Assessing unrealized yield potential of maize producing districts in India

B. M. K. Raju[1,]*, C. A. Rama Rao[1], K. V. Rao[1], Ch. Srinivasarao[1], Josily Samuel[1], A. V. M. Subba Rao[1], M. Osman[1], M. Srinivasa Rao[1], N. Ravi Kumar[1], R. Nagarjuna Kumar[1], V. V. Sumanth Kumar[2], K. A. Gopinath[1] and N. Swapna[1]

[1]ICAR-Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad 500 059, India
[2]International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Hyderabad 502 324, India

The projected demand of maize production in India in 2050 is 4–5 times of current production. With the scope for area expansion being limited, there is need for enhancement of yield. This calls for identifying areas where huge unrealized yield potential exists. With a view to address the issue, the present study delineates homogeneous agro-climatic zones for maize production system in India taking district as a unit and using the factors production, viz. climate, soil, season and irrigated area under the crop. There are 146 districts in India that grow maize as a major crop. They were divided into 26 zones using multivariate cluster analysis. Study of variation in yield between districts within a zone vis-à-vis crop management practices adopted in those districts was found useful in targeting the yield gaps. These findings can have direct relevance to the maize farmers and district level administrators.

Keywords: Agro-climatic zone, climate, cluster, irrigation, potential yield, yield gap.

Background

MAIZE is the third largest food crop in India (in terms of area). As per 2013–14 statistics, its production was 24.26 mt from 9.06 m ha with a productivity of 2.68 t/ha. Projected demand for maize production by 2050 in India is around 121 mt (ref. 1). Much of this demand may be attributed to rising number of poultry farms. Raju *et al.*[2] reported a growth rate of 3% per annum in maize area in the early years of the 21st century. However scope for area expansion is limited and it becomes imperative to explore regions having potential for yield expansion. Maize is predominantly grown as a rainfed crop in India. Currently rainfed yields (1.9 tonne/ha) are much lower than irrigated yields (3.5 tonne/ha) in India[3]. This indicates huge untapped yield potential in rainfed maize production system. Studies are aimed towards breaking the yield barriers in rainfed production systems.

Maize is cultivated in 146 districts with a sown area of at least 10,000 ha in India accounting for about 80% maize area in the country (Figure 1). Based on area sown (thousand ha), the districts were divided into 3 groups as 10–50 thousand ha, 50–100 thousand ha and more than 100 thousand ha. Maize yield in tonne/ha at district level was also considered for portrayal and overlaid on the area map. It is apparent from Figure 1 that the districts, viz. Bhilwara, Udaipur and Banswara of Rajasthan, Sabarkantha and Panchmahal of Gujarat and Jhabua of Madhya

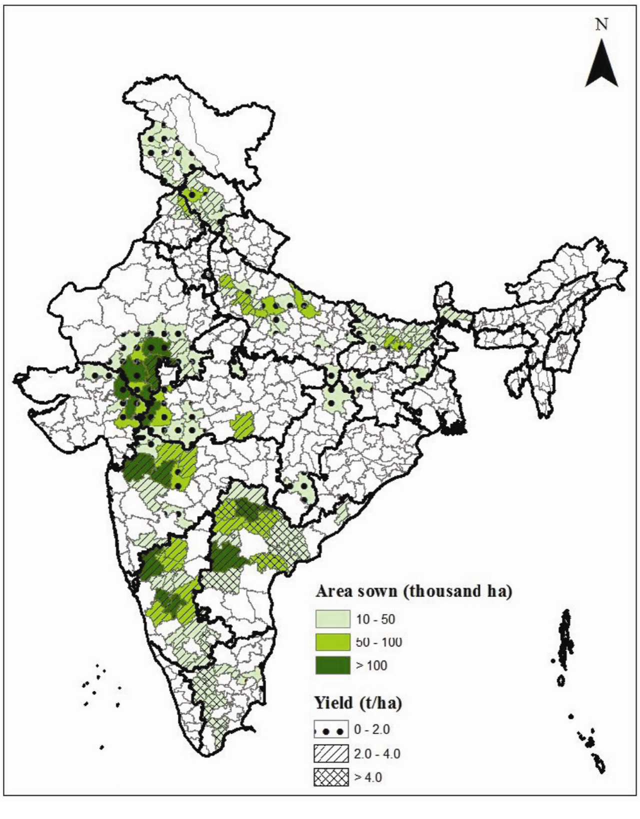

Figure 1. Major districts of maize in India along with area sown and yield.

*For correspondence. (e-mail: bmkraju@yahoo.com)

Pradesh have more than 100 thousand ha area, but the productivity is less than 2 tonne/ha. Impact on production will be immense if the yield levels are altered in this zone. But the question is: whether these districts (with given climate, soil and other resources available for maize) have potential for yield enhancement? If not, what are the districts that have potential for yield improvement? What is the extent of unrealized yield potential in them? This study aims to answer these questions by considering the districts *per se* growing maize as a major crop.

The approach

It is known that climate, soil, irrigation and season (*kharif*/*rabi*) are key determinants of crop choice and its productivity in a region. Farmers have little control over climate and soil while factors such as access to irrigation and season in which the crop is grown are relatively less amenable to changes. On the other hand, farmers have a choice in case of factors like adoption of technologies such as improved variety, nutrient management, etc. which are relatively more amenable at the farm level with appropriate policy and other interventions. The idea is to divide the major maize growing districts into clusters homogeneous in terms of climate, soil, share of irrigated area under the crop and growing season so that the differences in productivity within the cluster can be attributed to factors that are amenable to changes. In a nutshell, homogeneous agro-climatic zones are being delineated for maize production system using multivariate cluster analysis. As the resources that farmers have little control on for raising the crop within a cluster are largely similar, the district producing highest yield in a cluster may be regarded as a potential target for the remaining districts in the cluster. Unrealized yield potential (yield gap) for district X may be computed as the difference between the yield of the potential target district (highest yield in the cluster to which district X belongs) and yield of district X. The yield gap is assessed, subject to the level of resources in the cluster. The yield gap that we refer to in the literature, is assessed as difference in yields between the one obtained in the research station and the average obtained by farmers in a region. The difference with the conventional yield gap is that the potential yield in the present study is a reality and is attained by farmers of a certain district. Therefore this potential yield may be referred to as achievable yield and the concerned yield gap as bridgeable yield gap. Using this approach, yield efficiency of a district is assessed as efficiency of district X = (yield of district X)/(potential yield). Districts yielding at less than 50% of the potential (efficiency < 0.5) are designated as high potential districts. Unrealized yield potential in these districts is at least 50%. Using this criterion, districts having high unrealized yield potential (yield gap) for a given level of resources are identified.

Inter-cluster variation in yield can largely be attributed to variation in clustering variables (resources) whereas intra-cluster variation in yield arises from differences in other factors such as crop management practices and adoption of technology. The exercise helps in identifying crop management practices and technology responsible for higher productivity and taking up necessary interventions in the lagging districts. The present study examined these factors to explain yield variation within a cluster. The districts with low yield efficiency are compared to the district with potential yield or districts with very high/high yield efficiency with respect to consumption of nutrients like nitrogen (N), phosphorus (P) and potassium (K) per ha of maize area and extent of use of high yielding varieties (HYV) in the crop. Possible interventions in terms of input use through fertilizer nutrients and replacing traditional varieties with HYV are suggested for improving productivity in districts with low yield efficiency.

Previous studies

The districts of the country were divided into 127 agro-climatic zones using physical characteristics such as topography, rainfall, soils, cropping patterns and irrigation availability by the Indian Council of Agricultural Research (ICAR) in 1979 under the National Agricultural Research Project (NARP). The ICAR–National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Nagpur has come up with 20 agro-ecological regions and 60 agro-ecological sub-regions (AESR) for the country[4,5]. This classification was based on physiography, soils, bio-climatic types, and growing period which influence the supply of water for plant growth.

ICRISAT and ICAR[6] constructed an agricultural typology of India's rainfed areas using cluster analysis. The study integrated both socioeconomic and agro-ecological factors. The study constructed 16 district zones. Williams *et al.*[7] delineated agro-eco-regions from the landscapes of Iowa State using climatic, edaphic and topographic variables. Clustering was performed using K means algorithm using five *a priori* grouping schemes of 5–25 agro-eco-zones. These regions are useful in crop suitability analysis, strategic agro-economic development and risk analysis.

Kumar *et al.*[8] delineated homogeneous zones with respect to sensitivity of yield at district level to change in various climatic factors for crops, viz. sorghum, pearl millet and maize using cluster analysis. The zones aid in planning suitable adaptation strategies for each group as a whole rather than individual districts. Cluster analysis of data on various soil fertility variables was used to delineate soil nutrient management zones that provide basis for variable fertilizer management, a key task in precision agriculture[9–11]. Ruβ and Kruse[12] used hierarchical clustering with spatial constraints to ensure contiguous clusters while delineating management zones for precision agriculture. Data from ground-based sensors, aerial and satellite imagery and soil sampling were used in the study.

Materials and methods

District-wise statistics of yield, season-wise area sown under maize and area under irrigation were congregated from the websites of Directorate of Economics and Statistics (DES)[13], Department of Agriculture, Cooperation and Farmers Welfare (DACFW), Government of India and Agricultural Census[14], DACFW, Government of India. The study tried to minimize the number of clustering variables for parsimony. Accordingly various climatic parameters like rainfall, minimum temperature, maximum temperature, sunshine hours, wind speed, etc. were summarized in the form of moisture index (MI), the indicator commonly used for climatic classification. Available water holding capacity (AWHC) of the soil was considered as a summary indicator of soil properties such as soil texture and soil depth. Besides MI and AWHC at district level, percentage irrigated area under maize and percentage *rabi* area under maize at district level which have direct bearing on yield were used as clustering variables.

The study used the moisture index computed by Raju *et al.*[15] which brought out climatic classification at district level. Based on MI value, districts were classified as arid (MI < –66.6), dry semi-arid (MI = –66.6 to –50), moist semi-arid (MI = –50 to –33.3), dry sub-humid (MI = –33.3 to 0), moist sub-humid (MI = 0 to 20), humid (MI = 20 to 99.9) and per-humid (MI > 99.9) districts. District level AWHC values were derived by integrating the soil texture and soil depth maps and averaging in GIS environment. Soil maps of NBSS and LUP and Dunne and Wilmott[16] were used for the purpose. AWHC of less than 60 mm is considered as low and more than 100 mm as high. Soils with higher AWHC retain more moisture and provide better support for crop growth.

Multivariate cluster analysis was carried out using standardized clustering variables. The pairwise distance among the districts with respect to clustering variables in the study was computed using squared Euclidean distance. Ward's method of hierarchical agglomeration was used to divide the 146 districts into clusters. The criterion used for determining the number of clusters was to increase the number of clusters sequentially (one at a time) till the share of intra-cluster variation went below 5%. All the analysis was carried out using SPSS.

To compute yield efficiency of a district with respect to a given crop, yield of that district was compared to the highest yield obtained (with potential target district) in the cluster to which the district belongs. Let the yield in the *j*th district belonging to the *k*th cluster be X_{jk} and the maximum yield in the *k*th cluster be M_k.

Yield efficiency of *j*th district, $Z_j = X_{jk}/M_k$.

Based on Z_j value (Table 1), the districts may be classified as shown in Table 2.

In order to explain the between-district yield variation within a cluster, the variation in per ha nutrient consumption in maize with respect to N, P and K and percentage maize area under HYV were used. The data of cropwise nutrient use and use of HYV were drawn from Input Survey of Agricultural Census[14], DACFW, Government of India.

Results

Multivariate cluster analysis divided the 146 major maize growing districts of India into 26 homogeneous agro-climatic zones (Figure 2). Unlike the study by Ruß and Kruse[12], which used hierarchical clustering with spatial constraints to ensure contiguous clusters, the present study does not impose such constraints. The authors intend to exploit the diversity in crop management within a cluster that caused variation in yield. Imposing spatial constraints may put two districts having similar agro-climatic features but far apart, in different clusters. If the district far apart has potential to set the target with very high yield on account of better crop management practices, we may miss the opportunity to learn from it. The characteristics of each zone with respect to clustering variables, number and list of districts that belong to a zone along with yield and range of yield efficiency and average maize yield of the zone are furnished in Table 2.

Discussion

Scope for improving maize yield in districts with low efficiency

As discussed in the approach earlier, intra-cluster variation in yield is largely attributed to difference in crop management between districts within a cluster. Crop management includes many factors such as adoption of technology including use of high yielding varieties, timely sowing, timely and optimum nutrient use through fertilizers, timely plant protection from pests and diseases using appropriate methods, timely and proper weed management, timely irrigation, etc. However district level

Table 1. Classification of districts based on yield efficiency

Z_j	Efficiency	Unrealized potential
0–0.50	Low	High
0.50–0.75	Medium	Medium
0.75–0.90	High	Low
0.90–1.00	Very high	Very low

Table 2. Summary statistics of maize clusters (26 clusters from 146 districts)

Cl	ND	Cluster features	E	Districts in cluster with yield
1	8	MI: 6 (–9 to 26) AWHC: 58 (48 to 60) % Irri. area: 11 (0 to 26) % Rabi area: 0 (0 to 2) Yield: 1288 (800 to 2674)	L	Doda – J&K (1141), Baramulla – J&K (947), Kupwara – J&K (933), Budgam – J&K (882), Gonda – UP (800)
			M	Anantnag – J&K (1507), Dumka – JHA (1418)
			H	–
			VH	Rajouri – J&K (2674)
2	4	MI: 4 (–10 to 18) AWHC: 20 (20 to 20) % Irri. area: 1 (0 to 4) % Rabi area: 0 (0 to 0) Yield: 2181 (1793 to 2867)	L	–
			M	Kathua – J&K (2073), Shimla – HP (1989), Poonch – J&K (1793)
			H	–
			VH	Kullu – HP (2867)
3	8	MI: 5 (–14 to 21) AWHC: 99 (79 to 118) % Irri. area: 4 (0 to 10) % Rabi area: 0 (0 to 0) Yield: 1819 (705 to 2990)	L	Bahraich – UP (1070), Shravasti – UP (705)
			M	Hamirpur – HP (1914), Dehradun – UK (1860), Bastar – CHHT (1690), Jammu – J&K (1557)
			H	–
			VH	Shimoga – KK (2990), Mandi – HP (2767)
4	2	MI: 51 (46 to 55) AWHC: 22 (20 to 24) % Irri. area: 8 (3 to 12) % Rabi area: 0 (0 to 0) Yield: 2019 (1861 to 2177)	L	–
			M	–
			H	Kangra – HP (1861)
			VH	Chamba – HP (2177)
5	5	MI: –1 (–13 to 7) AWHC: 140 (127 to 150) % Irri. area: 16 (8 to 25) % Rabi area: 0 (0 to 0) Yield: 2355 (2126 to 2795)	L	–
			M	–
			H	Solan – HP (2387), Una – HP (2235), Gurdaspur – PNJ (2231), Bilaspur – HP (2126)
			VH	Sirmaur – HP (2795)
6	6	MI: –35 (–51 to –9) AWHC: 98 (81 to 122) % Irri. area: 81 (67 to 99) % Rabi area: 0 (0 to 0) Yield: 4159 (3068 to 5491)	L	–
			M	Jalandhar – PNJ (3600), Hoshiarpur – PNJ (3371), Salem – TN (3068)
			H	Shahid Bhagat Singh Nagar – PNJ (4147)
			VH	Erode – TN (5491), Coimbatore – TN (5276)
7	8	MI: –34 (–43 to –23) AWHC: 149 (137 to 155) % Irri. area: 5 (0 to 15) % Rabi area: 0 (0 to 1) Yield: 1524 (648 to 3311)	L	Kanpur City – UP (1652), Hardoi – UP (1479), Jaunpur – UP (1354), Unnao – UP (1234), Sonbhadra – UP (698), Sitapur – UP (648)
			M	Budaun – UP (1813)
			H	–
			VH	Rupnagar – PNJ (3311)
8	7	MI: –63 (–73 to –57) AWHC: 103 (92 to 112) % Irri. area: 10 (2 to 17) % Rabi area: 2 (0 to 5) Yield: 2225 (785 to 4523)	L	Bundi – RAJ (2278), Chitradurga – KK (2048), Sirohi – RAJ (1568), Banaskantha – GUJ (1551), Pali – RAJ (785)
			M	Davanagere – KK (2824)
			H	–
			VH	Thoothukudi – TN (4523)
9	21	MI: –58 (–70 to –42) AWHC: 125 (115 to 134) % Irri. area: 3 (0 to 10) % Rabi area: 2 (0 to 9) Yield: 1854 (811 to 3424)	L	Jalna – MAH (1578), Kota – RAJ (1417), Dewas – MP (1360), Dhule – MAH (1353), Khargone – MP (1332), Dahod – GUJ (1238), Dhar – MP (1211), Jhabua – MP (1121), Barwani – MP (1067), Tonk – RAJ (986), Ajmer – RAJ (893), Osmanabad – MAH (811)
			M	Jalgaon – MAH (2535), Nandurbar – MAH (1996), Khandwa – MP (1840)
			H	Buldhana – MAH (3025), Nasik – MAH (2886), Aurangabad – MAH (2755), Mahabubnagar – TG (2723)
			VH	Rangareddy – TG (3424), Medak – TG (3390)

(*Contd*)

Table 2. (*Contd*)

Cl	ND	Cluster features	E	Districts in cluster with yield
10	8	MI: –56 (–66 to –42)	L	Dungarpur – RAJ (1242), Kheda – GUJ (668), Sabarkanta – GUJ (589)
		AWHC: 69 (44 to 81)		
		% Irri. area: 2 (0 to 11)	M	Cuddalore – TN (1944), Bhilwara – RAJ (1708), Udaipur – RAJ
		% Rabi area: 2 (0 to 19)		(1621), Rajsamand – RAJ (1580)
		Yield: 1496 (589 to 2614)	H	–
			VH	Chittorgarh – RAJ (2614)
11	13	MI: –42 (–49 to –29)	L	Perambalur – TN (1467), Baran – RAJ (1389), Panchmahal -
		AWHC: 110 (88 to 120)		GUJ (1241), Palamu – JHA (1067), Lalitpur – UP (893)
		% Irri. area: 5 (0 to 20)	M	Jhalawar – RAJ (2550), Haveri – KK (2512), Chhindwara – MP
		% Rabi area: 2 (0 to 13)		(2352), Ratlam – MP (1963), Banswara – RAJ (1777)
		Yield: 2042 (893 to 3451)	H	Chamarajanagar – KK (2667)
			VH	Mysore – KK (3451), Hassan – KK (3220)
12	6	MI: –51 (–55 to –46)	L	Mainpuri – UP (2300), Aligarh – UP (2236), Auraiya – UP
		AWHC: 149 (133 to 160)		(2168), Bulandshahar – UP (2057), Etah – UP (2006)
		% Irri. area: 90 (75 to 100)	M	–
		% Rabi area: 0 (0 to 0)	H	–
		Yield: 2814 (2006 to 6117)	VH	Theni – TN (6117)
13	8	MI: –52 (–66 to –41)	L	Bellary – KK (2768), Tumkur – KK (2403), Dharwad – KK
		AWHC: 123 (110 to 150)		(2254), Farrukhabad – UP (2203), Kannauj – UP (1891)
		% Irri. area: 41 (27 to 49)	M	–
		% Rabi area: 1 (0 to 4)	H	Virudhunagar – TN (4929), Bangalore – Rural (KK) (4740)
		Yield: 3343 (1891 to 5555)	VH	Dindigul – TN (5555)
14	4	MI: -24 (-31 to -17)	L	Patna – BIH (1305), Ballia – UP (787)
		AWHC: 50 (45 to 52)	M	Sarguja – CHHT (1420)
		% Irri. area: 17 (0 to 38)	H	–
		% Rabi area: 6 (0 to 12)	VH	Banka – BIH (2783)
		Yield: 1574 (787 to 2783)		
15	5	MI: 12 (5 to 25)	L	–
		AWHC: 34 (20 to 50)	M	–
		% Irri. area: 70 (54 to 81)	H	Purnea – BIH (3341), Supaul – BIH (3128), Katihar – BIH (3008)
		% Rabi area: 29 (16 to 37)	VH	Araria – BIH (3965), Champaran – West (BIH) (3700)
		Yield: 3429 (3008 to 3965)		
16	5	MI: –16 (–22 to –10)	L	Gopalganj – BIH (1452)
		AWHC: 48 (39 to 50)	M	Champaran – East (BIH) (2234), Muzafarpur – BIH (2155)
		% Irri. area: 74 (50 to 92)	H	–
		% Rabi area: 37 (31 to 41)	VH	Saharsa – BIH (3714), Madhepura – BIH (3490)
		Yield: 2609 (1452 to 3714)		
17	3	MI: –22 (–24 to –21)	L	–
		AWHC: 50 (50 to 50)	M	–
		% Irri. area: 76 (71 to 83)	H	Samastipur – BIH (3322), Darbhanga – BIH (3026)
		% Rabi area: 57 (54 to 60)	VH	Khagaria – BIH (3818)
		Yield: 3389 (3026 to 3818)		
18	5	MI: -21 (–24 to –16)	L	–
		AWHC: 50 (50 to 50)	M	Begusarai – BIH (1678), Saran – BIH (1422), Siwan – BIH (1367)
		% Irri. area: 45 (31 to 55)	H	–
		% Rabi area: 22 (19 to 27)	VH	Bhagalpur – BIH (2257), Vaishali – BIH (2129)
		Yield: 1771 (1367 to 2257)		
19	2	MI: 104 (104 to 104)	L	–
		AWHC: 28 (21 to 35)	M	–
		% Irri. area: 5 (1 to 10)	H	Jalpaiguri – WB (2314)
		% Rabi area: 0 (0 to 1)	VH	Darjeeling – WB (2612)
		Yield: 2463 (2314 to 2612)		

(*Contd*)

Table 2. (*Contd*)

Cl	ND	Cluster features	E	Districts in cluster with yield
20	1	MI: –46 (–46 to –46)		
		AWHC: 121 (121 to 121)		
		% Irri. area: 38 (38 to 38)		Vadodara – GUJ (951)
		% Rabi area: 87 (87 to 87)		
		Yield: 951 (951 to 951)		
21	2	MI: –60 (–62 to –58)	L	–
		AWHC: 129 (124 to 134)	M	Sangli – MAH (2080)
		% Irri. area: 13 (11 to 14)	H	–
		% Rabi area: 27 (19 to 36)	VH	Ahmednagar – MAH (3143)
		Yield: 2611 (2080 to 3143)		
22	5	MI: –38 (–40 to –30)	L	–
		AWHC: 127 (116 to 134)	M	Adilabad – TG (3770), Belgaum – KK (3099)
		% Irri. area: 61 (40 to 81)	H	Warangal – TG (4376)
		% Rabi area: 32 (22 to 41)	VH	Karimnagar – TG (5254), Nizamabad – TG (5220)
		Yield: 4344 (3099 to 5254)		
23	2	MI: –27 (–27 to –27)	L	–
		AWHC: 108 (98 to 119)	M	Vizianagaram – AP (3780)
		% Irri. area: 54 (53 to 54)	H	–
		% Rabi area: 56 (54 to 58)	VH	Khammam – TG (6373)
		Yield: 5077 (3780 to 6373)		
24	3	MI: –41 (–49 to –33)	L	–
		AWHC: 102 (88 to 110)	M	–
		% Irri. area: 87 (73 to 97)	H	Krishna – AP (7672), West Godavari – AP (7403)
		% Rabi area: 93 (84 to 99)	VH	Guntur – AP (9486)
		Yield: 8187 (7403 to 9486)		
25	3	MI: –65 (–68 to –64)	L	Koppal – KK (2839)
		AWHC: 117 (109 to 125)	M	Gadag – KK (3009),
		% Irri. area: 59 (47 to 70)	H	–
		% Rabi area: 14 (7 to 24)	VH	Kurnool – AP (5844)
		Yield: 3897 (2839 to 5844)		
26	2	MI: –67 (–68 to –67)	L	–
		AWHC: 122 (120 to 123)	M	Bijapur – KK (2772)
		% Irri. area: 99 (98 to 100)	H	–
		% Rabi area: 23 (19 to 26)	VH	Bagalkot – KK (3805)
		Yield: 3289 (2772 to 3805)		

Cl, Cluster (zone) number; ND, Number of districts; MI, Average moisture index; AWHC, Average available water holding capacity in mm; % Irri. area, % Irrigated area; Yield, Average yield (kg/ha); E, Efficiency category (L, Low; M, Medium; H, High and VH, Very high); AP, Andhra Pradesh; BIH, Bihar; CHHT, Chhattisgarh; GUJ, Gujarat; HP, Himachal Pradesh, J&K, Jammu & Kashmir; JHA, Jharkhand; KK, Karnataka; MP, Madhya Pradesh; MAH, Maharashtra; PNJ, Punjab; RAJ, Rajasthan; TG, Telangana; TN, Tamil Nadu; UP, Uttar Pradesh; UK, Uttarakhand; WB, West Bengal. Numbers in parentheses in last column are yields in respective districts. In other columns, range was given in parenthesis.

information is not available on many of these factors. An attempt was made to discriminate between low and high/very high yield efficiency districts with respect to factors like use of HYVs, nutrient use in terms of N, P and K for which district level data were available. Use of N, P and K in maize crop and percentage of area under HYV in maize were provided for low (<0.5) and very high/high (>0.75) yield efficiency categories (Table 3). The numbers are averages based on the data of districts shown in those categories. This analysis may give a fair idea of where low efficiency districts are lagging behind and scope for improving the yield in those districts.

The results in Table 3 reveal that use of HYVs is the area where low yield efficiency districts are lagging behind in cluster-1. The yield gap can be bridged to some extent if this issue is addressed. In cluster-3, there is scope for improving yield of Shravasti and Bahraich districts of Uttar Pradesh by enhancing nutrient use in terms of N, P and K and bringing more area under HYVs. In cluster-7 also, there is lot of scope for improving yield of low efficiency districts by enhancing nutrient use and area under HYVs. In cluster-8, maize area covered by HYV in low efficiency category is only 55% (average); whereas percentage maize area covered by HYV in

Thoothukudi, a district in very high/high efficiency category, is 100%. Substantial yield gain can be expected if the use of HYVs is promoted. In cluster-9, three districts of Telangana showed discernible difference in yield compared to the 8 districts in the low efficiency category. Higher nutrient use and much higher percentage of maize area under HYV could be among the important drivers for difference in yield. In clusters-10, 12 and 13, there is scope for yield improvement in districts in the low efficiency category by bringing more area under HYV. It is worth-mentioning that the percentage of maize area under HYV was relatively less in the low efficiency category in all the clusters shown in Table 3. So, this factor deserves further attention by researchers, extension agencies and policy makers and may be considered as the key driver for yield enhancement.

Joshi *et al.*[17] reported substantial difference in maize yield between traditional and non-traditional maize growing areas in India through a micro level study. The study attributed the difference in yield to mainly adoption of improved varieties. Farmers in non-traditional areas are growing maize as a commercial crop with 100% seed replacement (to hybrids) and higher level of nutrient use as compared to traditional areas. The findings of the present study as shown in Table 3 are, largely, in agreement with conclusions made by Joshi *et al.*[17]. The districts in the low efficiency category mostly belong to traditional maize areas with large gap in adoption of HYV and low input use whereas districts in high/very high efficiency category belong to non-traditional areas.

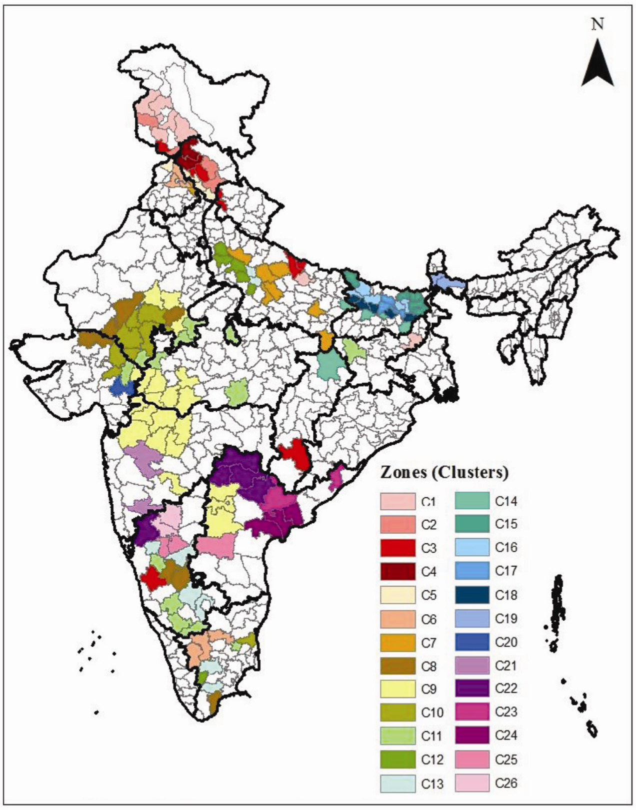

Figure 2. Agro-climatic zones of maize in India.

As seen in Table 3, Dhar and Dewas districts of Madhya Pradesh belonging to cluster-9 are operating at less than 50% of their potential. Srinivasarao *et al.*[18] recommended earthing up of maize 25 days after sowing using small blade harrow which can give an additional yield of 338 kg/ha with marginal cost as compared to flat bed sowing without such management. Similarly ridge planting in Sonbhadra and Jaunpur districts of Uttar Pradesh (belonging to cluster-7 with efficiency <0.5) can enhance maize yield by 37–73% as compared to flat bed sowing without such management.

Potential gain in production, when unrealized yield potential is realized, was assessed at district level by multiplying unrealized yield potential (yield gap) with area sown. This gain will be high if area sown is more and yield gap is large. An estimate of potential gain in production was provided at country level by aggregating district level gain in production. There are 14 districts with maize area more than 100 thousand ha. If unrealized yield potential is realized in these districts the gain in production will be 2.3 mt. Of these districts, Sabarkantha and Panchmahal districts of Gujarat and Jhabua district of Madhya Pradesh have high unrealized yield potential (efficiency <0.5). If these districts are targeted first, the returns will be high. Estimated potential gain in production at country level, when unrealized yield potential is realized in all the districts, is 8.4 mt.

Limitation of the study

A small portion of variation still exists between districts within a cluster with respect to clustering variables. This variation can contribute to intra-cluster yield variation to some extent but is not substantial. The moisture index used in the analysis to characterize climate is based on long-term data. It is not necessary that similar climate exists in all the years for which yield data were considered. However using three years' data and taking average yield may circumvent the problem to a large extent. It was observed that the level of nutrient use in some of the model districts or districts in very high/high efficiency category is below the recommended level (e.g. Thoothukudi (Tamil Nadu), Rajouri (Jammu and Kashmir), Mandi (Himachal Pradesh), etc.). Similarly, percentage maize area sown with HYV in some model districts is not 100% (e.g. Rajouri (Jammu and Kashmir), Mandi (Himachal Pradesh), Chittorgarh (Rajasthan), etc.). It implies that there is scope for yield improvement in model districts as well and the potential yield in those clusters could be more than the reported numbers. Hence, the potential yields reported in the present study may be viewed as observed potential yields. Economics of the adoption of improved technology and input use were not part of the

Table 3. Nutrient use (N, P, K) and extent of use of HYV in very high/high and low efficiency categories

Cluster	Efficiency	Districts in descending order of yield	Average			
			N (kg/ha)	P (kg/ha)	K (kg/ha)	HYV (% area)
1	Very high/high	Rajouri – J&K (2674)	26	11	2	80
	Low	Doda – J&K (1141), Baramulla – J&K (947), Kupwara – J&K (933), Budgam – J&K (882), Gonda – UP (800)	66	17	7	54
3	Very high/high	Mandi – HP (2767)	38	12	7	92
	Low	Bahraich – UP (1070), Shravasti – UP (705)	21	7	0	51
7	Very high/high	Rupnagar – PNJ (3311)	130	38	0	100
	Low	Kanpur City – UP (1652), Hardoi – UP (1479), Jaunpur – UP (1354), Unnao – UP (1234), Sonbhadra – UP (698), Sitapur – UP (648)	38	12	0	62
8	Very high/high	Thoothukudi – TN (4523)	21	0	4	100
	Low	Sirohi – RAJ (1568), Banaskantha – GUJ (1551), Pali – RAJ (785)	54	27	0	55
9	Very high/high	Rangareddy – TG (3424), Medak – TG (3390), Mahabubnagar – TG (2723)	84	56	7	89
	Low	Kota – RAJ (1417), Dewas – MP (1360), Khargone – MP (1332), Dahod – GUJ (1238), Dhar – MP (1211), Barwani – MP (1067), Tonk – RAJ (986), Ajmer – RAJ (893)	60	15	7	47
10	Very high/high	Chittorgarh – RAJ (2614)	64	28	0	87
	Low	Dungarpur – RAJ (1242), Sabarkanta – GUJ (589)	85	3	0	60
12	Very high/high	Theni – TN (6117),	80	2	0	100
	Low	Mainpuri – UP (2300), Aligarh – UP (2236), Auraiya – UP (2168), Bulandshahar – UP (2057), Etah – UP (2006)	75	31	0	93
13	Very high/high	Dindigul – TN (5555)	80	47	54	100
	Low	Farrukhabad – UP (2203), Kannauj – UP (1891)	65	24	0	80

GUJ, Gujarat; HP, Himachal Pradesh; J&K, Jammu and Kashmir; MP, Madhya Pradesh; PNJ, Punjab; RAJ, Rajasthan; TG, Telangana; TN, Tamil Nadu; UP, Uttar Pradesh. Note: (1) The clusters in which there exist some districts in low efficiency category were only considered for presentation. (2) Although there exists few districts in low efficiency category in cluster numbers 11, 14, 16 and 25, data on nutrient use and area under HYV were not available. (3) Only those districts for which data were available were used in computing average. (4) Numbers in parentheses are maize yield in those districts.

study. Before implementing the recommendations (if any) suggested for improving yield by enhancing use of HYVs and nutrient use, it should be ensured that the recommendations are commensurate with economic viability at farmer level.

The present study examined the factors of nutrient use and use of HYVs to explain low yield in districts within a cluster. There are many other crop specific factors such as methods and timeliness of various operations such as sowing, irrigation, plant protection, weed management, etc. that contribute to yield variation; but data were not available at district level for these factors. Besides, low yields may be due to factors such as weak socio-economic conditions of farmers, poor literacy, infrastructure, lack of/inadequate access to timely credit, weak reach-out of technology to farmers in a district. These enabling factors influence yields of all the crops in a district. It was not possible to explore all factors exhaustively in the present study.

Conclusion

Findings of the study may have direct relevance to maize farmers and district level administrators. Maize farmers who are unable to harvest better yield or administrators in the agriculture department of a district may look at the efficiency of their district. If it is very low (<0.5), one needs to examine the cluster to which the district belongs, yield obtained by the model district, adoption of technology by districts with very high/high efficiency including use of HYV, nutrient use in terms of N, P, K, etc. This may give some idea of where the target district is lagging behind and scope for interventions for improving yield in the target district. Gathering information on other crop management variables enables precise identification of interventions. For more clarity, a visit to the model district may prove to be helpful.

1. Amarasinghe, U. A. and Om Prakash Singh, Changing consumption patterns of India: implications on future food demand. In *India's Water Future: Scenarios and Issues* (eds Amarasinghe, U. A., Shah, T. and Malik, R. P. S.). International Water Management Institute, Colombo, Sri Lanka, 2008, pp. 131–146.
2. Raju, B. M. K., Rama Rao, C. A. and Venkateswarlu, B., Growth performance of major rainfed crops in India. *Indian J. Dryland Agric. Res. Dev.*, 2010, **25**(1), 17–22.
3. CRIDA, Annual Report 2013–2014. Central Research Institute for Dryland Agriculture, Hyderabad, India, 2014, p. 197.
4. Sehgal, J., Mandal, D. K., Mandal, C. and Vadivelu, S., Agro-Ecological Regions of India. Second Edition, Tech. Bull. No. 24, NBSS and LUP, Nagpur, India, 1992, p. 130.
5. Sehgal, J., Mandal, D. K. and Mandal, C., Agro-Ecological Subregions of India (Map). NBSS and LUP, Nagpur, India, 1995.
6. ICRISAT, ICAR, Typology construction and economic policy analysis for sustainable rainfed agriculture. A report on sustainable rainfed agriculture research and development: Database development, typology construction and economic policy analysis (Module I), International Crops Research Institute for Semi-Arid Tropics, Hyderabad, Andhra Pradesh, India, 1999, pp. 142.
7. Williams, C. L., Hargrove, W. W., Liebman, M. and James, D. E., Agro-ecoregionalization of Iowa using multivariate geographical clustering. *Agric., Ecosyst. Environ.*, 2008, **123**, 161–174.
8. Kumar, S., Raju, B. M. K., Rama Rao, C. A., Kareemulla, K. and Venkateswarlu, B., Sensitivity of yields of major rainfed crops to climate in India. *Indian J. Agric. Econ.*, 2011, **66**(3), 340–352.
9. Davatgar, N., Neishabouri, M. R. and Sepaskhah, A. R., Delineation of site specific nutrient management zones for a paddy cultivated area based on soil fertility using fuzzy clustering. *Geoderma*, 2012, **173–174**, 111–118.
10. Fu, Q., Wang, Z. and Jiang, Q., Delineating soil nutrient management zones based on fuzzy clustering optimized by PSO. *Math. Comput. Model.*, 2010, **51**, 1299–1305.
11. Ortega, R. A. and Santibanez, O. A., Determination of management zones in corn (*Zea mays* L.) based on soil fertility. *Comput. Electron. Agric.*, 2007, **58**, 49–59.
12. Ruß, G. and Kruse, R., Data Mining in Agriculture: Exploratory Hierarchical Clustering for Management Zone Delineation in Precision Agriculture. In *Advances in Data Mining Applications and Theoretical Aspects*, Proceedings of 11th Industrial Conference-ICDM-2011, LNAI 6870 (ed. Perner, P.), Springer-Verlag Berlin Heidelberg, 2011, pp. 161–173.
13. DES, 2014; http://eands.dacnet.nic.in/
14. Agricultural Census, 2014; http://agcensus.nic.in/
15. Raju, B. M. K. *et al.*, Revisiting climatic classification in India: a district level analysis. *Curr. Sci.*, 2013, **104**(4), 492–495.
16. Dunne, K. A. and Willmott, C. J., Global distribution of plant-extractable water capacity of soil (Dunne). Oak Ridge, Tennessee, USA (Oak Ridge National Laboratory Distributed Active Archive Center), 2000; doi:10.3334/ORNLDAAC/545.
17. Joshi, P. K., Singh, N. P., Singh, N. N., Gerpacio, R. V. and Pingali, P. L., Maize in India: Production Systems, Constraints, and Research Priorities. Mexico, DF: CIMMYT, 2005, p. 42.
18. Srinivasarao, Ch., Ravindra Chary, G., Mishra, P. K., Subba Reddy, G., Sankar, G. R. M., Venkateswarlu, B. and Sikka, A. K., *Rainfed Farming A Compendium of Doable Technologies*, All India Coordinated Research Project for Dryland Agriculture, ICAR – Central Research Institute for Dryland Agriculture, Hyderabad, India, 2014, p. 194.

ACKNOWLEDGEMENT. We thank ICAR-CRIDA for necessary infrastructure support.

Received 27 August 2016; revised accepted 4 January 2018

doi: 10.18520/cs/v114/i09/1885-1893