltration under each treatment. Only miR construct and pBinAR were also transferred to plants through agroinfiltration in the same way as checks. Three days post agroinfiltration (dpa) the same leaves were mechanically inoculated with PVY Del66 and PVX ptDel9 strains, separately. The inoculum was prepared by grinding 100 mg of freshly harvested infected (PVY/PVX) leaf tissues in 1 ml of 0.1 M phosphate buffer, pH 7.0 containing 0.2% sodium sulfite and 0.01 M 2-mercaptoethanol using chilled mortars and pestles. The extract was filtered using cheesecloth. One per cent of Celite 545 (S.D. Fine Chem. Ltd., Hyderabad, India) was added to the inoculum. Leaves to be inoculated were predusted with carborundum (600 mesh) (HiMedia Laboratories, Mumbai, India). Inoculation was done by rubbing leaves with fore finger that had been

wetted in the inoculum. Symptom development was observed at the whole plant level at 14 days post inoculation (dpi). PVY and PVX virus concentrations were also measured at 14 dpi through Enzyme Linked Immunosorbent Assay (ELISA) using PVY and PVX specific polyclonal antibodies. Absorbance was measured at 405 nm in an ELISA reader (BIOTEK Instruments, USA)

Agroinfiltration studies with PVY and PVX infected potato

Four to six week old potato plants (5 plants for each treatment), which had already been identified using ELISA for the presence of PVY, PVX and double infections were agro infiltrated with HC-PromiR and *p*25miR constructs in the same way as described in the previous section for *N. benthamiana*. Virus concentrations of agro infiltrated leaves were quantified using ELISA as described above at 14 dpi.

Agroinfiltration studies with healthy potato followed by challenge inoculations

In this experiment field potato plants identified as healthy through DAC-ELISA using PVY and PVX specific antibodies were agro infiltrated with HC-PromiR and *p*25miR constructs and challenge inoculated 03 days post agroinfiltration (dpa) as follows. HC-PromiR in 12 plants followed by PVY inocultaion, *p*25miR in 8 plants followed by PVX inoculation and PVY HC-Pro and PVX-*p*25 together in 8 plants followed by PVY and PVX mixed inoculations. In each case positive controls (only the respective virus inoculation) and negative controls (healthy) were maintained. Virus concentrations of treated leaves were quantified at 14 dpi using DAC-ELISA as described previously.

Confirmation of HC-PromiR and p25miR constructs in agro infiltrated leaves

Total leaf DNA was isolated from agro infiltrated leaf samples using DNAeasy plant minikit (Qiagen, Valencia, CA, USA) 07 dpa. The presence of constructs were confirmed with construct specific primers in PCR.

RESULTS AND DISCUSSION

Amplification of miR159a precursor, PVY-HC-Pro and PVX-*p*25 genes

BM 341 and BM 342 primers amplified 277 nt miR159a precursor (Figure 1a). BM 270F and BM 271 R primers amplified a 1395 bp portion for PVY-HC-Pro and BM 296 F and BM 297 R a 681 bp portion for PVX-*p*25. (Figure 1b and 1c).

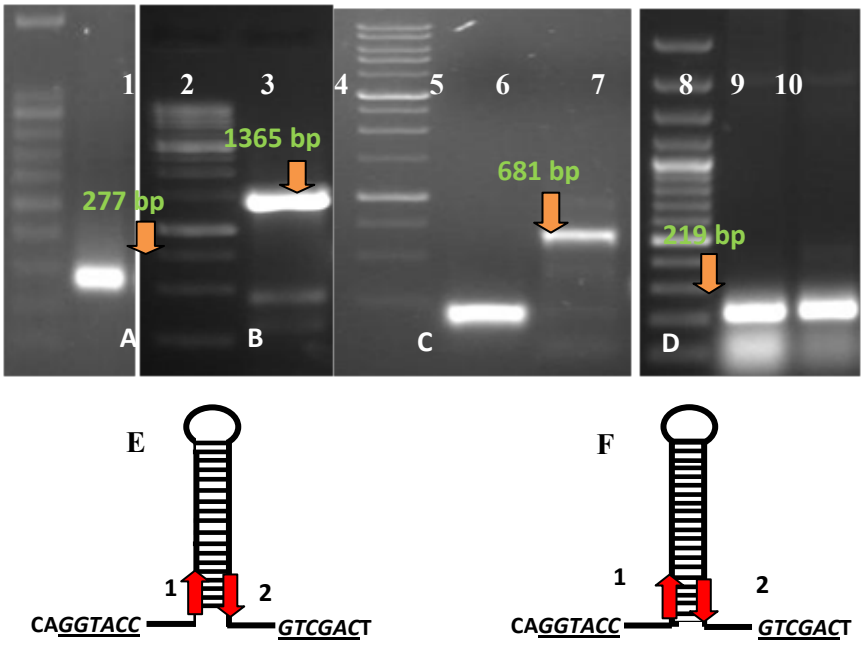


Figure 1. Amplification of precursor, suppressor genes, gene constructs
Note: (A). miR159a precursor (277 bp), (B) *Potato virus Y*-HC-Pro (1365 bp) from PVY Del66 strain, (C) *Potato virus X-p*25 (681 bp) from PVX ptDel9 strain. (D) amiR159a with HC-Pro and *p*25 siRNA sites, (E) HC-PromiR construct, (F) p25miR construct. Lane 1 = 100 bp ladder, Lane 2 = miR159a precursor, Lane 3 = 1KB ladder, Lane 4 = PVY-HC-Pro, Lane 5 = 1kb ladder, Lane 6 = PVX-p8 (an internal control) Lane 7 = PVX-*p*25. Lane 8 = 100 bp ladder, Lane 9 = PVY-HC-Pro, Lane 10 = PVX-*p*25, Underlined sequences are restriction sites for *Kpn*1 and *Sal*1.

Selection of siRNA and development of HC-PromiR and *p*25miR constructs

Best suited siRNA sequences selected from the Ambion siRNA target

finder, which were subsequently used in HC-PromiR and *p*25 miR construct preparations are indicated in the Table 2. BM 361F, BM 362R primers amplified HC-PromiR (219 bp) fragment and BM 367F, BM 368R primers *p*25miR (219 bp) from the TA vector containing miR159a backbone (Figure 1d). Sketches of the precursors of HC-PromiR and *p*25miR are indicted in the Figure 1e and 1f.

Table 2. Selected siRNA sequences form *Potato virus Y*-HC-Pro and *Potato virus X*-*p*25 sequences that were used to prepare artificial micro RNA constructs

Gene	**Targeting sequence (5′ to 3′)**	**Sense strand (5′ to 3′)**	**Antisense strand (3′ to 5′)**
HC-Pro	aaacgcagacatgccatgtgg	acgcagacaugccauguggtt	ttugcgucuguacgguacacc
*p*25	aauagaggaaauuggccaguc	uagaggaaauuggccaguctt	ttaucuccuuuaaccggucag

Confirmation of HC-PromiR and *p*25miR constructs

PCR with primers BM361F, BM362R and BM 367F, BM 368R confirmed the presence of HC-PromiR and *p*25miR in agro infiltrated leaves of *N. benthamiana* (Figure 2 A).

Symptom expression and coat protein levels in *Nicotiana benthamiana* with HC-PromiR and *p*25miR

All the inoculated (+ ve control) plants showed symptoms at 14 dpi. However, no visual symptoms were observed in *N. benthamiana* plants, in which HC-PromiR and *p*25miR had been kept and challenge inoculated with PVY-Del66 and PVX-ptDel9 isolates, respectively at 14 dpi. Results revealed that the constructs: HC-PromiR + PVY, *p*25miR+PVX had a good control of respective viruses at 14dpi (Table 3, Figure 2 B).

Symptom expression and coat protein levels in PVY and PVX infected potato after the agroinfiltrations

A reduction in symptoms in the newly appearing leaves was observed in infected potato plants, which had been agroinfiltrated with HC-PromiR and *p*25miR constructs at 14 dpi. ELISA absorbance values showed a considerable reduction in the virus concentration of PVY and PVX in PVY, PVX and PVY+PVX infected plants, which were agro infiltrated with HC-PromiR, *p*25miR singly and doubly, respectively (Table 4).

Table 3. Symptom development in agro infiltrated *N. benthamiana* plants at 14 days post inoculation

Construct	Challenge inoculation	Symptomatic plants out of 5 inoculated (numbers)	Symptoms
Healthy	PVY	5	Yellow spots, Puckering
HC-PromiR	PVY	0	No symptoms
HC-PromiR	No inoculation	0	No symptoms
Healthy	PVX	5	Yellow mottling
*p*25miR	PVX	0	No symptoms
*p*25miR	No inoculation	0	No symptoms
miR159a	No inoculation	0	No symptoms
pBinAR	No inoculation	0	No symptoms
Healthy	No inoculation	0	No symptoms

Note: [x] Infection was confirmed by ELISA

Response of HC-PromiR and *p*25miR agro infiltrated potato plants to PVY and PVX post inoculations

Significant reductions in PVY and PVX contents of HC-PromiR and *p*25miR agro infiltrated and followed by challenge inoculated leaves when compared to none agro infiltrated followed by challenge inoculated leaves were observed. This was also evident in the leaves, which were agro infiltrated with both the constructs followed by PVY and PVX duel inoculation (Figure 3 B and 3 C).

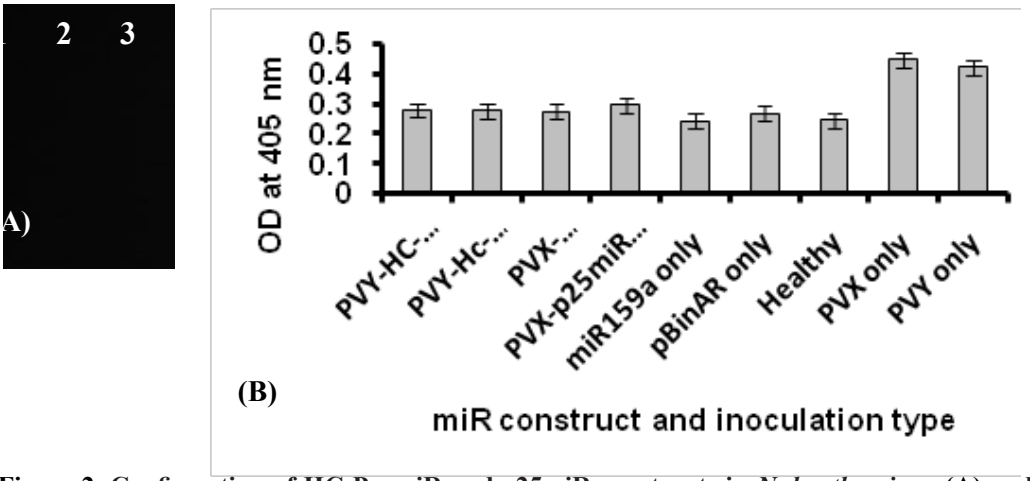


Figure 2. Confirmation of HC-PromiR and *p*25miR constructs in *N. benthamiana* (A) and Detection of virus concentrations in *Nicotiana benthamiana* leaf tissues agro infiltrated with HC-PromiR and *p*25miR constructs and challenge inoculated with respective viruses and in control treatments (B)'.Note: Lane 1 = 1kb ladder, Lane 2 = PVY-HC-PromiR, Lane 3 = PVX-*p*25miR,

Table 4. Symptoms and ELISA values of *Potato virus Y* and *Potato virus X* infected plant leaf tissues, agro infiltrated with HC-PromiR and *p*25miR constructs

Virus present	Construct	Before the agroinfiltration with construct		14 days after the challenge inoculation	
		Symptoms	OD at 405 nm	Symptoms	OD at 405 nm
Healthy	No construct	No symptoms	0.068	No symptoms	0.120
PVY	No construct	Curling, puckering of leaves, stunting	0.300	Curling, puckering of leaves, stunting	1.12
PVY	HC-PromiR	Curling, puckering of leaves, stunting	0.300	New leaves without symptoms	0.209
Healthy	No construct	No symptoms	0.056	No symptoms	0.041
PVX	No construct	Leaf necrosis	0.507	Leaf necrosis	1.100
PVX	*p*25miR	Leaf necrosis	0.507	New leaves without symptoms	0.229

Unavailability of suitable resistance genes and high ploidy level of crops such as potato make it difficult for breeders to generate resistance for plant pathogens. In this circumstance, pathogen derived resistance along with transgenic approaches are important in managing plant pathogens. siRNA based and miR based transgenic silencing approaches have been tried worldwide to tackle various plant invading viruses. Vaucheret *et al*. (2004) reported that some nucleotides of mature miR sequences of plants can be replaced with some other nucleotides without compromising the biogenesis of miR. Such modified miRNAs are known as artificial microRNAs (amiR) and they can be used to target viruses. In this study the same concept was employed. Many investigators have attempted to improve the resistance efficiency through choice of preponderant precursor backbones, expression of a dimeric amiRNA precursors/amiRNAs (Ai *et al*., 2011; Niu *et al*., 2006). Niu and co-workers in 2006 made the first attempt with miR constructs for *Turnip yellow mosaic virus*.

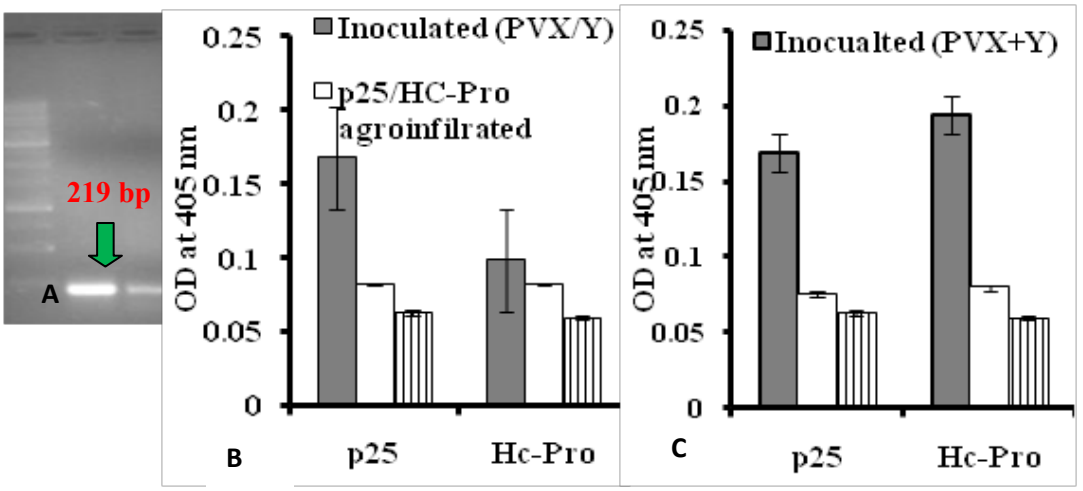


Figure 3. Confirmation of HC-PromiR and *p*25miR constructs in potato leaves (A), Average level of virus concentrations in agro infiltrated potato leaves (either with HC-PromiR or *p*25miR), which were post inoculated with PVY/PVX (B), Average level of virus concentrations in agro infiltrated potato leaves (mixed with HC-PromiR and *p*25miR), which were post inoculated with PVY+PVX (C)

Note: Lane 1 = 1kb ladder, Lane 2 = PVY-HC-PromiR, Lane 3 = PVX-*p*25miR, B & C. Detection of virus concentrations in potato leaves (14dpi), first agro infiltrated with HC-PromiR and *p*25miR constructs followed by challenge inoculated with PVY and PVX singly and doubly. Healthy = Healthy, uninoculated

Qu *et al*. in 2007 showed that the expression of miR was more effective than siRNA in inhibiting virus suppression in *Cucumber mosaic virus*. Jiang and co-workers (2011) designed an artificial microRNA (amiRcp-8) targeting the 30 end region of PVY-CP, which induced a very high virus resistance and they further demonstrated that transgenic plants carrying pre amiRNAs can effectively express 21 nt, mature, functional amiRNAs, which confer a good virus resistance. Zhang *et al.* (2011) showed that artificial micro RNA can generate stable resistance against CMV in tomato. In this study, a similar approach was made.

The results were promising in controlling the virus infection and a significant reduction in the concentrations of PVY and PVX viruses were observed with HC-PromiR and *p*25miR in transient assays with *N. benthamiana* and potato.

Jiang *et al*. (2011) stressed that the siRNA target selection is crucial for achieving a successful virus control in transgenic plants and the best results to avoid the microheterogenecity nature of the pathogen can be achieved selecting highly conserved regions of the sequences. In this study siRNA sequences were carefully selected not only from highly conserved regions but also from highly target specific sequences using *in-silico* analyses. The selected sequences did not show off target attacks and the same was evident phenotypically (data are not shown) by the observation that confirmed none availability of any malformation in the plants (data are not shown), agroinfiltrated with the HC-Pro-miR and *p*25miR in the study.

Qu *et al*. (2007) showed that *Cauliflower mosaic virus* (CaMV) 35S promoter driven miRNA precursor sequence was more effective targeting *2b* of CMV and inhibiting CMV viral activity in transient expression systems and transgenic plants of tobacco than *Pol* III promoter-driven shRNA construct. In this experiment, HC-PromiR and *p*25miR constructs were kept downstream a 35S CaMV promoter and that must have also contributed to the success of constructs in controlling virus level and reducing symptoms in target plants with pre and post infections of PVY and PVX.

When compared to long dsRNA-mediated antiviral silencing, the artificial miRNA strategy is reported with several advantages (Jiang *et al*., 2011). First,

they are friendlier to the environment since only 21 nt portion is used, which is also in naturally occurring viral nature (Garcia and Simon-Mateo, 2006; Qu *et al*., 2007). Second, a long viral cDNA fragment may find a greater homology with host plant genes, creating more off target effects, influencing the expression of plants native genes. In contrast, a small RNA fragment used in a miR based construct minimizes such effects (Duan *et al*., 2008). Third, being small portions of nucleotides, multiple virus-specific miRNAs can be combined together to give protection to multiple viral infections (Niu *et al*., 2006). The constructs used in this study is from plant origin (*Arabidopsis thaliana*), which is naturally involved in RNA silencing mechanism across a number of plant species. Therefore, these constructs are environmental friendly. The siRNA portion of each of construct was only 21 nt long. Therefore, there is less possibility for the construct to aim off targets when compared to larger gene portions used in developing transgenic resistance for plant viruses. Being plant origin and small nt portions the immunity generated by these two constructs may sustain and would not create biosafety problems in the generation of transgenic plants for commercial use. However, further studies at large scale are needed to confirm any other effect of these constructs before commercial use.

CONCLUSIONS

HC-PromiR and *p*25miR constructs are effective in controlling PVY and PVX in single and mixed infections. The constructs are friendlier to the environment since only 21 nt portion has been used and it is also in naturally occurring viral nature and they are effective in reducing PVY and PVX virus loads in already infected (single and mixed) plants. There is less possibility for the construct to aim off-targets when compared to larger gene portions used in developing transgenic resistance for plant viruses. The HC-PromiR and *p*25miR constructs can be used effectively to develop transgenic resistance for Potato virus Y and Potato virus X.

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ESTIMATION OF HETEROSIS, HETEROBELTIOSIS AND GENETIC EFFECT FOR YIELD AND SOME YIELD RELATED AGRONOMIC CHARACTERS IN CHILLI (*Capsicum annuum* L.)

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ABSTRACT

Twelve locally developed F1 hybrids and their parents (10 parents) were selected to study heterosis, heterobeltiosis and genetic effect for yield and some yield related agronomic characters in chilli (Capsicum annuum L.) In a Randomized Complete Block Design with two replicates. The crosses, GK-1 x CAH 218-1, MICH 3-1 x CAH 218-1, MI 1-1 x MI Waraniya 1-1 which recorded significance heterosis for yield were also heterotic for number of pods per plant, pod length, plant height and canopy width. These crosses can be utilized to extract higher yielding breeding lines to develop pure lines with great vigour through generation advancement. Highest heterobeltiosis was shown in the cross, MICH 3-1 x CAH 218-1 for number of pods per plant, plant height and canopy width. The cross, MI 1 x MI Waraniya 1-1 showed the highest mean performance and significant heterosis for yield, number of pods per plant and plant height indicating close agreement between mean performance and heterosis. This positive relationship can be used as one indicator to isolate this cross as a successful hybrid. Numerical values of dominance effect greater than additive effect for yield, plant height, number of pods per plants and pod length in most of the crosses indicated that the genes of those characters are dispersed between parents resulting more segregates in the next generation of selfing.

Key words: chilli, heterosis, heterobeltiosis, genetic effects

INTRODUCTION

Chilli (*Capsicum annuum* L) is grown worldwide both as a spice and as a vegetable crop. It is one of the major condiments in Sri Lanka. The total extent

of green chilli in 2013 was 15,454 ha producing 72,020 mt (DOA, 2013). Since dry chilli production within the country is not sufficient, dry chilli is imported from India and China. Development of open pollinated and hybrid chilli varieties having high productivity and desirable qualities is identified as a key factor to increase the production of chilli within the country.

Exploitation of heterosis has been recognized as a practical tool in providing a means of increasing yield and other economic traits of chilli (Senevirathna and Kannangara, 2004). East and Hays (1912) were the first to advocate heterosis breeding as an alternative crop improvement strategy. In chilli, heterosis was reported by Doshi and Sukula (2000) who observed that heterosis effect is high for number of fruits per plants, fruit length, fruit girth, and fruit shape index and fruit volume. Higher early and total yield, improved chemical composition as well as other morphological features of the fruit are the heterosis effect in chilli (Banga and Banga, 1998). According to Mllawithanachchi *et al.* (2006) high heterobeltiosis was reported for total yield, while heterosis for total number of pods, average pod weight and dry matter percentage was low.

Additive genetic effect and dominant effect are important in genetic analysis. Additive genetic effect is fixable effect and it will not change due to selfing. Dominance effect is an unfixable variation. It will segregate in the next generation on selfing. According to Banga and Banga (1998) both additive and non additive (dominance, overdominance, epistasis) gene effects have been reported to be important with varied extent from character to character. Considering the importance of chilli for Sri Lanka and necessity of developing high yielding open pollinated and hybrid chilli varieties within the country, this study was conducted to study heterosis, heterobeltiosis and genetic effect for yield and some yield related agronomic characters in chilli.

MATERIALS AND METHODS

Location

This experiment was conducted at the Field Crop Research and Development Institute (FCRDI), Sri Lanka. It is located in Mahailluppallama,

DL1b agro-ecological region.

Parent material and seed production of F1 hybrids

Ten inbred lines (GK- 1, MICH 3-1, CAH 218-1, HB-1, MI Waraniya 1-1, CAH 36-1, KA 2-1, 985.3-1, MI Hot-1, MI 1-1) developed at the FCRDI were used as parents to incorporate characters related to yield such as number of pods/plant, pod length, pod diameter, pericarp thickness, plant height and canopy width. These inbred lines were developed using the varieties, MI 1, KA 2, MI Hot (Kannangara, 2003) Galkiriyagama (Kannangara, 2012), MICH 03 (Kannangara *et al.*(2013) and breeding lines, CAH 218, Hot Beauty, CAH 36 and 985.3 (Kannangara, 2003) developed at the FCRDI. Selection of germplasm was done on the basis of previous germplasm evaluation under field conditions at the FCRDI. Thirty day old seedlings of these parental lines were planted in clay pots during *Yala* 2013. Fifteen pots from each parent were maintained inside the net house. Plants were grown under good management conditions providing enough amounts of water and fertilizer according to the recommendation of Department of Agriculture (DOA). Crossing program was started with the onset of flowering. The crosses (MICH 3-1 x GK-1 , MICH 3-1 x CAH 218-1 , GK-1 x CAH 218-1 , HB-1 x MI Hot-1 , MI 1-1 x MI Waraniya 1-1 , MI 1-1 x GK-1 , MI 1-1 x MICH 3-1 , CAH 218-1 x CAH 36-1 , MI 1-1 x CAH 218-1 , MI 1-1 x KA 2-1 , MI 1-1 x 985.3-1 , MI 1-1 x MI Hot-1) were made through hand emasculation and pollination. Pollinated flowers were covered using oil paper bags. Ripened pods were harvested. F1seeds were extracted from ripened pods, separately.

Field experiment

F1 seeds of the crosses and their parents were sown in nursery trays and after thirty days they were transplanted in the field during *Maha* 2013/14. Randomized complete block design with two replicates was adopted. Each plot (6.0 m x 1.8 m) consisted of five rows of plants at the spacing of 60 cm x 60 cm and 2 plants per hill. Each plot contained 100 plants. Well decomposed cattle manure was incorporated before planting at the rate of 500g/per planting hole. Chemical fertilizer application was done according to the recommendation of

DOA. Insecticides and fungicides were applied to protect the crop from pests and diseases. Weed control was done manually. Enough water was supplied throughout the cropping period.

Data recording

Agronomic characters were assessed based on the descriptors published by DOA (DOA, 1995). Harvesting was started 70 days after field planting and continued in 10 days intervals. Number of pods and fresh green chilli yield of F1 hybrids and parents were recorded at each harvesting. The yield was measured using electronic balance. Pod diameter, pericarp thickness were recorded on randomly selected 10 pods from 10 plants from each replicate of each treatment using digital vernier caliper. Pod length, was recorded on randomly selected 10 pods from 10 plants from each replicate of each treatment using a ruler. Height and canopy width of the randomly selected 10 plants from each hybrid and parent were measured using a ruler.

Data analysis

Analysis of variance was done to find whether there is significant difference among hybrids and parents for tested characters. Mean separation was done using Duncan Multiple Range Test (DMRT). Heterosis and heterobeltiosis values for yield and other agronomic characters were calculated using the mean values of the yield and yield related agronomic characters as suggested by Chaudhary *et al.* (2013).

Heterosis = (F1 - MP)/MP) x 100

Where, F1 = mean performance of hybrid, MP = average performance of both parents

Heterobeltiosis = (F1 - BP)/BP) x 100

Where, F1 = mean performance of hybrid, BP = mean performance of better parents.

Significance (p=0.05) of the heterosis and heterobeltiosis values was tested using the t test explained by Wynne *et al.* (1970).

T test for heterosis values

$T = F1ij\text{-}MPij / \sqrt{3/8}\ EMS$

Where, Fij = The F1 hybrid value of i^{th} and j^{th} parents, MPij = Mid parent value of i^{th} and j^{th} parents, EMS = Error mean square for the respective traits.

T test for heterobeltiosis values

$T = F1ij\text{-}BPij / \sqrt{1/2}\ EMS$

Where, Fij = The F1 hybrid value of i^{th} and j^{th} parents, BPij = Best parent value of i^{th} and j^{th} parents, EMS = Error mean square for the respective traits.

Parents and chilli hybrids were analyzed to estimate the genetic components of means according to Chahal and Gosal (2002) by assuming that there is no non-allelic interaction for the characteristics that were tested in the experiment.

Estimation of mid parent value, m

$m = 1/2(AA + aa)$

Where, AA = Average value of respective trait of parent 1, Aa = Average value of respective trait of parent 2.

Estimation of additive genetic component, a

$a = 1/2(AA - aa)$

Where, AA = Average value of respective trait of parent 1, Aa = Average value of respective trait of parent 2.

Estimation of dominant genetic component, d

$d = \bar{F1} - 1/2(AA + aa)$

Where, $\bar{F1}$=Average value of respective trait of the cross, AA = Average value of respective trait of parent 1, Aa = Average value of respective trait of parent 2.

RESULTS AND DISCUSSION

Analysis of variance and mean separation showed significant difference among parents and crosses for the characters (Table 1) studied indicating the sufficient genetic variability, directional dominance and heterosis.

Heterosis and heterobeltiosis for yield and yield related agronomic characters

Heterosis and heterobeltiosis was observed for all the characters. Number of hybrids showing significant heterosis and names of the hybrid on the basis of heterosis and heterobeltiosis are shown in Table 2. The number of crosses, which indicated significant heterosis among the twelve crosses, were 6 for yield, 4 each for pod length and plant height, 9 for number of pods/ plant, 8 for canopy width, 2 for pod diameter and 1 for pericarp thickness. The number of crosses, which indicated significant heterobeltiosis were 4 each for plant height and canopy width, 3 for yield, 7 for number of pods/ plant. None of the crosses exhibited significant heterobeltiosis for pod length, diameter and pericarp thickness (details are given in Appendix 1). Significant heterosis observed for yield, number of pods per plant and pod length was high and was in varying proportion probably due to dominance gene effect rather than additive gene effect. According to Ahmed and Muzafar (2000) heterosis observed for most of the characters, plant height, plant spread, branch number, fruit length, fruit weight, fruit girth, pericarp thickness, fruit number and fruit yield was high and was in varying proportion. The cross, MI 1-1 x MI Waraniya 1-1 showed highest mean performance and significant heterosis for the characters, yield, number of pods/plant and plant height indicating close agreement between mean performance and heterosis. This positive relationship can be used as one indicator to isolate this cross as successful hybrid. The top heterotic cross for the pod length, MICH 3-1 x CAH 218-1 had significant heterosis for yield, number of pods/per plant, plant height and canopy width. Similar pattern of heterosis was observed by Ahmed and Hurra (2000) in sweet pepper. The cross combination, GK-1 x CAH 218-1 showed significant heterosis for yield and number of pods/plant. Six hybrids over mid parent and 3 hybrid over better parent exhibited positive heterosis for yield. The heterosis was high as 87 % (GK-1 x CAH 218-1) and heterobeltiosis was high as 48 % (MI 1-1 x 985.3-1),

Table 1. Means of yield and some yield related agronomic characteristics of parents and F1 hybrids

Crosses	Yield t/ha	Pod length (cm)	Pod diameter (mm)	Pericarp thickness(mm)	Number of pods per plant	Plant height (cm)	Canopy width (cm)
MICH 3-1 x GK -1	8.31bcdef	8.8c	13.1bcdef	1.6abcd	105defg	46.3bc	47.35def
MICH 3-1 x CAH 218-1	7.79cdef	8.8c	10.9ijk	1.5bcde	127cdefg	66.1ab	56.3bc
GK-1 x CAH 218-1	10.10bcde	8.4c	11.4ghij	1.2cde	187bcd	57.9abc	45.5efg
HB-1 x MI HOT-1	7.92cdef	10.0bc	12.1efgh	1.6abcd	117cdefg	54.7abc	45.25efg
MI 1-1 x MI Waraniya1	35.66a	13.2ab	13.6bcd	1.8abc	353 a	75.8a	34.4jk
MI 1-1 x GK-1	12.22bcd	9.1c	11.8fghi	1.2cde	193bcd	49.6bc	61.05ab
MI 1-1 x MICH 3-1	9.54bcdef	9.3c	11.9fgh	1.6abcde	140bcdef	46.1bc	50cde
CAH 218-1 x CAH 36-1	4.76ef	10.7bc	11.4ghi	1.4bcde	49g	68.3ab	44.15efgh
MI 1-1 x CAH 218-1	7.09def	8.6c	9.48l	0.95e	132cdefg	54.5abc	54.45bcd
MI 1-1 x KA 2-1	12.84bcd	8.9c	11.19ijkh	1.19cde	159bcde	49.15bc	42.8efghi
MI 1-1 x 985.3-1	15.03b	9.7bc	12.72cdefg	1.32bcde	143bcdef	51.6bc	42.25fghi
MI 1-1 x MI Hot-1	14.01bc	8.25c	11.36ghij	1.24cde	217bc	53.6abc	41.65fghij
Parents	**Yield t/ha**	**Pod length (cm)**	**Pod diameter (mm)**	**Pericarp thickness(mm)**	**Number of pods per plant**	**Plant height (cm)**	**Canopy width (cm)**
GK-1	7.60cdef	8.7c	12.5cdefgh	1.5bcde	128cdefg	49.8bc	41.2fghij
MICH 3-1	5.32ef	6.7cd	13.5bcde	1.4bcde	78efg	39.9c	36.6hijk
CAH 218-1	3.20f	4.5d	9.8kl	1.2cde	63efg	50.9bc	39.1ghijk
HB-1	4.74ef	10.5bc	14.2b	1.7abc	61efg	35.7c	34.7jk
MI Waraniya 1-1	34.61a	15.8a	18.5a	2.1a	253 b	64.9ab	63.7a
MI 1-1	10.17bcde	7.5cd	10.0jkl	1.0de	113defg	46.6bc	50.2cde
CAH 36-1	4.55ef	10.5bc	13.9bc	1.9ab	36g	54.1abc	31.7k
KA 2 -1	6.77def	7.3cd	11.1ijkh	1.4bcde	107defg	37.0c	35.6ijk
985.3 -1	9.48bcdef	10.1bc	14.2b	1.5bcde	99defg	49.8bc	46.8ef
MI Hot -1	9.43bcdef	7.5cd	12.46defgh	1.41bcde	140bcdef	51.5bc	45.3efg
CV%	25.53	17.4	5.04	17.59	31.19	18.48	7.11

Note: Within the column, the means followed by the same letters are not significantly different at p=0.05

Table 2. Number of hybrids and names of the hybrids showing significant heterosis and heterobeltiosis

Characters	No.of hybrids showing significant heterosis	Names of the hybrids showing significant heterosis and heterosis %	No.of hybrids showing significant heterobeltiosis	Names of the hybrids showing significant heterobeltiosis and heterobeltiosis %
Yield (t/ha)	6	GK-1 x CAH 218-1 (87), **MICH 3-1 x CAH 218-1** (83), MI 1-1 x MI Waraniya 1-1 (59), **MI 1-1 x 985.3-1** (53), MI 1-1 x KA 2-1 (52), **MI 1-1 x MI Hot-1** (43)	3	MICH 3-1 x CAH 218-1 (46), MI 1-1x MI Hot-1 (38), MI 1-1 x 985.3-1 (48)
Number of pods per plant	9	**MI 1-1 x MI Waraniya 1-1** (103), **GK-1 x CAH 218-1 (96)**, **MICH 3-1 x CAH 218-1** (80), **MI 1-1 x GK-1 (60)**, MI 1-1 x MICH 3-1(46), MI 1-1 x CAH 218-1 (50), **MI 1-1 x KA 2-1** (45), **MI 1-1 x 985.3-1** (35), **MI 1-1 x MI Hot-1**(71)	7	MICH 3-1 x CAH 218-1 (63), MI 1-1 x GK-1 (51), MI 1-1 x MI Waraniya 1-1 (50),GK-1 x CAH 218-1 (46), MI 1-1 x KA 2-1 (41), MI 1-1 x 985.3-1 (26), MI 1-1 x MI Hot-1 (55)
Pod length (cm)	4	MICH 3-1 x CAH 218-1 (55), MI 1-1 x MICH 3-1 (30), CAH 218-1 x CAH 36-1 (43), MI 1-1 x CAH 218-1 (44)	0	-
Pod diameter (mm)	2	MI 1-1 x KA 2-1 (6), MI 1-1 x 985.3-1 (5)	0	-
Pericarp thickness (mm)	1	MI 1-1 x MICH 3-1 (32)	0	-
Plant height (cm)	4	**MICH 3-1 x CAH 218-1** (46), HB-1 x MI Hot-1 (25), **MI 1-1 x MI Waraniya 1-1** (36), **CAH 218-1 x CAH 36-1** (30)	4	MICH 3-1 x CAH 218-1 (30), GK-1 x CAH 218-1 (14), MI 1-1 x MI Waraniya 1-1 (17), CAH 218-1 x CAH 36-1 (26)
Canopy widh (cm)	8	**MICH 3-1 x GK-1** (22), **MICH 3-1 x CAH 218-1** (49), GK-1 x CAH 218-1 (13), HB-1 x MI Hot-1 (13), **MI 1-1 x GK-1** (33), MI 1-1 x MICH 3-1 (15),**CAH 218-1 x CAH** 36-1 (25), MI 1-1 x CAH 218-1 (22)	4	MICH 3-1 x GK-1 (15), MICH 3-1 x CAH 218-1 (44), MI 1-1 x GK-1 (22), CAH 218-1 x CAH 36-1 (13)

Note: Bolt figures indicate crosses of both heterosis and heterobeltiosis

respectively. The cross, MI 1-1 x MI Waraniya 1-1 exhibited significant heterosis and heterobeltiosis for number of pods/plant with value of 103 % and 50% respectively and the crosses, MICH 3-1 x CAH 218-1 , MI 1-1 x MI Hot-1, MI 1-1 x GK-1 exhibited significant heterobetiosis for the same character with the value of 63%, 55% and 51%, respectively. The cross MICH 3-1 x CAH 218-1 showed significant heterobeltiosis for yield, number of pods/plant, plant height and canopy width with the value of 46%, 63%, 30% and 44%, respectively. The crosses, especially GK-1 x CAH 218-1, MICH 3-1 x CAH 218-1, MI 1-1 x MI Waraniya 1-1 heterotic for yield and most of the yield related characters like number of pods/plant, pod length, plant height and canopy width. Since, yield and most of the yield related agronomic characters are positively associated, it indicates that high heterosis observed for yield in many crosses is a result of combined heterosis of yield and yield related agronomic characters.

Additive genetic component [a] and dominant genetic component [d]

Numerical values of additive genetic component [a] and dominant genetic component [d] indicated existence of both additive and dominant gene action in the expression of the yield and tested agronomic characters (Table 3). The number of crosses, which exhibited higher numerical value of [d] than [a] were 9 each for yield and plant height, 7 for pod length, 8 for number of pods/plant, 5 for canopy width, 3 for pericarp thickness, 2 for pod diameter.

Numerical values of [d] greater than [a] for yield, plant height, number of pods/plants and pod length in most of the crosses indicate that the genes of those character are dispersed between parents resulting more segregates in the next generation of selfing. Higher numerical value of [a] than [d] for pod diameter and pericarp thickness in the 10 crosses and 9 crosses, respectively indicated the less possibility of segregates in the next generation of selfing. Singh and Singh (1978) told that morphological characters of chilli with none additive gene effect (dominance, overdominance, epistais) are total yield, plant height, number of fruits/ plant and days to maturity. According to Hasanuzzaman and Farug Golam (2011) all three type of gene action, additive, dominance and interaction components were found to play a role in the inheritance of fruit length, fruit width and number of pod/plant of chilli.

Table 3. Genetic effect of yield and some yield related agronomic characteristics of chilli estimated using the F1 hybrids and the parents

Cross	Characteristics							
	Genetic effect	**Yield (t/ha)**	**Pod Length (cm)**	**Pod Diameter (mm)**	**Pericarp Thickness (mm)**	**Number of pods per plant**	**Plant Height (cm)**	**Canopy Width (cm)**
1.MICH 3-1 x GK-1	M	6.46	7.79	13.01	1.44	103	44.87	38.95
	[a]	1.14	0.95	0.5	0.06	25	4.92	2.3
	[d]	1.85	0.07	0.02	0.15	1	1.48	8.4
2.MICH 3-1 x CAH 218-1	m	4.26	5.66	11.66	1.28	70	45.42	37.85
	[a]	1.06	1.17	1.85	0.09	7.5	5.47	1.2
	[d]	3.52	3.09	-0.73	0.18	57	20.68	18.45
3.GK-1 x CAH 218-1	m	5.4	6.61	11.16	1.34	96	50.35	40.15
	[a]	2.2	2.12	1.35	0.16	32.5	0.55	1.1
	[d]	4.7	1.72	0.25	-0.11	92	7.6	5.35
4.HB-1 x MI Hot-1	m	7.08	9.00	13.36	1.56	100	43.6	40.02
	[a]	2.34	1.52	0.89	0.15	40	7.9	5.32
	[d]	0.84	1.04	-1.21	0.03	17	11.1	5.23
5.MI 1-1 x Waraniya 1-1	m	22.38	11.65	14.26	1.55	174	55.77	57
	[a]	12.22	4.17	4.27	0.55	61	9.17	6.75
	[d]	13.28	2.05	-0.62	0.21	179	20.08	-22.6
6.MI 1-1 x GK-1	m	8.88	8.11	11.25	1.25	120	48.2	45.75
	[a]	1.28	0.63	1.26	0.25	7.5	1.6	4.5
	[d]	3.34	0.97	0.59	-0.04	73	1.45	15.3
7.MI1-1 x MICH 3-1	m	7.74	7.16	11.75	1.19	95	43.27	43.45
	[a]	2.42	0.32	1.76	0.18	18	3.32	6.8
	[d]	1.8	2.16	0.18	0.38	44	2.88	6.55
Cross	**Characteristics**							
	Genetic effect	**Yield (t/ha)**	**Pod Length (cm)**	**Pod Diameter (mm)**	**Pericarp Thickness (mm)**	**Number of pods per plant**	**Plant Height (cm)**	**Canopy Width (cm)**
8.CAH 218-1 x CAH 36-1	m	3.87	7.49	11.88	1.56	50	52.47	35.4
	[a]	0.67	3	2.07	0.38	13.5	1.57	3.65
	[d]	0.89	3.24	-0.44	-0.18	-1	15.8	8.75
9.MI 1-1 x CAH 218-1	m	6.68	5.98	9.90	1.09	88	48.75	44.65
	[a]	3.48	1.49	0.09	0.09	25.5	2.15	5.6
	[d]	0.41	2.65	-0.42	-0.14	45	5.75	9.8

Table 3 Continued

10.MI 1-1 x KA 2-1	m	8.46	7.41	10.56	1.21	110	41.8	42.92
	[a]	1.69	0.06	0.57	0.21	3.5	4.8	7.32
	[d]	4.37	1.45	0.63	-0.02	53	7.35	-0.12
11.MI 1-1 x 985.3-1	m	9.82	8.78	12.12	1.25	106	48.22	48.55
	[a]	0.34	1.3	2.12	0.24	7	1.62	1.7
	[d]	5.21	0.94	0.6	0.07	37	3.38	-6.3
12.MI 1-1 x MI Hot-1	m	9.79	7.48	11.23	1.20	126	49.05	47.8
	[a]	0.37	0	1.23	0.2	13.5	2.45	2.45
	[d]	4.21	0.77	0.13	0.04	91	4.55	-6.15

m = Mid parent value, [a] = Additive genetic effect, [d] = Dominance effect

Negative [d] value for the pericarp thickness in the crosses, GK-1 x CAH 218-1, MI 1-1 x GK, MI 1-1 x CAH 218-1, MI 1-1 x KA 2-1 will provide an opportunity to extract chilli breeding lines with less pericarp thickness suitable for developing chiilli varieties suitable for dry chilli production.

CONCLUSIONS

In the study, none of the crosses was consistent for all the tested characters in case of heterosis and heterobeltiosis. Majority of the crosses showed considerable amount of heterosis in desired direction. The hybrids namely, GK-1 x CAH 218-1, MICH 3-1 x CAH 218-1, MI 1-1 x MI Waraniya 1-1 which revealed higher positive heterosis for yield and yield contributing characters can be utilized to extract higher yielding breeding lines to develop pure lines with great vigour through generation advancement. The cross MI 1-1 x MI Waraniya 1-1 can be utilized for further testing of adaptability to release as a chilli F1 hybrid. Since, both additive and dominant gene actions are presence, pedigree breeding with recurrent selection can be used to extract both dominant and additive genetic effect simultaneously in the improvement of chilli.

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APPENDIX 1

Appendix 1. Heterosis (%), Heterobeltiosis (%) of yield and yield related agronomic characteristics of F1 hybrids.

Cross	Yield t/ha		Pod length cm		Pod diameter		Pericarp thickness	
	Heterosis	HB	Heterosis	HB	Heterosis	HB	Heterosis	HB
MICH 3 X GK	28.6	9.34	13.12	0.85	0.15	-3.58	10.41	5.64
MICH 3 X CAH 218	82.75 *	46.29*	55.00*	28.34	-6.32	-19.15	14.4	6.54

Apendix 1 continued								
GK X CAH 218	87.05*	32.9	26.30	-4.4	2.21	-8.79	-8.55	-18.27
HB X MI Hot	11.75	-16.00	11.58	-4.51	-9.05	-14.76	1.75	-7.53
MI 1 X MI Waraniya 1	59.28*	3.04	12.97	-16.82	-4.36	-26.38	13.00	-16.58
MI 1 X GK	37.56	20.19	12.02	3.94	5.22	-5.35	-3.18	-19.26
MI 1 X MICH 3	23.26	-6.1	30.19*	24.66	1.5	-11.72	31.93*	14.18
CAH 218 X CAH 36	22.87	4.66	43.20*	2.23	-3.74	-18.02	-11.68	-28.86
MI 1 X CAH 218	6.14	-30.23	44.27*	15.44	-4.29	-5.15	-12.78	-19.40
MI 1 X KA 2	51.55*	26.7	19.55	18.51	5.93*	0.49	-1.64	-16.14
MI 1 X 985.3	52.99*	47.87*	10.67	-3.61	4.95*	-10.70	6	-11.37
MI 1 X MI Hot	42.97*	37.77*	10.32	10.28	1.2	-8.82	2.69	-12.05

* - Significance (p=0.05), HB= Heterobeltosis

Appendix 2. Heterosis (%), Heterobeltiosis (%) of yield related agronomic characteristics of F1 hybrids.

Cross	**Number of pods/plant**		**Plant height cm**		**Canopy width**	
	Heterosis	**HB**	**Heterosis**	**HB**	**Heterosis**	**HB**
MICH 3 X GK	1.39	-18.51	3.28	-6.92	21.56*	14.78*
MICH 3 X CAH 218	79.78*	62.57*	45.51*	29.86*	48.74*	44.17*
GK X CAH 218	96.36*	46.39*	15.09	13.58*	13.32*	10.30
HB X MI Hot	16.6	-16.4	25.45*	6.21	13.05*	-0.22
MI 1 X MI Waraniya 1	102.78*	50.39*	35.99*	16.78*	-39.64	-46.03
MI 1 X GK	59.91*	50.75*	3.00	-0.30	33.44*	21.49*
MI 1 X MICH 3	46.08*	23.15	6.64	-0.9	15.07*	-0.49
CAH 218 X CAH 36	-9.03	-22.08	30.10*	26.30*	24.71*	13.06*
MI 1 X CAH 218	50.17*	16.72	11.79	7.07	21.94*	8.35
MI 1 X KA 2	44.96*	40.86*	17.58	5.47	-0.29	-14.82
MI 1 X 985.3	34.63*	26.06*	6.99	3.51	-12.97	-15.92
MI 1 X MI Hot	71.2*	54.95*	9.27	4.07	-12.86	-17.11

* - Significance (p=0.05), HB= Heterobeltosis

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ELUCIDATION OF SPATIAL VARIABILITY OF SALINITY OF SOILS IN A RICE - OTHER FIELD CROPS CROPPING SYSTEM USING PROXIMAL SOIL SENSING

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ABSTRACT

Soil salinity is traditionally measured on the basis of the electrical conductivity of the saturation extract of the soil (EC_e). However, ECe measurement is laborious and thus not practically feasible for spatial characterization which requires large number of observations. The proximal sensing is an evolving technology to quantify soil parameters in quick, reliable and cost effective manner. A study was conducted to assess the potential of proximal sensing of soil apparent electrical conductivity (EC_a) for spatial characterization of salinity of soils in a rice - OFCs cropping system in the Dry zone of Sri Lanka. A site of approximately five hectares was selected in Thalawa area where rice - OFCs cropping system has been practiced for around thirty years. The Dualem - 1S proximal soil sensor was used to measure the EC_a and the measurements were taken before the commencement of *Maha* 2014-15. Soil samples representing top (0 - 40 cm) and subsoil (40 - 80 cm) were collected at 30 locations that identified using Conditional Latin Hypercube sampling technique. Geographical Information System (GIS) maps showing the spatial variability patterns of EC_a were constructed using Ordinary Kriging procedure using Idrisi Kilimanjaro software. Subsequently, the Regression Kriging procedure was used to develop the EC_e maps. Independent samples of top and subsoils (n = 10, each) were collected randomly and their EC_e were measured to be used for the accuracy assessment of the EC_e prediction models. EC_a survey resulted in 30,586 measurements of EC_{aPRP} and EC_{aHCP}. The EC_{aPRP} ranged from 0.2 to 123.7 mS/ m, whereas the EC_{aHCP} ranged from 8.6 to 134.2 mS/ m and both data were normally distributed. The prediction models with linear

regression relationships, 'EC_e = 0.5 EC_{aPRP} + 0.248' and 'EC_e = 0.3 EC_{aHCP} + 0.238' were found best for the prediction of topsoil and subsoil EC_e (dS/ m) respectively, using proximally sensed EC_a (dS/ m). The predicted EC_e of both top and subsoils ranged from around 0.30 dS/ m to around 0.80 dS/ m. Strong correlations were found between both topsoil EC_e and EC_{aPRP} (r = 0.89) and subsoil EC_e and EC_{aHCP} (r = 0.80). Strong correlations found between predicted and observed EC_e both in top (r = 0.96) and subsoils (r = 0.98) together with the other validation indices proved the more applicability of using the developed models for EC_e prediction in both top and subsoils. Further, Fuzzy k-mean classification algorithm was used to demarcate the potential salinity hazard zones using the GIS based FuzMe software and three optimal salinity classes were identified for both top and subsoils. The study indicates a strong potential of proximal sensing of apparent electrical conductivity as a promising tool for spatial prediction of salinity in Low Humic Glay soils (Typic Endoaqualfs) in rice - other field crops cropping system in the Dry zone of Sri Lanka.

Keywords: Proximal soil sensing, spatial variability of salinity

INTRODUCTION

Mahaweli irrigation scheme is one of the main irrigation systems in Sri Lanka under which, the rice - other field crops (OFCs) cropping system is commonly practiced in the dry zone. Other field crops such as chilli, maize, big onion and legumes are cultivated in a considerable land extent under supplementary irrigation in paddy lands during the *Yala* season whereas rice is cultivated in both *Yala* and *Maha* seasons. Soil salinization or accumulation of soluble salts, namely Na^+,Mg^{++}, Ca^{++}, K^+, Cl^-, $SO_4^=$, HCO_3^-, NO_3^- and $CO_3^=$ (FAO, 1999) in soil is a major problem associated with irrigation agriculture worldwide. Salinity problems have been reported in a number of irrigated areas in the Dry zone of Sri Lanka (Matsumo *et al*., 1998). A large extent of rice lands (about 150,000 ha) in the coastal areas and the major irrigation schemes in the island have become low productive due to high salinity conditions in the soil (Sirisena and Abeysiriwardena, 2005). Nayakkorala (1998) reported the development of salinity in some of the agricultural lands of the Mahaweli irrigation systems.

Salts in the soil solution can impose a stress to plants by reducing evapotranspiration by making soil water less available for plant root extraction. In addition, some salts cause toxic effects in plants and can reduce plant metabolism and growth (FAO, 1998). Impacts of salts in the soil include toxicities of sodium and chloride and induced nutrient deficiencies. These deficiencies reduce plant growth by reducing the rate of leaf elongation, the enlargement, and the division of cells in leaves and finally the loss of crop yields (FAO, 1998). Bandara (1998) recorded the importance of local-scale hydrological studies addressing the inland salinity caused by improper management of soil drainage, salinity intrusion of surface water and ground water and drainage problems in agriculture. Emerging water quality and salinity problems in Mahaweli areas are some of the consequences of inadequate water-related research in the country (Bandara, 1998). Hence, to ensure the productivity of irrigated lands of the Dry zone there is an urgent need to spatially characterize the areas affected by salinity.

Soil salinity is traditionally measured and expressed on the basis of the electrical conductivity of the saturation extract of the soil (EC_e). Crop yields begin to drop when a threshold electrical conductivity of the saturation soil water extract ($EC_{ethreshold}$) is reached (FAO, 1998). However, EC_e measurement is laborious and time consuming, thus not practically feasible for spatio-temportal characterization of salinity which requires a large sample size. The proximal sensing is an evolving technology to quantify soil parameters in quick, reliable and cost effective manner (Corwin and Lesch, 2005). Electromagnetic Induction (EMI) based soil apparent electrical conductivity (EC_a) measurements is one of widely used soil proximal soil sensing methods. Apparent soil electrical conductivity is influenced by a combination of physico-chemical properties including soluble salts, clay content and mineralogy, soil water content, bulk density, organic matter, and soil temperature (Corwin and Lesch, 2005). Therefore, there is a considerable potential to use EMI based EC_a sensing to assess soil salinity effectively. However, soil specific prediction model development is essential to infer EC_e values from EC_a measurements (Corwin and Lesch, 2005).

Studies have shown that the proximal soil sensing of EC_a is a very

satisfactory method for explaining the soil variability at field scale (Vitharana, 2008). Vitharana (2008) further reported that the usage of proximal sensing techniques for EC_a for soil mapping is worthwhile. Sharma and Gupta (2000) reported that with proper calibration of the proximal sensor EM 38, can lead for a quick diagnostic survey of soil salinity in India. Chaudhry and Baig (2000) concluded that EM38 can be used successfully for EC_a determination up to 150 cm depth of soil, which is the range of active root zone for almost all crops grown in Pakistan. Bandara (1998) recommended harnessing more modern electronic technology for upgrading water related research also in Sri Lanka.

Geonics EM38 (G-EM38) and Dualem 1S (D-1S) sensors are used frequently for assessment of soil salinity and other soil characteristics by electromagnetic induction technique in agriculture and could be used interchangeably with similar results (Urdano and Aragues, 2012). Taylor (2011) reported that the shallower-sensing Dualem-1S was introduced in 2004 to address applications in agriculture and since then, a growing number of soil scientists were publishing results using Dualem instruments with accurate data. It is timely very important to study the applicability of proximal sensing of EC_a for assessing the soil salinity and other soil characteristics also in Sri Lanka. This study was conducted to assess the potential of proximal sensing of EC_a for spatial characterization of salinity of soils in a rice-OFCs cropping system in the Dry zone of Sri Lanka.

MATERIALS AND METHODS

Site selection

A five hectares study site was selected (8^0 14' 12.87" N, 80^0 17' 41.50" E) in Thalawa area that belongs to Mahaweli 'H' Zone. The preliminary information from farmers revealed a salinity development in the study area. This was further confirmed by the analysis results of EC (soil : water - 1 : 5) measured in a limited number of samples. The study site belongs to the DL_{1b} agro-ecological region where rice-OFCs cropping system has been practiced for about thirty years period. The dominant soil subgroup is Low Humic Gley (Typic Endoaqualfs) (Mapa *et al*., 2010).



Plate 1: Boundary of studied area at Thalawa posted on a satellite image

Apparent electrical conductivity survey

The Dualem-1Sproximal soil sensor was used to measure the apparent electrical conductivity. Sensor measurements were taken before the commencement of *Maha* 2014 - 15 season (October, 2014) at a measurement configuration of 2m x 2m. Soil temperature measurements were also taken during EC_a survey. The Dualem-1Ssensor provides simultaneous measurement of surface soil and subsurface EC_a through horizontal (EC_{aHCP}) and perpendicular (EC_{aPRP})co-planner measurements. The Universal Transverse Mercator (UTM) coordinates of EC_a measurements were automatically recorded by a Global Positioning System (GPS) receiver embedded with the Dualem - 1S sensor.

Geographical Information System (GIS) maps showing the spatial variability patterns of EC_{aPRP} and EC_{aHCP} were constructed using Ordinary Kriging procedure with the help of Idrisi Kilimanjaro software (Vitharana, 2008). Conditional Latin Hypercube sampling technique (Minasny and McBratney, 2005; Vitharana, 2008) was used to select 30 sampling sites that represent the feature space comprised of 30,586 measurements of EC_{aHCP} and EC_{aPRP}. Top (0 - 40 cm) and subsoils (40 - 80 cm) were collected from each sampling site using the Gouge auger. The UTM coordinates were recorded using Germin Etrax (Germin Ink. USA) GPS receiver. Electrical conductivity of those samples were determined in soil-water suspension (1 : 5). Electrical conductivity of saturated extract (EC_e)

is the recommended soil parameter to identify salt affected soils. However, the determination of EC_e is time consuming and laborious. Thus, a sub sample (n=10) representing low to high EC_a was selected and their EC_e were determined. Afterwards, the regression relationship between electrical conductivities at soil : water of 1 : 5 and EC_e was investigated. The resultant regression mode was used to determine EC_e of the rest of the collected soil samples. These measurements were used to develop the models for soil salinity predictions and subsequently, EC_e maps for top and subsoils using Regression Kriging procedure with the help of Idrisi Kilimanjaro software (Vitharana, 2008).

Model validation

Independent samples of top and subsoils (n=10, each) were collected randomly and their EC_e were measured. These values of EC_e were used for the accuracy assessment of the EC_e prediction models of both top and sub soils. The Mean Estimation Error (MEE), Mean Square Estimation Error (MSEE) and Root Mean Squared Estimation Error (RMEE) were calculated using the following equations (Equations 1, 2 and 3) and used as validation indices.

$$MEE = 1/n \sum^{n}_{(a=1)}(z^*(xa)-z(xa)) \quad (1)$$

$$MSEE = 1/n \sum^{n}_{(a=1)}(z^*(xa)-z(xa))^2 \quad (2)$$

$$RMSEE = \sqrt{(1/n \sum^{n}_{(a=1)}(z^*(xa)-z(xa))^2} \quad (3)$$

where z(x) denotes observations and z(x) denotes corresponding estimations* (Vitharana, 2008; Cockx, 2010).

Demarcating the potential salinity hazard zones

Fuzzy k-mean classification algorithm was used to demarcate the potential salinity hazard zones using the FuzMe software (Vitharana, 2008). Fuzzy k-means classification partitions objects into continuous classes of management zones forming diffuse boundaries between classes overcoming the weakness of classical approach which classify the objects into hard classes on the basis of predefined class boundaries (Vitharana, 2008).

RESULTS AND DISCUSSION

Spatial variability of EC_a

Descriptive statistics of EC_a measurements are given in the Table 1. The Kolmogorov-Smirnov test for normality indicated normal distributions (< 0.01 level of probability) associated with both ECa_{PRP} and EC_{aHCP} measurements. This was confirmed by the relatively smaller (< 1.0) coefficients of skewness boundaries (Vitharana, 2008).

Table 1. Summary statistics of EC_a (mS/ m) measurements (n = 30,586)

	Mean	Median	Min	Max	Stdev	CV (%)	Skewness
EC_{aPRP}	38.5	34.7	0.2	123.7	19.1	49.6	0.87
EC_{aHCP}	50.3	47.4	8.6	134.2	22.9	45.5	0.63

The interpolated maps showing the spatial distribution of EC_{aPRP} and EC_{aHCP} are shown in the Plates 2 and 3, respectively. Lower ECa_{PRP} and EC_{aHCP} values were recorded in the Northern, the North-Eastern and the Eastern parts while higher ECa_{PRP} and EC_{aHCP} values were recorded in the Western and the South-Eastern parts of the site. Ninety nine percent of the data points (total data points = 30,586) showed the ratio between ECa_{PRP} and EC_{aHCP} was less than 1.0 indicating the presence of higher conductive subsoil in the study area. A strong correlation (r = 0.96) was observed between ECa_{PRP} and EC_{aHCP} indicating similar patterns of spatial variability in conductivity of both top and subsoils within the field.

Relationship between EC_e and EC - Soil : Water (1 : 5)

There was a strong correlation(r = 0.94) between ECe and EC - Soil : Water (1 : 5) in the land block at Thalawa. The regression relationship between EC_e and EC - Soil : Water (1 : 5) is shown in the Figure 1. This linear regression relationship was used in determination of EC_e of the rest of the soil samples.

Development of prediction models of EC_e

Strong correlations were found between both topsoil EC_e and EC_{aPRP} values (r = 0.89) and subsoil EC_e and EC_{aHCP} values (r = 0.80). Moreover, regression models fitted between EC_e and proximally sensed EC_{aHCP} suggested that the latter can be used as a covariate to characterize the soil salinity status of the study area (Figures 2 and 3).

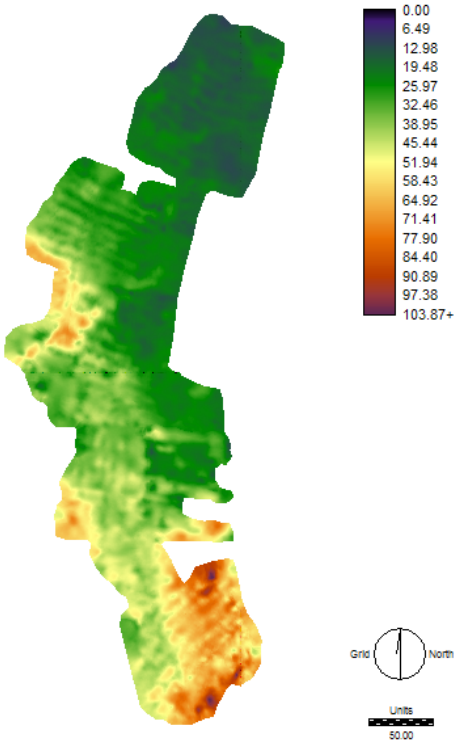


Plate 2: Spatial distribution of EC_{aPRP} (mS/ m)

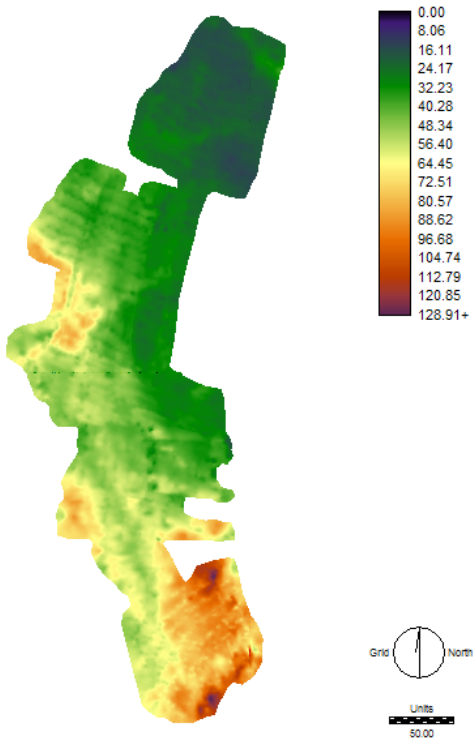


Plate 3: Spatial distribution of EC_{aHCP} (mS/ m)

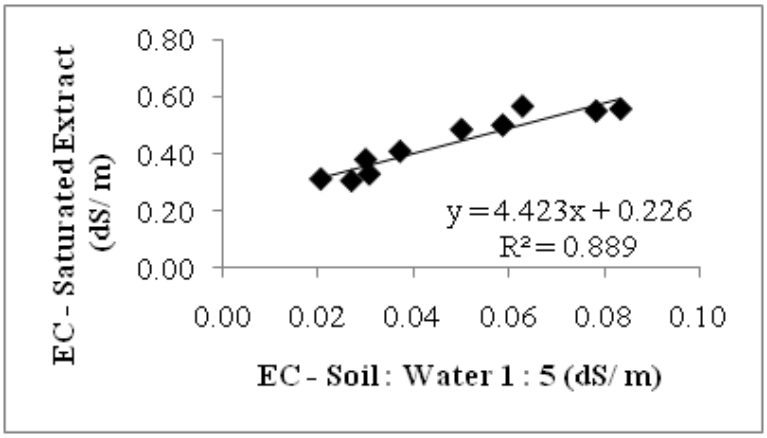


Figure 1: Regression relationship between ECe and and EC - Soil : Water (1 : 5)

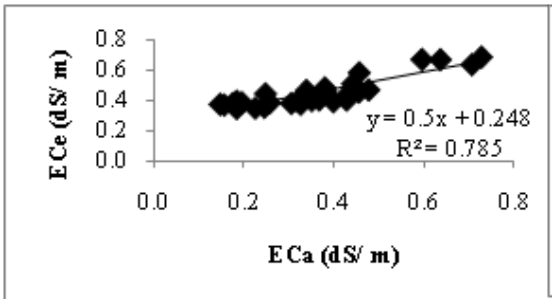


Figure 2: Regression relationship between topsoil EC_e and EC_{aPRP}

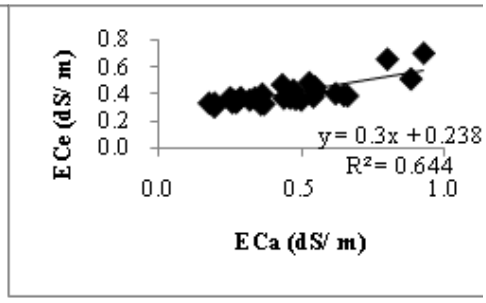


Figure 3: Regression relationship between subsoil EC_e and and EC_{aHCP}

The following prediction models with linear regression relationships (Equations 4 and 5) were found best for the prediction of topsoil and subsoil EC_e using proximally sensed EC_a.

Topsoil $EC_e = 0.5\ EC_{aPRP} + 0.248$.....(4)
Subsoil $EC_e = 0.3\ ECa_{HCP} + 0.238$.....(5)

where EC_e, EC_{aPRP} and ECa_{HCP} in dS/ m

EC_e maps of the top and subsoils were developed using the above prediction models by the Regression Kriging interpolation technique (Plates 4 and 5).

EC_e of both top and subsoils ranged from around 0.30dS/ m to around 0.80dS/ m. Previous studies indicated an average EC_e of 0.20 dS/ m in Low Humic Gley soils (Typic Endoaqualfs) in Hurathgama series in Medawachchiya - Ranorawa - Elayapattuwa - Hurathgama - Nawagaththegama soil association (Mapa *et al*., 2010). Even though most of the EC_e levels were well below the threshold levels, some zones within the surveyed land block were showing higher EC_e levels (EC_e of around 0.80 dS/ m) closer to the threshold levels of most the crops grown in the rice - OFCs cropping system in the Dry Zone (FAO, 1998).

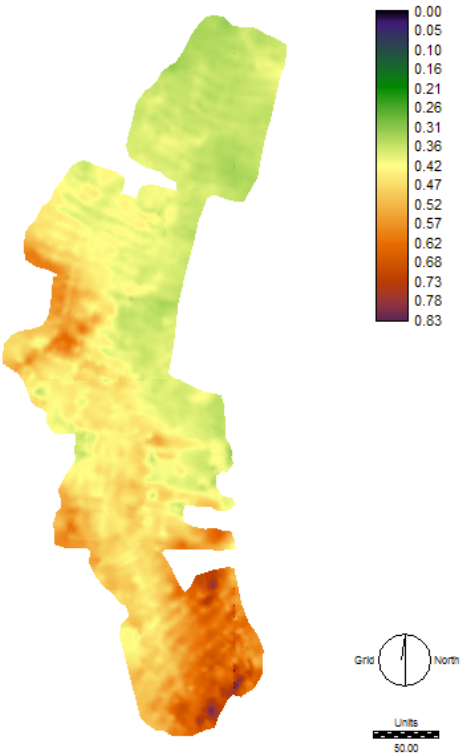


Plate 4:EC_e (dS/ m) map of the topsoil

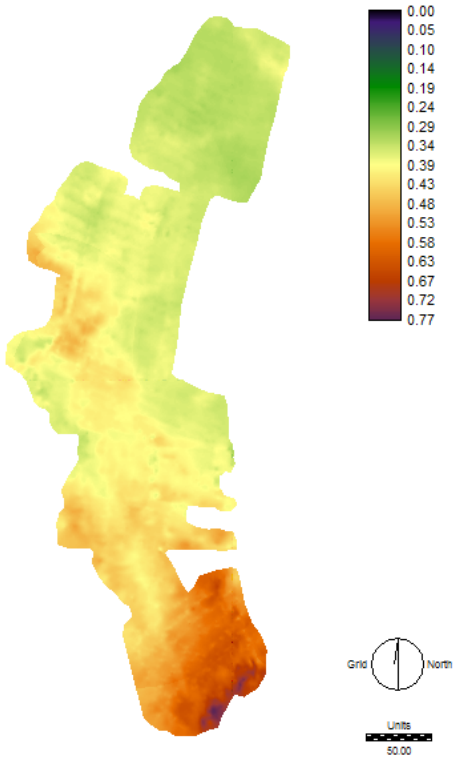


Plate 5: EC_e (dS/ m) map of the subsoil

Validation of the prediction models

Strong correlations were found between predicted and observed EC_e both in top and subsoils combined with very low values for validation indices; MEE,

MSEE and RMSEE (Table 2). It showed a great potential of using the developed models for the prediction of EC_e in both top and subsoils. Vitharana (2008) and Cockx (2010) also mentioned that the higher correlation coefficients (r = near 1.0) combined with very low values for validation indices (near 0.0) indicate the higher accuracy of prediction models.

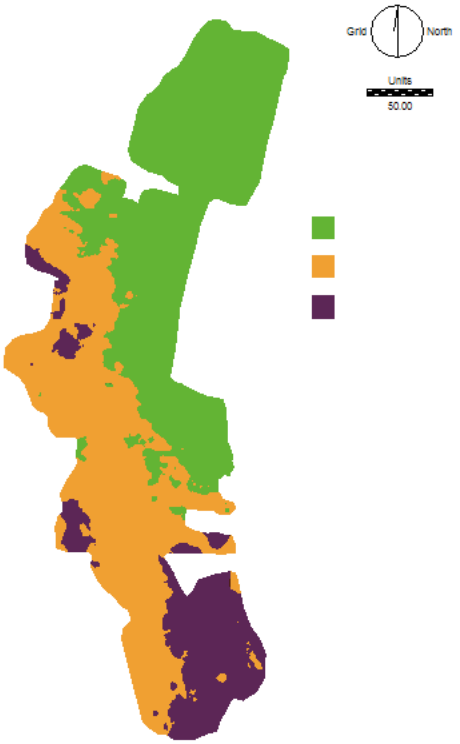
Classification of potential salinity hazard zones

Three optimal classes were identified by fuzzy k-mean classification algorithm for both top and subsoils in the study area. The maps indicating the potential salinity hazard zones are shown below (Plates 6 and 7).

Table 2. The validation indices with respect to the prediction model of both top and subsoils

	Correlation coefficient (r)	Mean estimation error (MEE)	Mean squared estimation error (MSEE)	Root mean squared estimation error (RMEE)
Topsoil	0.96	0.02	0.001	0.032
Subsoil	0.98	-0.01	0.002	0.045

The EC_e levels and the area of the salinity classes in both top and subsoils are given in the Table 3. Around 50 % of the total land of the study area recorded a lower mean soil salinity level (< 0.40 dS/m) whereas, around 15 % of the area showed comparatively a higher mean soil salinity level (> 0.50 dS/m) giving the evidence for the emerging problem of higher soil salinity in the area (Table 3).



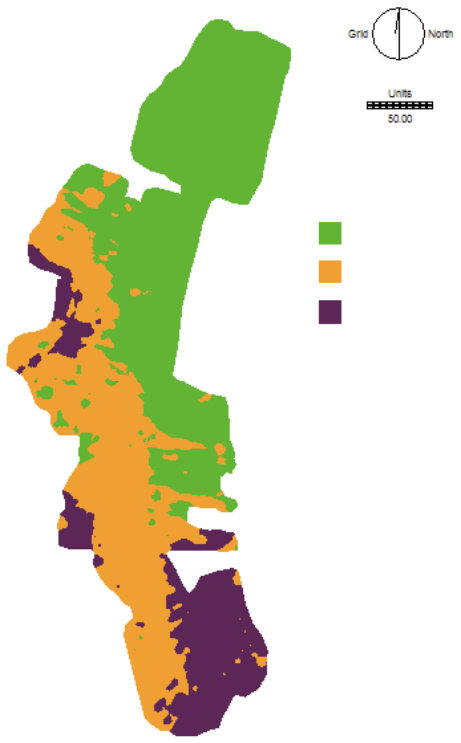


Plate 6:EC_e classes in topsoil **Plate 7: EC_e classes in subsoil**

Table 3. The EC_e levels and the area of the salinity classes

	Class	Mean EC_e (dS/ m)	Area (% of the total)
Topsoil	1	0.37	47
	2	0.48	36
	3	0.60	17
Subsoil	1	0.34	45
	2	0.44	40
	3	0.54	15

CONCLUSIONS

The study indicates a strong potential of proximal sensing of apparent

electrical conductivity as a promising tool for spatial prediction of salinity in Low Humic Glay soils (Typic Endoaqualfs) in rice- other field crops cropping system in the Dry Zone of Sri Lanka. Further, proximal soil sensing can be used in identifying salinity hazard zones in soil with a minimum effort of field sampling to determine the appropriate site specific management decisions of soil salinity.

ACKNOWLEDGEMETS

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TECHNICAL AND ALLOCATIVE EFFICIENCIES OF RICE FARMING UNDER MAJOR IRRIGATION IN MAIN RICE GROWING DISTRICTS OF SRI LANKA

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ABSTRACT

Stochastic frontier production functions of Cobb-Douglos form were estimated for 252 rice farms in *Yala* 2009 season and 248 rice farms during *Maha* 2009/10 season to measure technical and allocative in-efficiencies of rice farming under irrigated water regimes of Ampara, Pollonnaruwa, Anuradhapura and Hambantota districts, and to measure costs of these in-efficiencies to the rice farmers. Rice production of the farm was used as dependent variable, district differences were handled by intercept dummy variables, and land, labour, and capital were used as independent variables. The averages of technical efficiency were, 0.741 (*Yala*) and 0.825 (*Maha*), allocative efficiency were 0.848 (*Yala*), and 0.724 (*Maha*), and economic efficiency were 0.634 (*Yala*) and 0.606 (*Maha*) of the four districts. The potential cost savings/farm by eliminating both technical and allocative inefficiencies range from Rs. 27,000 in Polonnaruwa district to Rs. 43,200 in Anuradhapura district during *Yala* season, and from Rs. 37,500 in Ampara district to Rs. 49,600 in Polonnaruwa district during *Maha* season. The potential aggregate cost savings for the four districts by eliminating both technical and allocative inefficiencies are Rs billion 7.7 for *Yala* season, Rs. billion 18.8 for *Maha* season, and Rs. billion 26.5/annum.

Key words: Allocative efficiency, technical efficiency, economic efficiency, rice farming,

INTRODUCTION

Efficiency of rice farming is a subject that has been researched repeatedly and periodically over time in Sri Lanka because of the importance of rice as the staple food, the majority of Sri Lanka farmers depend on rice farming for livelihood, and raising efficiency of rice farming is vital for poverty alleviation of rural masses. There are some studies that estimated the efficiency of rice farming relative to the best performance among peer groups. These studies, in general, have provided evidence on the existence of substantial technical inefficiency on average with wide differentials in the level of inefficiencies in the rice sector of Sri Lanka (Ekanayake, 1987; Ekanayake and Jayasuriya, 1987; Ekanayake and Jayasuriya, 1989; Karunarathna and Herath, 1989; Gunarathne and Thiruchelvam, 2002; Thiruchelvam, 2005; Thibbatuwawa *et al.,* 2012; Aruna Shantha *et al.,* 2012; Aruna Shantha *et al.,* 2013) and differences of efficiency according to land size and land tenure (Bogahawatte, 1982; Udayanganie *et al.,* 2006; Thibbatuwawa *et al.,* 2012).

Findings of some of these studies also imply that the efficiency differentials widen when the growing environment is associated with higher levels of risk (Ekanayake, 1987; Gunarathne and Thiruchelvam, 2002). Most of the above studies have used Stochastic Frontier Production Function framework in measurement of efficiency. Exceptions are Bogahawatte, (1982) profit function; Karunarathna and Herath (1989) Corrected Ordinary Least Square Frontier and, in general, they have overlooked measurement of allocative inefficiency component. Thibbotuwawa *et al.,* (2012) have measured technical and allocative components of efficiency of Sri Lankan rice farming within Data Envelopment Analysis framework. However, using data of 90 farmers, Thibbotuwawa *et al., (2012)* have covered three water regimes (major irrigated, minor irrigated, and rainfed) in 6 districts. Obviously, the differences in intrinsic characteristics of the districts and water regimes that affect conversion efficiency of inputs in to yield lead to measurement errors of technical efficiency in such a grouping of districts and water regimes. Most of the above studies are location specific, and no attempts have been made to estimate the aggregate costs of inefficiencies to the society. The current study uses relatively larger samples than of previous studies and cover four most important major

irrigated districts of the country to measure technical and allocative efficiencies within Stochastic Frontier Production Function Framework and aggregate costs of these inefficiencies to the society. Accordingly, the objectives of the present study are to measure technical and allocative inefficiencies of rice farming under irrigated water regimes in Ampara, Pollonnaruwa, Anuradhapura and Hambantota major rice growing districts, and to measure costs of these inefficiencies to the rice farmers during *Yala* and *Maha*, seasons.

METHODOLOGY

The stochastic frontier production function model proposed by Aigner *et al.,* (1977) and Meeusen and van den Borek (1977), and further developed by and Coelli (1996) is used to measure efficiency of production in this study. In his seminal paper on productive efficiency, Farrell (1957) introduced two indexes of technical efficiency: one in input output (output oriented technical efficiency or $TE^{[o]}$) space and the other in the input input space (input oriented technical efficiency or $TE^{[i]}$). Technical efficiency index ($TE^{[i]}$), allocative efficiency index (AE), and associated economic efficiency (EE) index in input input space (Kopp 1981; Karagiannis *et al*., 2003) are used in this study to measure efficiency of production.

The method of measuring allocative and technical efficiencies, in input-input space is depicted in Figure 1 for a two-factor case of production. *AB* Efficient Unit Isoquant represents the various combinations of the two factors, X_1 and X_2 used by technically perfectly efficient firm of an industry to produce an output, *P*. Any firm producing an output *P* cannot be positioned in between *AB* and the origin *O*. *Q* and *S* respectively are two technically efficient and inefficient firms that produce an output *P.* These two firms lie on a "Fixed Inputs Use Proportion Ray" (OT) where inputs X_1 and X_2 are used in the same ratio. a technically and allocatively efficient firm lies on *AB* " Efficient Unite Isoquant" on the point which touches the price line

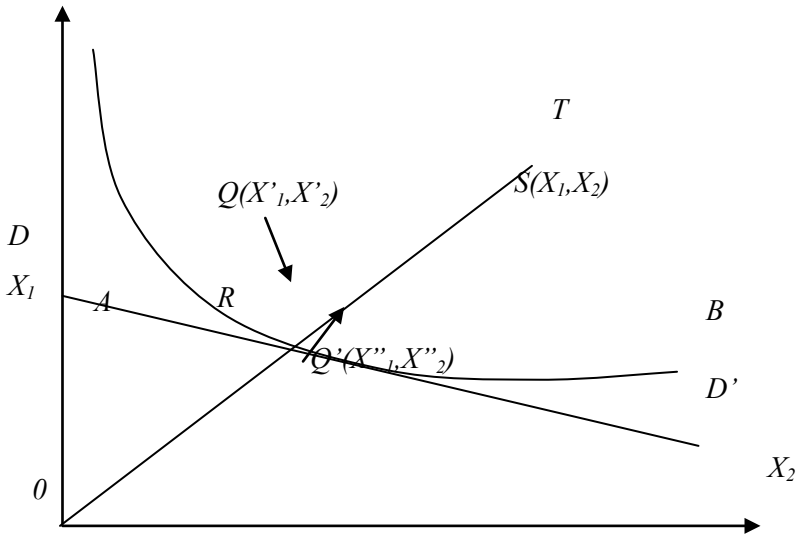


Figure 1. Measurement of efficiency in input-input space

The input based technical efficiency (hereafter $TE^{[i]}$) of the firm *j* is given as, $TE_j^{[i]}=C'/C$, where, C_j, and respectively are the cost of firm *j* and the cost of firm *Q* which is a technically efficient firm that produces, output *P* using inputs in the same proportion as firm *j*. Since same input proportions are used by the efficient firm (*Q*) and inefficient firm (*j*), input based technical efficiency ($TE_j^{[i]}$) is given also by the vector norm formula *OQ/OS*. $TE_j^{[i]}$ and output based technical efficiency ($TE_j^{[o]}=Y_j/\hat{Y}_j$) are equal when the return to scale is constant and otherwise they are not (Kopp, 1981). Allocative Efficiency of the firm j has been defined as: $AE_j^{[i]}=C''/C'$ where, C'' is the cost of firm Q' (a technically and allocatively efficient firm with the same output level as of firm j) and C' is as given above. Since measurements are made along the fixed input use proportion ray, OT, $AE_j^{[i]}$ is represented also by the vector norm formula *OR/OQ*. Economic- Efficiency *(AE)* index indicates possibility of cost reduction feasible by eliminating both technical and allocative inefficiencies. The *EE* of a firm is given by $EE_j^{[i]}=C''/C_j$ where, C''and C_j are as given above. By definition, *EE* is equal to product of $TE^{[i]}$ and $AE^{[i]}$ and given also by the vector norm formula *OR/OS*.

Since fixed factor proportions are assumed in estimating $TE^{[i]}$ and $TE^{[o]}$, they are free from the effects of factor pricing. The advantage of measurement of allocative efficiency in input-input space is that the AE indices always lie in the range of 0-1. Further, the product of AE and TE results in Economic Efficiency (Kopp, 1981).

Specification of the analytical model

The following Cobb-Douglos stochastic frontier production function model was used.

$$\ln Y_j = \alpha + \sum^{j(}_{j=1)} \theta_k D_k + \sum^{j}_{(j=1)} \beta_j \ln X_{ij} + v_j - u_j \quad \text{.....(1)}$$

Where y_j is the output of j^{th} farmer, $D_k=\{0,1\}$, k, is a dummy variables that takes value of 1 for k^{th} district and 0 for other districts, Xij are denoted as: Landj is the land extent used by j^{th} farmer, $Labor_j$ is amount of labor used for production operations excepting labor used for water management and transport operations, $Capital_j$ is the operating expenditure incurred on all inputs excepting any costs on land, labor, and resources cost of transport of the produce. ε_j is a composit error tem where $\varepsilon_j=v_j-u_j$: is an error term assumed to be distributed identically and independently as $N(0,\sigma_v^2)$ that reckons random variation of output, and u_j, is one sided ($uj\geq 0$) error term that reckons variation of output due to inefficiency. In this paper u_j is assumed to follow a half normal distribution (u. $N(0, \sigma_u^2)$. The efficiency parameter $\gamma=(\sigma_u^2/\sigma_u^2+\sigma_v^2)$ lies between 0 and 1, and if $\gamma=0$, the difference between farmer's production and production estimated by the frontier function is entirely due to statistical noise. Conversely, $\gamma=1$ indicates that the difference of actual and estimated production is entirely due to less than efficient use of technology.

Data and assumptions used for the study

All input use and output data needed to compute cost of production and profitability, collected by the Socio-Economics and Planning Center, Department of Agriculture for Cost of Cultivation studies of paddy farming during the above two seasons are processed and used for this study. The sample for Yala 2009 season includes data collected from randomly selected 252 farms under irrigated water regimes of four districts (Ampara, Polonnaruwa, Anuradhapura, and Hambantota) that represent 57% of the rice grown area under major irrigated water regime during

that season. The sample for Maha 2009/10 season under major irrigated water regime includes data collected from randomly selected 248 farms of four districts (Ampara, Polonnaruwa, Anuradhapura, and Hambantota) that represent 54% of the rice grown area under major irrigated water regime during Maha season. The variable 'capital' is a composite variable formed by aggregating operating expenditure incurred on material inputs (herbicides, fertilizer, and pesticides) and services of machinery. The cost components of 'capital' are valued at the costs incurred by the farmer, and costs of 'own' seed, and services of own machinery are valued at market prices of similar inputs. Lands were mostly owned by the farmers and were rarely rented in. The paddy lands Act of 1958 and subsequent Agrarian Services Acts prescribe a land rent of 25% of the output. Accordingly, value of 25% of the farm output was considered as the land rent for farmers whose gross margin is above 25% of the value of output, and farmer's gross margin was attributed as the land rent for farmers whose gross margin was less than 25% of the value of output.

Estimation of the model

Frontier 4.1 software **(**Coeli, 1996) was used to estimate the model. The output based technical efficiency index $[TE_j^{[o]}]$ is given by the software. The input based technical efficiency for a double log frontier production function is given as $[TE]_j^{[i]}=[TE_j^{[o]}]^{(1/\Sigma\beta i)}$ where, $\Sigma\beta_i$ is the sum of estimated production elasticities or scale coefficient. The allocative efficiency of the firm j is estimated by minimizing the cost of the firm at the firm's output level relative to the stochastic frontier production function. Accordingly, allocative efficiency (AE_j) of the firm j is measured by the following equation,

$$AE_j=\exp[-\ln[\sum^{m}_{(1=0)}P_i X_{ij}]+[\ln\hat{Y}_j-\alpha_0/(\sum^{m}_{(i=1)}\alpha_i]-(\sum^{m}_{(i=1)}\alpha_i \ln \alpha_i/P_i)/(\sum^{m}_{(i=1)}\alpha_i)+\ln\sum^{m}_{(i=1)}\alpha_i].....(2)$$

where, P_i is the price of the i^{th} input, and other variables are as defined before.

Estimates of potential cost savings

Cost savings feasible for each farm firm by raising technical efficiencies to unity are estimated as where, C_j is the total cost of production of farmer j and is the potential cost savings for farmer j with raising his technical efficiency to unity.

Cost savings feasible for each farm firm by raising allocative efficiencies to unity are estimated as , where is the potential cost savings for farmer j by eliminating his allocative inefficiency. Then sample sums of cost savings are made, and these sums are divided by sum of district sample extent (ha) to estimate average cost savings Rs/ha for the district. Subsequently, the aggregate costs of inefficiencies at district levels are estimated by multiplying per hectare savings by gross harvested extent for the particular season.

RESULTS AND DISCUSSION

Descriptive statistics of the sample

The averages of land, labor and capital indicates that farms in Ampara are relatively large during both *Yala* and *Maha* seasons, and more or less equal in other districts except in Anuradhapura district during *Yala* season where farm size was relatively small (Table 1). A detailed presentation of the descriptive statistics for district case studies are given in SEPC (2010).

Table 1. Arithmetic means of independent variables.

District	*Yala* 2009			*Maha* 2009/10		
	Land ha	Labor (md)	Capital (Rs)	Land (ha)	Labor (md)	Capital (Rs)
Ampara	1.3	45	55,725	1.4	59	63,890
Anuradhapura	0.5	34	17,755	0.9	68	34,567
Hambantota	1.0	48	47,550	0.9	45	47,635
Polonnaruwa	0.8	48	31,510	1.0	70	40,500
Average	1.0	44	41,700	1.1	61	50,885

Note : md = Man days

Estimated production functions for irrigated farms

The intercept terms in frontier production functions of both *Maha* and *Yala* seasons are significant. The exponential values of the dummy variable coefficients exhibit the level of productivity differences among districts. The exponential

values of dummy coefficients are 0.99 for Polonnaruwa, 1.13 for Hambantota, and 0.85 for Anuradhapura in *Yala* season and 1.06 for Polonnaruwa, 1.22 for Hambantota, and 1.17 for Anuradhapura during *Maha* season. With the same level of input use in farms of Ampara district, yields in farms of Polonnaruwa district are lower by 15% during *Yala* season, and 17% higher during *Maha* season whereas yields in Hambantota district are higher by 13% in *Yala* season, and 22% higher in *Maha* season (Table 2). The coefficients for land, labour, and capital, which are elasticities of production, have expected positive signs, and are highly significant during both seasons except in the case of labor during *Yala* season where the level of significance is only 10%. Land has the largest elasticity, capital has the second largest elasticity, and labour has the smallest elasticity in both *Yala* and *Maha* seasons (Table 2). Having the largest elasticity coefficient for land is acceptable as Sri Lanka has expanded paddy production mainly through area expansion. Having the second largest elasticity coefficient in either season for capital also is easily explicable as the adoption of mechanical harvesting and threshing and substitution of manual weeding by herbicides that use capital intensively would lead to high elasticity of capital. The importance of labour is low with the flexibility of substitution of labour by capital services in the form of mechanization and agrochemicals.

Table 2.Estimates of stochastic frontier production functions.

Variable	Frontier Production Function in	
	Yala 2009 season	**Maha 2009/10 season**
Intercept	3.444*** (5.563)	5.765*** (9.135)
Anuadhapura	- 0.0157 (- 0.2)	0.059 (1.556)
Hambantota	0.119** (2.025)	0.198*** (5.184)
Polonnaruwa	- 0.165** (-2.669)	0.156*** (4.15)
Ln Land	0.573** (6.746)	0.732*** (9.52)
Ln Labour	0.108* (1.776)	0.068*** (2.046)
Ln Capital	0.432*** (7.738)	0.198*** (3.246)
σ^2	0.25*** (7.08)	0.086*** (6.705)
Γ	0.847*** (7.08)	0.802*** (11.427)
Log likely hood Function	- 18.26	- 18.79

*** significant at 1% level, ** significant at 5% level * significant at 10% level; t ratios are in parenthesis.

The γ coefficients of 0.847 in *Yala* season and of 0.802 in *Maha* season indicate that major portion of the variation of output is explained by technical efficiency in both seasons.

Average efficiency estimates

There is a marked difference in average technical efficiencies between *Yala* and *Maha* seasons with an overall means of 0.741 for *Yala* and 0.825 for *Maha* (Table 3). Relatively high level of technical efficiency during *Maha* season is acceptable as lower levels of water constraints reduce management difficulties and enable farmers with relatively low management capabilities also to reach the production frontier. The average technical efficiency indexes indicate that about 26% of the resources cost during *Yala* season and about 17.5% of the resources cost during *Maha* season could be saved by raising technical efficiency. The variation of average technical efficiencies among districts within a season is very low, probably due to adequate representing of differences among districts within a season by the dummy variables in the models, and therefore, only the differences among farmers within the district are reckoned in measurement of efficiency (Table 3).

The estimated average allocative efficiency indices for districts range from 0.788 in Anuradhapura district to 0.915 in Hambantota district during *Yala* and from 0.693 in Polonnaruwa district to 0.762 in Anuradhapura ditrict in *Maha* with an overall average of 0.848 for *Yala* and 0.724 for *Maha* (Table 3). Accordingly, 15% of the cost at technically efficient point at *Yala* and 28% of such cost at *Maha* season, in general, could be saved by raising allocative efficiency. Implicit nature of prices makes estimation of allocative efficiency very difficult. Most of the farmers cultivate their own lands and use own labour and own capital in substantial proportions. Therefore, prices in many cases had to be estimated or assumed, and accuracy of measured efficiency indices depends on accuracy of estimated prices.

Economic efficiency is the product of the technical efficiency and allocative efficiency. The average Economic efficiency indices range from 0.567 in Anuradhapura to 0.702 in Hambantota district during *Yala* season and from 0.579

in Polonnaruwa district to 0.634 in Anuradhapura district during *Maha* season with overall means of 0.634 for *Yala* and 0.606 for *Maha* (Table 3). Accordingly, potential cost savings from reducing technical and allocative inefficiencies range from 30% to 43% *Yala* and 37% to 42% during *Maha* with overall averages of 37% for.*Yala* and 39% for *Maha.*

Feasibility of cost savings and impact on farm profitability

The average cost savings per farm feasible by eliminating technical efficiencies have a range starting from Rs. 18,700 in Polonnaruwa district to Rs. 26,590 in Ampara district during *Yala* and Rs. 16,335 in Anuradhapura district to Rs.21,490 in Polonnaruwa district during *Maha.* The average cost of economic inefficiency per farm is Rs. 33,000 in *Yala* season, and Rs 45,460 in *Maha* season. The average cost savings by eliminating allocative inefficiencies are relatively small during *Yala* season: the averages range from Rs 5,540 in Hambantota district to Rs 11,925 in Ampara district. In contrast, the potential cost savings feasible by eliminating allocative inefficiencies during *Maha* season is relatively high: the values range from Rs 17,425 in Anuradhapura district to Rs 29,505 in Ampara district. The average cost savings by eliminating both technical and allocative inefficiencies are relatively small during *Yala* season: the averages range from Rs 26,580 in Hambantota district to Rs 38,700 in Anuradhapura district. In contrast, the potential cost savings feasible by eliminating both technical and allocative inefficiencies during *Maha* season are relatively high: the values range from Rs 33,760 in Anuradhapura district to Rs 50,635 in Ampara district (Table 4).

Table 3.The arithmetic means of technical efficiencies.

District	***Yala* 2009 season**			***Maha* 2009/10 season**		
	TE	**AE**	**EE**	**TE**	**AE**	**EE**
Ampara	0.734	0.855	0.633	0.820	0.72	0.602
Anuradhapura	0.722	0.788	0.567	0.825	0.762	0.634
Hambantota	0.759	0.915	0.702	0.835	0.730	0.614
Polonnaruwa	0.755	0.827	0.631	0.811	0.693	0.579
Mean of Districts	0.741	0.848	0.634	0.825	0.724	0.606

Relatively low allocative efficiencies during *Maha* season and associated higher potential cost savings by eliminating allocative inefficiencies have caused the potential cost savings by eliminating both technical and allocative inefficiencies to be high during *Maha* season.

Aggregate cost savings for districts

The potential aggregate cost savings are relatively high in Ampara district, followed by Polonnaruwa district because of the relatively large rice extents cultivated in these two districts. Similarly, the potential cost savings by eliminating technical/allocative inefficiencies are relatively high in *Maha* season due to higher aggregate extent cultivated during that season. It is observed that the cost savings feasible for these major rice growing districts by eliminating both technical and allocative inefficiencies are substantial in magnitude (Table 5).

Table 4. The potential average cost savings per farm with eliminating inefficiencies

District	*Yala* **2009 Potential cost saving by raising***			*Maha* **2009/10 Potential cost saving by raising***		
	TE	**AE**	**EE**	**TE**	**AE**	**EE**
Ampara	26,590 (69%)	11,925 (31%)	38,515	21,180 (42%)	29,505 (58%)	50,685
Anuradhapura	22,785 (74%)	7,915 (26%)	30,700	16,335 (48%)	17,425 (52%)	33760
Hambantota	25,210 (82%)	5,540 (18%)	30,750	18,375 (43%)	24,375 (57%)	42,750
Polonnaruwa	18,710 (70%)	7,870 (30%)	26,580	21,490 (44%)	27,450 (56%)	48,940
Average	23,990 (73%)	9,010 (27%)	33,000	19,740 (43%)	25,720 (57%)	45460

*Percentages from potential cost savings from eliminating technical and allocative inefficiencies are in parenthesis

Table 5. The potential aggregate cost savings with raising efficiencies

District	*Yala* 2009 potential xot saving (Rs. billion) by raising			Maha 2009/10 Potential cost saving (Rs billion) by raising			Both seasons potential cost saving (Rs billion) by raising		
	TE	AE	EE	TE	AE	EE	TE	AE	EE
Ampara	2.1	1.0	3.1	3.1	4.3	7.4	5.2	5.3	10.5
Anuradhapura	0.6	0.2	0.8	1.2	1.3	2.5	1.8	1.5	3.3
Hambantota	1.2	0.3	1.5	0.9	1.2	2.1	2.1	1.5	3.6
Polonnaruwa	1.6	0.7	2.3	3.0	3.8	6.8	4.6	4.5	9.1
Total	5.5	2.2	7.7	8.2	10.6	18.8	13.7	12.7	26.5

*Extents Source – Department of Census and Statistics (2014).

CONCLUSIONS

Although, fairly high levels of technical, allocative, and economic efficiency levels for the two seasons is observed, it is evident that costs savings possible by eliminating technical and allocative inefficiencies are considerable at individual farmer level and district aggregate level. Therefore, programmes for reduction of technical and allocative inefficiencies such as extension programmes, farmer business schools could lead to increase of farm incomes The aggregate welfare gain estimates in the four districts indicate that economically rational investment to disseminate technology among farmers could be justified.

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POTASSIUM DYNAMICS IN IRRIGATED LOW LAND PADDY SOILS AND ITS RELATION TO PLANT K AND GRAIN YIELD OF RICE

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ABSTRACT

An experiment was conducted in irrigated low land paddy soils treated with rice straw and K fertilizer in the Low Country Intermediate Zone to identify the forms of potassium in paddy soil and its relationship to grain yield of rice and plant K contents. There were six treatments in the experiment (T1 - no K fertilizer or manure; T2 - rice straw at 5 t/ ha; T3 - rice straw at 5 t/ha with 15 kg K_2O (applied as basal); T4 - rice straw at 5 t/ha with 20 kg of K_2O applied at 6 week after planting (WAP); T5- rice straw at 5 t/ ha with 15 kg K_2O (at basal) and 20 kg K_2O applied at 6 WAP; T6 - 15 kg K_2O applied as basal and 20 Kg K_2O applied at 6 WAP. Experiment was set up in *Yala* 2011 and continued without changing plot arrangements until the 7th consecutive seasons up to *Yala* 2014. Soil samples were collected at the beginning of 7th season and analyzed for exchangeable and non- exchangeable K contents. Grain yield and plant K contents were measured at the end of the 7th season. The highest non-exchangeable K (160.2 mg /kg) and the highest exchangeable K (46.2 mg/kg) were recorded from plots treated with both rice straw at 5t /ha and K fertilizer at 35 kg k_2O/ha. These plots had the highest grain yield (5.42 t/ha) and the highest plant K content (1.02 %) as well. Significantly low non-exchangeable K (100.8 mg/kg) and the lowest level of exchangeable K (25.3 mg/kg) were recorded from control plots where neither straw nor K fertilizer was added. These plots had the lowest yield (4.78 t/ha) as well as the lowest level of plant K (0.57 %). Relationship between non-exchangeable K and exchangeable K was linear and significantly high ($r^2 = 0.93$). Though exchangeable K contents were significantly different among treated plots, non-exchangeable K contents and grain yield were not significantly different. Higher relationship ($r^2 = 0.69$) between non-exchangeable K content and plant K content was observed. Exchangeable K in all plots was below the

critical level (80 mg/kg) but no response of rice to application of K fertilizer. It is learned from this experiment that non-exchangeable K content has a positive relationship with grain yield and highly relates to plant K content and as such non-exchangeable K content should be taken as an indicator in the soil test based fertilizer recommendations to decide the K supplying capacity of paddy soils.

Key words: Exchangeable K, K fertilizer, non exchangeable K, rice, straw

INTRODUCTION

Rice occupies approximately 33 % of the total cultivated area in Sri Lanka, which accounts for 0.78 million ha (DCS, 2014). Of the above, 75 % of the rice area is in the Intermediate and Dry zones of Sri Lanka. Most of these lands in the above areas are grown with high yielding rice varieties. To get the maximum benefits from the high yielding rice varieties, application of fertilizer has become a must (Abeysiriwardena and Sandanayake 2000).

Potassium is a major nutrient which plays a critical role in regulating assimilate transportation. Short supply of potassium could affect the productivity of rice (Salisbury and Ross, 1978). Most of the paddy soils in low country of Sri Lanka is considered to be high in K and as a result, a low crop response to applied K is seen (Wickramasinghe *et al*., 2003). In addition, with the introduction of harvesting machines to paddy sector, straw is recycled *in-situ* and provides considerable amount of K. Since large quantity of K is returned to paddy fields through straw incorporation, K level in paddy soils would be adequate to satisfy the early K needs of rice crop. Considering the above, K has been removed from the basal rice fertilizers and only top dressing was introduced in 2013 (Sirisena, 2013). The removal of K from basal fertilizer mixtures would lead to a greater risk in rice production, unless proper estimation of K contents in rice soils is adopted. Since almost all K fertilizer is imported to the country and distributed at subsidized prices, application of K fertilizer in a more judicial manner is important to relieve the burden on the Government and also to reduce cost of production.

Soil test based fertilizer recommendation considered soil exchangeable

K level as an indicator of the K supplying capacity of paddy soils (DOA, 1997). According to soil test based fertilizer recommendation, fertilizer K application has been recommended when exchangeable soil K levels were below 80 mg/ kg. In many occasions soil exchangeable K levels were below the above critical level and as such same K recommendation has been given. Contrary to the above, Sirisena and Herath (2012) have reported that there was no response of rice to application of K fertilizer even though exchangeable K levels were below 40 mg/ kg. There is accumulating evidence that non exchangeable soil K also has a role to play in providing potassium to plants. A large number of exhaustive cropping experiments have demonstrated that as levels of exchangeable soil K are depleted, non-exchangeable K makes a significant contribution to plant uptake (Uddini *et al.,* 2011)

Plant K is an important parameter that protects plants form biotic and abiotic stresses (Williams and Smith, 2001, Chau and Heong, 2005). Therefore, whatever form of K in the soil should help to maintain K content in plant tissues. According to Wickramasinghe and others (2003), soil analytical data for soils from low country intermediate zone have shown that exchangeable soil K in most of these soils is low. Non-exchangeable K fraction of these soils is in sufficient range and as such no response to applied K fertilizers. In addition application of K even 150 kg K_2O/ ha has not significantly affected the grain yield of rice in any of these soils because non-exchangeable K fraction of these soils is in sufficient range. After crop harvest, the content of exchangeable K in soils was below the critical levels, showing the depletion of exchangeable K due to cropping. When amount of exchangeable potassium in soil is depleted there is a possibility to replenish non - exchangeable potassium to exchangeable potassium. So it is useful to find out the changes of non-exchangeable K and exchangeable K fraction of these soils with the application of K fertilizer and rice straw.

The objective of this study was to quantify exchangeable and non-exchangeable K in a irrigated low land paddy soils and their relation to grain yield and K content of rice plants.

MATERIALS AND METHODS

This study was conducted at Rice Research and Development Institute, Batalagoda in the Low Country Intermediate Zone. The experimental site was situated in a continuous rice producing area where two rice crops are usually grown in a year. The soils in the experimental site are sandy clay loam with 38% sand, 15% clay and 47% silt, and poorly drained. At the commencement of the study, the soil pH was 5.9, and the soil contained 0.18% total Nitrogen (N), 43 mg/ kg exchangeable K, 185 mg/kg non-exchangeable K, and 8.7 mg/kg available Phosphorus (P). This study was initiated in *Yala* 2011 and continued with same treatments for seven consecutive seasons until *Yala* 2014 without changing original plot arrangements. Treatments tested in the experiments were T1- Control – (No fertilizer and straw application), T2- straw 5t ha^{-1} , T3- straw 5t ha^{-1}+ 15 kg K_2O (basal) + 20 kg K_2O 6 weeks after establishment (6WAE), T4- straw 5 t /ha + 15 kg K_2O (basal), T5- straw 5t /ha +20 kg K_2O (6 WAE) and T6- 15 kg K_2O (basal) + 20 kg K_2O (6 WAE). Stubble of the preceding rice crop was incorporated into soil in all treatments. Treatments were arranged in a randomized complete block design and replicated four times. Rice variety Bg 352 was transplanted after raising in nursery beds for 20 days. Phosphorous was given at the rate of 45 kg P_2O_5/ ha as basal dressing. N was split applied as 5 kg, 30 kg , 55 kg and 25 kg / ha as basal, 2, 4 and 6 weeks after planting, respectively. Crop management was done uniformly across all treatments.

Crop was harvested at 3.5 months after planting and grains were sun dried after threshing and cleaning, and total grain weight was recorded in each plot at 13 % moisture. Soil samples were collected up to 15 cm depth at two weeks after incorporation of stubbles and rice straw. Samples were air dried and sieved by 2 mm sieve. Exchangeable K content in soil was determined by using 1M ammonium acetate (NH_4OAc) extractant using Atomic Absorption Spectrophotometer (AAS), (SSSSL, 2007). For determination of non-exchangeable K, 1 M Nitric solution was used. Mixture was heated gently on a hot plate until boiling and cooled. Filtrates were analyzed for non-exchangeable soil K using Atomic Absorption Spectrophotometer. Arial parts of the plant were collected as 5 plants per plot at flowering stage. Plant samples were dried at 70^oC for three days until constant weight was obtained and total K content in plant tissues was determined by wet

digestion method (Campbell and Plank, 1988) The analysis of variance and mean separation were performed for the experimental data using SAS statistical package.

RESULTS AND DISCUSSION

Results of this experiemnt revealed that non- exchangeable K content was significantly different between control plots and treated plots and lowest value of 100.8 mg/kg was recorded in control plots and the highest value (160.2 mg/ kg) was recorded in plots treated with straw at 5 t /ha and K at 35 kg K_2O/ ha (Table 1). Soil fixed or non exchangeable K is an important reservoir of K in soil and makes an important contribution to plant K supply (Parker *et al*., 1989). According to Uddini *et al.* (2011) soil solution and exchangeable K increased with added K. These form of K decreased with time after crop was transplanted and drastic reduction was found during one month time period. Thus split application of K gave better results instead of single application. According to Uddini *et al.*, the amount of non-exchangeable K decreased inconsistently and that helpful to provide potassium in long run. As such non exchangeable K content plays a significant role in rice production. However, research studies on effect of non exchangeable K on rice production in Sri Lanka is still at an early stage.

It has been proved form these results that potassium in rice straw is similar to K in MOP fertilizer and both K sources maintained non-exchangeable and exchangeable K content in the soil. Exchangeable K contents were significantly low at the beginning irrespective of the treatments. It was the lowest (25.3 mg/ kg) in control plots while highest (46.2 mg /kg) in plots treated with straw 5 t/ ha and K at 35 kg K_2O/ ha (Table 1)

Control plots which did not receive any fertilizer or straw recorded lower levels of exchangeable and non-exchangeable K at the end of 6^{th} seasons. These results have confirmed the findings of Dobermann and Fairhurt (2000) and Uddini *et al.* (2011) that continuous cultivation of rice without application of chemical K fertilizer or rice straw leads to deplete soil exchangeable as well as soil non-exchangeable K contents. Exchangeable K has been considered as an indicator to decide K supplying capacity of soil (DOA, 1997). Figure 1 shows the linear relationship between non-exchangeable K content and exchangeable K contents.

According to the results given in Figure 1 there is a significantly high (r^2 = 0.93) relationship between the non exchangeable K content and exchangeable K contents. As such it can be suggested that soils having higher exchangeable K content also have higher non exchangeable K content as well. Therefore, taking exchangeable K as an indicator to decide K supplying capacity of soil is justifiable. As stated by De Datta and Mikkelsen (1985), potassium from non-exchangeable soil solution provide K to rice plants when soil solution K is depleted and as such exchangeable K content is not a good indicator to decide the K requirement of rice plants. Results of the present experiments have also shown that even with continuous application of rice straw and K fertilizer, exchangeable K content of soil has not been increased above 46 mg/kg. Therefore, according to soil test based fertilizer recommendation, application of K fertilizer at full quota is recommended for all plots (DOA, 1997) even without significant yield advantage. When K nutrition is low, rice is more susceptible to many plant diseases, which can cause yield and/or quality losses beyond that caused from the physiological effects of insufficient K nutrition. High incidence of brown leaf spot (*Bipolaris oryzae*), stem rot (*Sclerotium oryzae*) and other opportunistic diseases are important signs of potential K deficiency in rice (Dobermann and Fairhurst, 2000). Therefore, consideration of critical levels of both non-exchangeable K and exchangeable K content is important before deciding the application of K fertilizer.

Table 1. Non exchangeable K contents and exchangeable K contents of the paddy soils at the beginning of 7th season.

Treatments	Non-exchangeable K (mg/kg)	Exchangeable K (mg/kg)
No K	100.8b	25.3d
Straw 5t ha^{-1}	131.0ab	33.4 c
Straw 5t ha^{-1}+ 15 kg K_2O ha^{-1} (Basal) + 20 kg K_2O ha^{-1} (6 WAP)	160.2a	46.2a
Straw 5t ha^{-1}+ 15 kg K_2O ha^{-1} (Basal)	158.7ab	42.9ab
Straw 5t ha^{-1}+ 20 kg K_2O ha^{-1} (6 WAP)	132.4ab	38.7abc
15 kg K_2O ha^{-1} (Basal) + 20 kg K_2O ha^{-1} (6 WAP)	126.7ab	35.3bc

* Mean values within a column with different letters are significantly different at $p<0.05$.

Results presented in Table 2 revealed that application of rice straw and chemical K fertilizer increased grain yield and plant K contents. Accordingly, in comparison to treated plots significantly lower yield of 4.78 t/ha has been recorded

from control plots where rice straw or chemical K fertilizer has not been added for the last 7 seasons. Grain yields were non-significant among the treated plots revealing that rice straw can provide considerable amount of K to paddy fields. This is an agreement with the findings of Senaratne *et al.* (2006) that K provided by rice straw is similar to K supplied by the MOP fertilizer. As such, application of rice straw and chemical K fertilizer increased grain yield significantly over control.

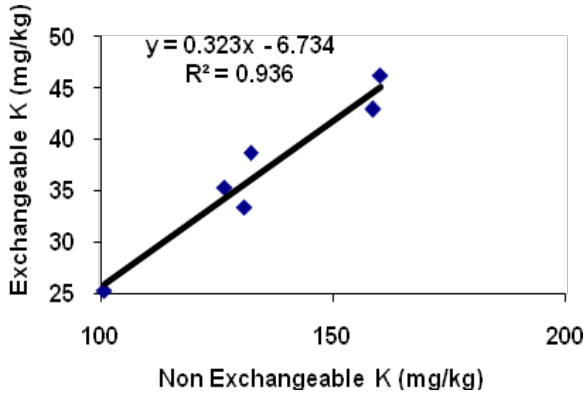


Figure 1. Relationship between non exchangeable K content and exchangeable K content.

Table 2. Grain yield and plant K content of the plots treated with rice straw and different rates of chemical K fertilizer.

Treatments	Grain yield (t/ha)*		Plant K contents (%)*
	Average of the past 6 seasons*	7th season*	
No K	4.25c	4.78 b	0.57d
Straw 5t ha^{-1}	4.49bc	4.90 ab	0.74c
Straw 5t ha^{-1}+ 15 kg K_2O ha^{-1} (Basal) + 20 kg K2O (6 WAP) ha^{-1}	4.78 a	5.07 ab	1.02a
Straw 5t ha^{-1}+ 15 kg K_2O ha^{-1} (Basal)	4.90a	5.30 ab	0.81bc
Straw 5t ha-1+ 20 kg K_2O ha^{-1} (6 WAP)	4.90 a	5.42 a	0.80bc
15 kg K_2O ha^{-1} (Basal) + 20 kg K_2O ha^{-1} (6 WAP)	4.72ab	5.19 ab	0.86ab

*Note : Mean values within a column with different letters are significantly different at $p<0.05$.

Plant K is an important parameter that protects plants from pests and diseases. Higher levels of plant K help plants to withstand biotic and abiotic stress conditions (Williams and Smith, 2001; Chau and Heong, 2005). Application of straw and MOP at the rate of 35 kg k_2O/ha significantly increased plant K content. Results shown in Figures 2 and 3 revealed that there is good relationships (r^2 = 0.66 and 0.77) between non-exchangeable K and exchangeable K content with plant K content. Therefore, instead of exchangeable K contents non-exchangeable content can be measured to decide the ability of soil to provide K to plants

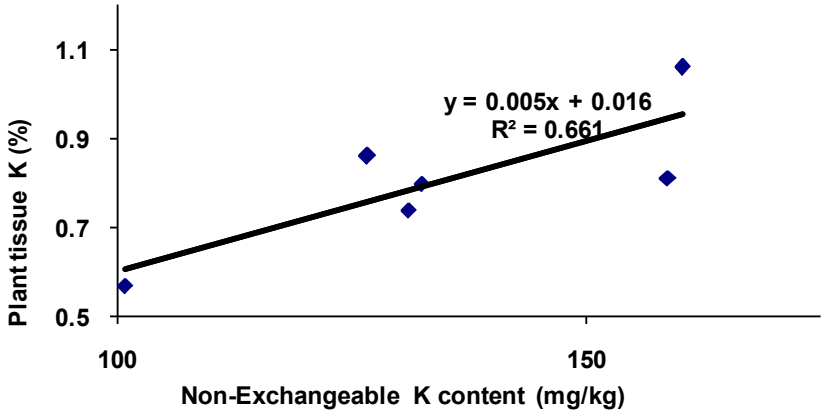


Figure 2. Relationship between non exchageable K contnet and plant K content

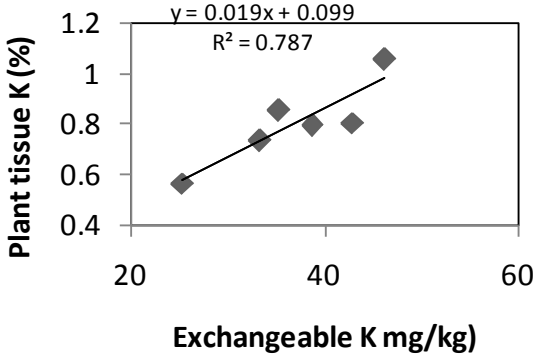


Figure 3. Relationship between exchangeble K contnet and plant K content

According to the above results application of chemical K fertilizer is necessary to maintain exchangeable K and non exchangeable K in soil. Similarly it is observed in this experiment that application of chemical fertilizer enhanced the plant K contents as well (Table 2). Therefore, even with the application of rice straw application with K fertilizer is important not only to get higher grain yield but also to get higher K content in plant tissues for protecting plants from pest and diseases (Williams and Smith, 2001; Chau and Heong, 2005).

Senaratne *et al.* (2006) indicated the potential contribution by K fertilizers, and increased yield benefits in the application of K towards flowering instead of at the basal dressing stage, when the initial K needs are satisfied by decaying stubble and straw. Since there is no significant difference between treatments (split vs basal) (Table 2) split application of K fertilizer at growth stage would be better than basal only, apart from time involved and cost of application.

CONCLUSIONS

The removal of K from basal fertilizer mixtures, promotion of straw recycling to return K removed by the rice crop and maintenance of high soil K content in rice soils are logically related to each other. Application of rice straw along with chemical K fertilizer in long run significantly increases exchangeable as well as non exchangeable K content in paddy fields. It also increases grain yield of rice as well as plant K contents. Non-exchangeable K content has a positive relationship with grain yield and highly relates to plant K content and as such non-exchangeable K content is a better indicator in the soil test based fertilizer recommendations to decide the K supplying capacity of paddy soils.

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Table 2. Grain yield and plant K content of the plots treated with rice straw and different rates of chemical K fertilizer.

*Note : Mean values within a column with different letters are significantly different at $p<0.05$.