Journal of Agrometeorology (Special issue - Part I): 150- 158 (2008)

Cropping systems options in relation to ENSO phase for Nandyal in Andhra Pradesh—A simulation analysis

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ABSTRACT

In rainfed environments, the productivity of cropping systems is primarily determined by the amount and distribution of rainfall. In southern India, the ENSO condition to some degree determines the potential of the ensuing rainy season in terms of amount of summer monsoon rainfall that is likely to be received in the region. Although it is difficult to predict the distribution of rainfall at a site or region, the prediction of rainfall amount would help farmers to plan cropping strategies to minimize climatic risks to crop production. Using crop simulation models and long-term weather records (1961 to 2006), productivity and net income of three sequential cropping systems (maize-chickpea, soybean-chickpea and groundnut-chickpea) and three intercrop systems (maize/pigeonpea, soybean/pigeonpea and groundnut/pigeonpea) were evaluated for the three ENSO conditions for Nandyal situated in the Kurnool district of Andhra Pradesh. The simulation analysis showed that groundnut-chickpea sequential, groundnut/pigeonpea and soybean/pigeonpea intercrop systems during the La-Niña years, while maize/pigeonpea and groundnut/pigeonpea intercrop systems during the El Niño years gave higher net income at low risk among the cropping systems studied. During Neutral years, groundnut/pigeonpea intercrop systems was the most promising in terms of net income The study has demonstrated that assessing the potential of seasons based on ENSO condition would help farmers maximize incomes and reduce climatic risks by providing more efficient cropping systems options in the region.

Key words: Rainfall prediction, ENSO condition, cropping systems, climatic risk.

Climatic variability, particularly inter- and intra-seasonal rainfall, is the major climatic risk to crop production in the rainfed areas of the semi-arid tropics (SAT). In the monsoon climate, the date of onset and withdrawal of the rains, amount and distribution of rainfall, occurrence of wet and dry spells and the associated variability in air temperatures are the main components of climatic risk which farmers have to face for crop production. Under such uncertain circumstances farmers generally adopt conservative risk management strategies for making investments in agriculture that reduce the negative impacts of poor rainfall years, but often at the cost of low average productivity and profitability. But at the same time, if the season happens to be good rainfall year they forfeit the benefits that could be derived from good rainfall years to enhance productivity and their incomes (Hansen, 2002).

Understanding the potential of the ensuing seasons prior to their onset, in terms of expected amount of rainfall and its likely distribution, would help farmers to plan for most appropriate crops and cropping systems in advance and adopt management practices as the season would unfold (Carberry et al., 2000: Meinke and Hotchman, 2000). Among various factors that determine the temporal and spatial variability of rainfall in a region, El-Niño Southern Oscillation (ENSO) is the major ocean-atmosphere phenomenon contributing to variability in rainfall or shifts in rainfall probability distribution (Stone *et al.*, 1996; Ropelewski and Halpert, 1987; Kiladiz and Diaz, 1989; and Mason and Goddard, 2001). Of the three phases of ENSO, El-Niño is associated with low seasonal (summer monsoon) rainfall probability and La-Niña with high rainfall probability and the Neutral years with uncertain rainfall for peninsular India (Gadgil *et al.*, 2002). Thus the relationship between ENSO and expected amount of rainfall at a site provides the opportunity for improved decision making to prepare for the adverse or favorable rainfall seasons. The farmers can choose more suitable

Table 1 : Statistics of total rainfall and start of the season for the three ENSO phases (data period: 1961 – 2006).

Period	Statistics	El-Niño n=12	La-Niña n=13	Neutral n=21	All years n=46
			Annual rainfall (mm)		
Annual	Average	690	970	760	800
	CV (%)	17	25	27	28
			Seasonal rainfall (mm)		
June – Sept.	Average	480	710	520	560
	CV (%)	20	29	31	33
			Monthly rainfall (mm)		
June	Average	100	100	80	90
	CV (%)	58	75	67	67
July	Average	120	160	160	150
	CV (%)	45	61	44	50
August	Average	130	200	145	160
	CV (%)	84	60	66	69
Sept.	Average	120	250	130	160
	CV (%)	78	46	68	68
Oct.	Average	70	160	110	120
	CV (%)	102	92	80	94
			Start of the season (Julian day)		
	Average	166	166	171	169
	Max	195	203	207	207
	Min	152	152	152	152
	CV (%)	8	9	10	9

crops and cropping systems and adjust their agronomic management as per the potential of the ensuing season to manage climate risk for enhanced benefits. In the past seasonal rainfall predictions based on ENSO have been used by various workers (Hammer et al., 1996; Gadgil et al., 2002; Carberry *et al.*, 2000; Meinke and Hotchman, 2000; Meinke *et al.*, 1996; Phillips *et al.*, 1998) to select management options like crops and cultivars to grow, sowing dates and densities, management of soil fertility, livestock stocking rates and allocation of land and water resources for different crops.

In the present study we selected Nandyal location in the Kurnool district of Andhra Pradesh, which falls in the semi-arid tropical zone in peninsular India. The district has highly variable rainfall and falls in the rainfall scarcity zone of Andhra Pradesh. The purpose of this study was to (1) characterize the influence of ENSO phases on summer monsoon rainfall received during June to September; and (2) using cropping systems simulation models, determine the most suitable cropping systems options for farmers in terms of economic returns and climatic risks associated with rainfall prediction based on ENSO.

MATERIAL AND METHODS

Data used

We collected long-term (1961-2006) weather data for Nandyal (latitude 15°29" N, longitude 78°29" E) situated in Kurnool district of Andhra Pradesh, India. The data set comprised of daily values of solar radiation, maximum and minimum temperature and rainfall. The site has mean annual rainfall of 800 mm and mean seasonal rainfall (June to September) of 560 mm (Table 1). Average date of onset of the monsoon is 169 Julian day (18 June) with a range of 152 to 207 Julian day (1 June to July 26). The soils at the site are high water holding capacity Vertisols and mixed black soils. The sea surface temperature anomaly (SSTA) data for the Niño 3.4 region [3 month running mean of ERSST.v3 SST anomalies in the Niño 3.4 region (5°N-5°S, 120°-170°W) based on the 1971-2000 base period)] for the corresponding weather years were obtained from the web site: http://www.cpc.noaa.gov/ products/analysis monitoring/ensostuff/ensoyears.shtml. Southern oscillation index (SOI) data were obtained from the web site: http://www.bom.gov.au/ climate/current/ soihtml. shtml. From these data 3-month moving averages were calculated to relate it with the SST anomalies and the seasonal rainfall.

As the monsoon generally sets in during the last week of June at Nandyal, the total rainfall for the period July to October was correlated with both SOI and SST anomalies for the period May to October. Similarly, the second data set of extreme rainfall years (all rainfall years minus the years within ± 20% of long-term average rainfall) were also correlated with SOI and SST anomalies. Although, seasonal rainfall of both the data sets was significantly correlated with SOI and SST anomalies, the correlations of rainfall with SOI were better than those with SST anomaly (Table 2). Therefore, to partition the historical climate data into the three phases of ENSO, the mean SOI values for the period May to September were regressed against the SSTA values for the same period. As expected, the relationship between SOI and SSTA was significant ($SOI = -11.68*SSTA-0.639$, $R^2 = 0.80$ and $p < 0.001$). Based on this relationship the SOI value of 5.0 corresponded with SSTA value of -0.5, a SSTA threshold value for the La-Niña condition, and the SOI value of -7.0 corresponded with the SSTA value of 0.5, a SSTA threshold value for the El-Niño condition. Thus, if the SOI of a year for the period May to September was above 5.0 it was considered as a La-Niña year and if below -7.0 then it was an El-Niño years. The years between these two SOI values were taken as a Neutral years. The whole historical climate data was also partitioned into normal, high and low rainfall years based on percent deviation of rainfall from the mean, which was taken as ± 20% of mean rainfall.

Simulation of crop yields of cropping systems

We used crop models available in APSIM software (Keatinge et al., 2003) to simulate growth and yield of cropping systems. The cropping systems evaluated were three sequential systems and three intercrop systems. The sequential systems were maize-chickpea (MZ-CP), soybean-chickpea (SB-CP) and groundnut-chickpea (GN-CP). The intercrop systems were maize/pigeonpea (MZ/PP), soybean/pigeonpea (SB/PP) and groundnut/ pigeonpea (GN/PP). All the individual crops of the cropping systems were calibrated and validated for their cultivar-specific coefficients using crop growth and yield data generated at the ICRISAT farm. In case of intercrop systems the parameters related to the competition for light between the two component crops were calibrated to get growth pattern of crops as observed in the field. Various agronomic practices that were considered to simulate the growth and yield of crops are given in the Table 3.

The data on soil properties needed for the model was obtained from the Regional Research Station of ANGRAU situated at Nandyal in the Kurnool district of Andhra Pradesh in India. Layer-wise information on soil physical parameters related to upper and lower limits water retention, relative root distribution in the soil profile, runoff and drainage coefficients were entered in the soil file and used to run the crop models. The soil is a Vertisol that hold about 200 mm of plant extractable water in the top 1.27 m of the soil profile. Crop cultivars simulated were PK 472 of soybean, TMV 2 of groundnut, Ratna 2201 of maize, ICCC 37 of chickpea and ICPL 87119 of pigeonpea. The sowing window for the rainy season crops was 1 June to 15 July. The simulations were initiated on 1 June each year, and the crop was sown in the model when total rainfall during the sowing window was at least 30 mm for continuous five days and soil moisture in the top 37 cm depth was at least 40% of the extractable water. After the harvest of the rainy season crop, a minimum turnaround time of five days was given before sowing the post-rainy season crop of chickpea. The sowing window for chickpea was 1 September to 30 November. The crop was sown during the window when soil moisture in the top 37 cm depth was at least 40% of the extractable water.

Considering agronomic management conditions described above, the simulation of crop yields was carried out for 46 years using weather data from 1961 to 2006. After simulating the crop yields of each crop,

Table 2: Correlation of total rainfall of various months with SST anomaly and SOI considering all years and the extreme rainfall years' data.

Months	All years (n=46)		Extreme rainfall years (n=30)	
	SST	SOI	SST	SOI
	Correlation coefficient (r)*			
MJJ	-0.31	0.48	-0.40	0.61
JJA	-0.43	0.50	-0.55	0.61
JAS	-0.48	0.55	-0.62	0.64
ASO	-0.49	0.52	-0.62	0.60
May-Oct	-0.45	0.53	-0.58	0.64

* All 'r' values are statistically significant at 5% level of probability

Table 3 : Agronomic practices considered for each crop component to simulate the cropping systems.

Management	MZ-CP	MZ/PP	SB-CP	SB/PP	GN-CP	GN/PP
Row ratios	NA	3:1	NA*	4:1	NA	3:1
Row spacing (cm)	MZ: 50 CP: 37.5	MZ: 75 PP: 150	SB: 37.5 CP: 37.5	SB: 37.5 PP:150	SB: 37.5 CP: 37.5	GN:37.5 PP: 150
Plant population (plants m^{-2})	MZ: 7 CP: 30	MZ: 7 PP: 4.9	SB: 30 CP: 30	SB: 30 PP: 4.9	GN: 30 CP: 30	GN: 25 PP: 4.9
N and P applications at sowing of rainy and post-rainy season crops (kg ha^{-1})	MZ: 25 N and 50 P CP: 25 N and 50 P	MZ: 17 N and 33 P	SB: 25 N and 60 P CP: 25 N and 50 P	SB: 25 N and 60 P	GN: 25 N and 40 P CP: 25 N and 50 P	GN: 25 N and 40 P
Other applications to maize (kg ha^{-1})	50 N at 30 DAS#; 25 N at 52 DAS	33 N at 30 DAS; 17 N at 52 DAS				

* NA = Not applicable; # DAS= days after sowing

total productivity of the cropping systems (sum of yields of two component crops) was calculated. Net income from the cropping systems was calculated for each year using the prevailing costs of inputs and field operations for crop production and market prices of the produce. The outputs of crop yields and net incomes of each year were categorized into three ENSO classes (El-Niño, La-Niña and Neutral phases) and three rainfall classes (normal, high and low rainfall years). The means and coefficients of variation (CV) of the total crop productivity and net income for each of the six classes were calculated to study the performance of cropping systems as influenced by ENSO or rainfall category. A cropping system was ranked high in performance if its net income was high and its CV in net income was low.

RESULTS AND DISCUSSION

Rainfall characteristics of seasons in relation to ENSO

Mean annual rainfall for the site is 800 mm. Of all the weather years 26% were El-Niño, 28% La-Niña and 46% Neutral years. Mean rainfall for the La-Niña, Neutral and El Niño years is 970 mm, 760 mm and 690 mm, respectively. Mean seasonal rainfall (June-September) for the La-Niña, Neutral and El-Niño years is 710 mm, 520 mm and 480 mm, respectively (Table 1). Probability distribution of seasonal rainfall showed that at given probability level rainfall was more for the La-Niña years (Fig. 1). Although the amount of rainfall was more for the Neutral years than in the El-Niño

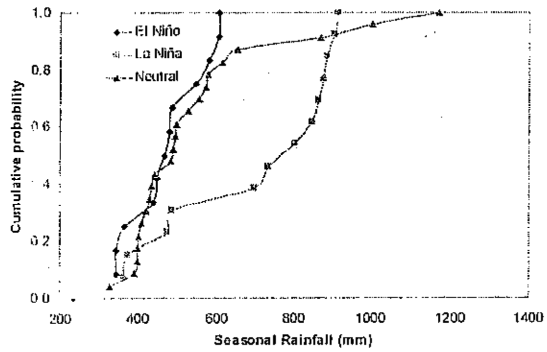

Fig. 1: Cumulative probability distribution of seasonal rainfall (June – September) at Nandyal for the three ENSO phases.

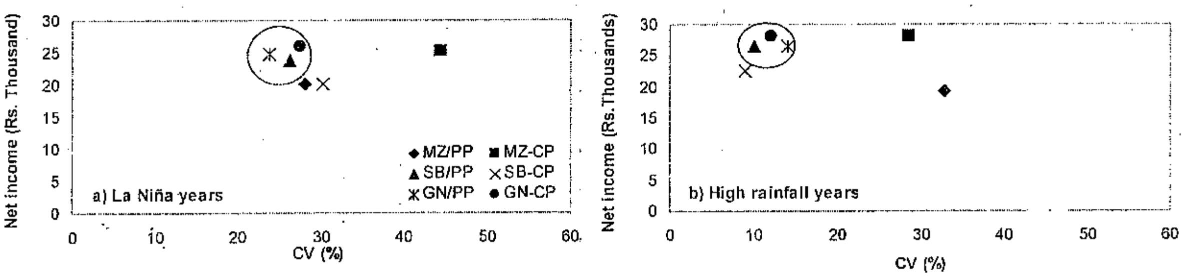

Fig. 2: Net income and associated CV of cropping systems during (a) La Niña and (b) high rainfall years

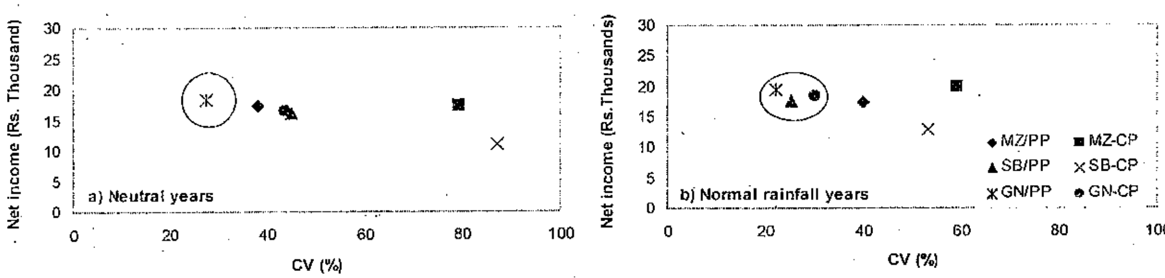

Fig. 3: Net income and associated CV of cropping systems during (a) Neutral and (b) normal rainfall years

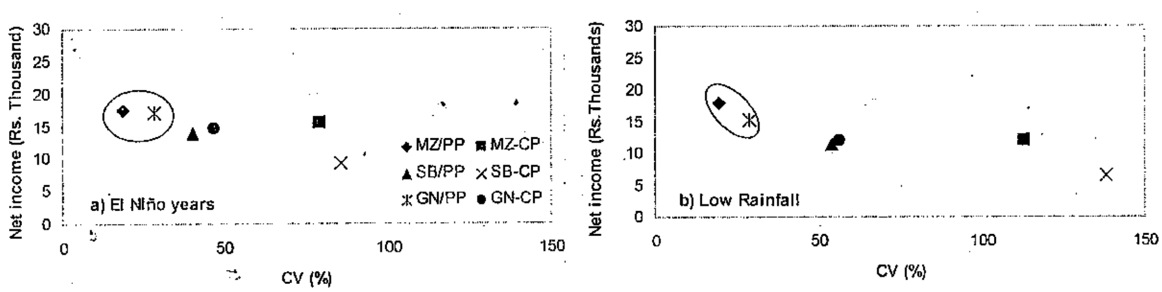

Fig. 4: Net income and associated CV of cropping systems during (a) El Niño and (b) low rainfall years.

Table 4 : Economic yields of component crops and total productivity of the cropping systems during ENSO phases.

Cropping systems	Rainy season crop		Postrainy Crop		Total	
	Yield	CV(%)	Yield	CV(%)	Yield	CV(%)
			La Niña phase			
MZ-CP	3480	52	1480	7	4970	37
MZ/PP	3260	16	820	34	4080	11
SB-CP	1730	37	1400	9	3130	21
SB/PP	1140	36	1550	15	2690	21
GN-CP	1850	14	1290	27	3130	15
GN/PP	1090	16	1510	19	2600	14
			Neutral phase			
MZ-CP	3270	54	1030	46	4300	44
MZ/PP	2850	37	740	37	3590	28
SB-CP	1600	30	850	58	2440	33
SB/PP	1080	29	1090	34	2170	26
GN-CP	1860	14	630	81	2480	20
GN/PP	1250	15	940	42	2200	14
			El Niño phase			
MZ-CP	2660	60	1150	32	3810	46
MZ/PP	2820	28	860	34	3680	19
SB-CP	1550	33	760	56	2300	29
SB/PP	1060	28	960	25	2020	23
GN-CP	1860	13	490	85	2350	20
GN/PP	1310	25	810	35	2120	15

years, it followed the same probability distribution pattern up to about 80% of cumulative probability and beyond this level rainfall amounts were substantially more than those for the El-Niño years. The seasonal rainfall means for the three rainfall classes were 850 mm for the high, 540 mm for the normal and 400 mm for the low rainfall years. These means represent the mean rainfall amounts if we were perfect in predicting the rainfall for the three rainfall classes.

Mean monthly rainfall of each of the five months (June to October) for the La Niña years was equal to or higher than that of the monthly means of El-Niño or Neutral years (Table 1). Except for the month of June, the rainfall for the July to October months was higher for the Neutral years than for the El Niño years with greater difference in rainfall for the months of July and October. This indicates that the crop during the El-Niño years will often face water stress during July and October and it will also be difficult to establish the second crop during October. In case of La-Niña years, the water availability during the month of October and later will be sufficient for crop establishment and growth.

Productivity of component crops in relation to ENSO and start of the season

Among the rainy season crops studied, maize was the most sensitive crop to the phases of ENSO. Mean yields of maize for the El-Niño phase were 76 to 87% of yields obtained for the La-Niña phase in the sequential and intercrop systems (Table 4). In case of soybean and groundnut the changes in yield because of ENSO phases were much less. This is due to the fact that because of sufficient seasonal rainfall and high water holding capacity of the soil at Nandyal, the chances of meeting the water requirements of these two crops are very high. Between the two post-rainy season crops, chickpea was more sensitive to ENSO phases than pigeonpea. Yield reductions of chickpea and pigeonpea from the La-Niña to El-Niño phase were the largest (46 to 62%) in the groundnut-based systems than in the soybean and maize based systems.

The major influence of ENSO phases was on the variability in crop yields, especially for the postrainy season crops. Except for the maize crop, the ENSO phases had a marginal influence on the variability in crop yields of rainy season crops (Table 4). However, for the postrainy season crops of chickpea and pigeonpea, the CV in yields was the lowest for the La Niña phase and significantly increased for the Neutral and El Niño phases of ENSO. The CV in yield of the post-rainy season crops was the highest for the Neutral phase.

The range in the start of the season varied from 43 to 55 days between the ENSO phases (Table 1). The yields of the rainy season crops were not significantly correlated with the start of the season (Table 5). However, the start of the season significantly influenced the yields of the post rainy season crops during El Niño and Neutral years, but not during the La Niña years. This is because of less rainfall in September and October for these two ENSO phases as compared to the La Niña phase (Table 1). This indicates the need to provide supplemental irrigation to the post-rainy season crops to increase the yields during the El Niño and Neutral years.

Total productivity in relation to ENSO

Total productivity of cropping systems was the highest during the La-Niña phase of ENSO with the lowest CV in yields as compared to the other phases. The maize-based cropping systems (MZ-CP and MZ/PP) were the most productive systems during all the phases of ENSO. This was followed by the soybean-based and groundnut-based systems. In maize-based systems, total productivity ranged from 4000 to 5000 kg ha^{-1} for the La Niña phase, whereas in other phases it ranged from 3600 to 4300 kg ha^{-1} (Table 4). The relative performance of cropping systems in terms of productivity followed the same trend across different phases of ENSO. Except for the groundnut-based systems, the CV in total productivity for the maize- and soybean-based systems was the highest for the Neutral phase. Among the cropping systems, the CV in yields was less in the intercropping systems as compared to sequential systems, indicating the stability yields albeit at lower levels of productivity.

Net income in relation to ENSO phases and rainfall classes

A cropping system was considered to be most promising if its net income was high and CV in net income was low. Therefore, the net income of cropping systems was plotted against their CVs for each ENSO phase and rainfall class. It was assumed that the performance of the cropping systems in the three rainfall classes was real if we were perfect in predicting seasonal rainfall to be normal, above normal (high rainfall) and below normal (low rainfall). Comparison of the performance of cropping systems in the La Niña rainfall years with the high rainfall years showed that in both the cases three copping systems, namely GN-CP, GN/PP and SB/PP had both higher net income and the lower CV as compared to the other cropping systems (Figs. 2a and b). In case of Neutral years the most promising cropping system was GN/PP (Fig. 3a), which formed a subset of the three most promising cropping systems (GN/PP, SB/PP and GN-CP) identified for the normal rainfall years (Fig. 3b). Similar results were obtained when the performance of cropping systems in the El-Niño years was compared with that of low rainfall years. The promising systems were MZ/PP and GN/PP intercrop systems and the worst were the SB-CP and MZ-CP in terms of economic gain and risks to net income (Figs. 4a and b). These results on the performance of cropping systems indicate that if we are able to predict the phases of the ENSO prior to the onset of the rainy season, then we can provide more suitable cropping systems options to the farmers to reduce climatic risks. This would help the farmers in making best use of the good rainfall years and minimize the negative effects in low rainfall years on their economic well being. However, the risks associated with cropping systems for the three ENSO phases are still higher than those obtained for the three corresponding rainfall classes, indicating the need to improve the seasonal rainfall predictions still further than what the ENSO phenomenon can provide.

CONCLUSIONS

Analysis of the long-term rainfall data for Nandyal showed that summer monsoon rainfall (June to September) at a given level of probability was higher for the La-Niña phase of ENSO than for the Neutral or

Table 5 : Correlation of crop yields with the start of the seasons for different ENSO phases.

ENSO phase	Sequential system Rainy season crop	Sequential system Postrainy crop (chickpea)	Intercrop system Rainy season crop	Intercrop system Postrainy crop (pigeonpea)
La Niña	0.27	0.06	0.09	-0.20
Neutral	0.13	-0.42*	0.12	-0.44*
El Niño	0.03	-0.34**	0.11	-0.35**

* Significant at 1% level of probability
** Significant at 5% level of probability

El Niño phases. Mostly the lowest amount of seasonal rainfall was associated with the El Niño phase. The yields of the post-rainy season crops were significantly influenced by the start of the season during the El Niño and Neutral phases of ENSO, but not during the La-Niña phase. The simulation analysis showed that among the cropping systems evaluated, groundnut-chickpea sequential, groundnut/pigeonpea and soybean/pigeonpea intercrop systems gave higher net income at low climatic risk during La-Niña years. During Neutral years, groundnut/pigeonpea intercrop systems gave higher net income, while during El Niño years the maize/pigeonpea and groundnut/ pigeonpea intercrop systems were the most promising. The study has demonstrated that until more accurate methods of seasonal rainfall predictions are available, assessing the potential of seasons based on ENSO would still help farmers to maximize incomes and reduce climatic risks by providing more efficient cropping system options in the region.

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