Soil-based fertilizer recommendations for precision farming

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In India, current fertilizer recommendations are very old and developed based on agro-climatic zones. The assumption is that agro-climatic zones are homogenous units. However, analyses of agro-climatic zones reveal variability in soil within each zone. Current agro-climatic zonal fertilizer recommendations are generalized for entire zone and not addressed to specific soil types. To know the soil variability within the National Agricultural Research Project (NARP) agro-climate zone and suitability of current fertilizer recommendations, sugarcane in northern dry zone of Karnataka was studied as a test crop. The results indicated that agro-climatic zones vary widely in soils and in their potentials, behaviour and response to management. It was also observed that fertilizer application efficiency varied within each zone and within the management units. These differences contributed to errors of both excess and insufficient applications. Besides, there is a continuous removal of secondary and micronutrients by crops in all farming situations resulting in inappropriate management practices. All these suggest that soil-based fertilizer recommendations should be preferred to achieve precision in farming and to maximize crop production, maintain soil health and minimize fertilizer misapplication.

Keywords: Agro-climatic zone, fertilizer recommendation, management unit, precision farming, soil variability.

SOIL forms the basis for any crop production activity and is the most precious resource. Declining soil fertility is one of the important factors that directly affects the productivity. Blanket crop production technologies including fertilizer recommendations have accelerated the situation over three to four decades. Therefore, soil fertility management is crucial to ensure evolving farming systems that are more sustainable.

Amongst the factors of production inputs, fertilizers have played a key role in increasing production of food grains and other commercial crops in India since 1960. Fertilizers are one of the costly inputs but continue to exert significant contribution to produce additional food grains for the ever increasing population. To get maximum benefit and reduce nutrient losses from fertilizers, they must be applied in the right quantity, source and combination at the right time using the right method.

The current agronomic package of practices are recommended uniformly for a zone, irrespective of the soil variability that occurs within a zone. Fertilizer recommendations worked out from experiments conducted in one soil type may not hold good for another soil type because of their basic variations in texture, reaction and mineralogy. The response to fertilizers is greatly influenced by soil type and spatial soil variability that has resulted from complex geological and pedalogical processes. Spatial variation of soil properties decreases the use-efficiency of fertilizers applied uniformly at the field scale[1–3]. At the same time, there is an increasing pressure to reduce the application of fertilizers in commercial agriculture and minimize non-point sources of pollution, of both surface and ground waters. Therefore, application of variable rather than uniform rates of fertilizers has been proposed to avoid application of excess fertilizers where it will not be properly utilized by crops[4,5]. There was a selective crop response to nutrients in different soils and the responsiveness varied with soil development and maturity of the soil[6].

Consideration of in-field variations in soil fertility and crop conditions and matching the agricultural inputs like seed, fertilizer, irrigation, insecticide, pesticide, etc. to optimize the input or maximizing the crop yield from a given quantum of input, is referred to as 'precision farming, precision agriculture' (precision crop management, site-specific crop management, soil-based crop management). The term 'precision farming' means carefully tailoring the management practices for soil and crop suiting to the different conditions found in each field.

Precision farming is desirable if agricultural productivity has to be increased. Though widely adopted in developed countries, precision farming is yet to take firm ground in India primarily due to its unique pattern of land

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holdings (<1.57 ha), poor infrastructure, lack of farmers' inclination to take risk, socio-economic and demographic conditions.

Alternatively, soil variability within the region can be identified through soil resource maps. Present fertilizer recommendations could be refined based on soils to increase the productivity of crops, and reduce the cost of production and environmental pollution. In order to apply variable rates of fertilizers, a methodology needs to be developed to divide farmlands into management units that behave and respond similar to a given level of management. Due to the blanket zonal recommendations, many changes have taken place in the level of input use, yield levels and intensity of cropping systems and soil fertility conditions. Of late, secondary and micronutrients deficiencies have become a serious concern due to faulty fertilizer management[7]. Therefore, the present article highlights the soil variations within the NARP zone, for fertilizer recommendations and emphasizes the necessity of soil-based fertilizer recommendation as a first step towards precision farming.

Material and methods

In India, most of the State Agricultural Universities (SAUs) are continuously strengthening research programmes in the present NARP zones with the assumption that climate and soils are homogenous within the zone. To study the soil variability, northern dry zone (NARP Zone III) of Karnataka was selected (Figure 1) and illustrated here. The soil details for this study area were collected from published reports and soil maps[8].

Soil variability and fertility variations in different parts of the zone were studied by using 480 grid samples. The soil types having similar characteristics like soil depth, texture, fertility status and limitations were grouped into management units. The details of soils, their distribution, fertility and recommended fertilizer dose to selected crops were compiled for interpretation of soil variability and productivity. To study the relevance of present fertilizer recommendation and fertilizer misapplication, sugarcane crop was taken as the test crop, a predominant cash crop to examine the soil variability and fertility status vis-à-vis recommended fertilizer dose within the northern dry zone. The sugarcane yield data for calculating variable fertilizer requirement for each management unit through targeted yield approach was collected from land suitability assessment studies conducted for sugarcane in Karnataka. Variable fertilizer requirement of each management unit was worked out based on the target yield approach[9] by considering the average cane yield. To examine the fertilizer application efficiency, the variable fertilizer requirement (targeted yield approach) of each management unit was subtracted from the current whole zone recommendations and the net difference (excess or under application) listed as application rate error or misapplication rate.

Results and discussion

Soil variability

Scrutiny of the present NARP zones of Karnataka indicated that they are geographically broader units, which are highly heterogenous in respect of soil properties and nutrient status. The soil variability varied from three to six types in different NARP zones (Table 1). Wide ranges of soil and length of growing period occur in each NARP zone with different potentials, limitations and response to management based on their inherent characteristics. Understanding of soil heterogeneity is essential to extension workers, research scientists and planners for better nutrient management.

Among the 10 NARP zones of Karnataka, northern dry zone has more variability (Table 2). This zone consists of nine districts partly or fully (Bellary, Bijapur, Bagalkot, Belgaum, Gadag, Raichur, Koppal, Dharwad and Haveri) and 24 taluks (Table 1) with a total geographical area of 47.84 lakh ha. Soil variability of this zone indicated that nine dominant soil types (Table 2) occur. Deep black soil

Figure 1. National Agricultural Research Project zones of Karnataka (marked area is the study area, northern dry zone).

Table 1. Soils and their distribution and crop growing situations in NARP zones of Karnataka

NARP zone	Crop growing situations and their geographic distribution		Dominant soils of the area (lakh ha)
	LGP* (days)	Crop growing situations (taluk/district)	
North-eastern transition zone	120–150	Aurad (Bidar)	Deep black soils (2.58), Medium deep black soils (2.14), Shallow black soils (2.10), Lateritic gravelly clay (1.89)
	150–180	Bhalki, Bidar, Basavakalyan, Humnabad (Bidar), Chincholi and Aland (Gulbarga)	
North-eastern dry zone	90–120	Manvi (Raichur)	Deep black soils (8.94), Shallow alluvial loamy (2.0), Moderately shallow red gravelly clay (1.04), Shallow black soil (0.95), Medium deep black (0.70)
	120–150	Jevargi and Afzalpur (Gulbarga), Raichur (Raichur)	
	150–180	Gulbarga, Chittapur, Sadam, Yadgir, Shahpur, Shorapur and Deodurg (Gulbarga)	
Northern dry zone	<90	Athni, Raibag, Gokak, Ramdurg and Soundatti (Belgaum), Jamkhandi, Mudhol, Bilgi, Bagalkote, Badami and Hungund (Bagalkote District), Navalgund (Dharwad District), Nargund (Gadag District), Kustogi, Yelburga and Gangavathi (Koppal District)	Deep black (24.0), Shallow black (8.94), Moderately deep red gravelly clay (6.11), Deep alluvial clay (2.0), Shallow red gravelly clay (1.5), Deep red clayey (1.0)
	90–120	Sindhnur, Siriguppa and Hospet (Bellary District), Koppal (Koppal District)	
	120–150	Ron and Gadag (Gadag District)	
	150–180	Sandur (Bellary District), Harapanahalli (Devanagare District)	
Central dry zone	<90	Jagalur (Davangere), Challakere (Chitradurga)	Moderately deep red gravelly clay (6.47), Deep red gravelly clay (2.03), Deep red clayey (1.11), Shallow red loam (1.0), Deep cal. Black (0.82), Deep black soils (0.82)
	90–120	Molakalmuru (Tumkur), Hiriyur and Hosdurga (Chitradurga District)	
	120–150	Harihar and Davangere (Davangere), Chitradurga and Holalkare (Chitradurga), Kadur (Chikmagalur)	
	150–180	Arsikere, Tiptur, Chiknayakanahalli, Madhugiri and Kortagere (Tumkur)	
Eastern dry zone	120–150	Bagepalli, Gudibanda, Chikaballapur, Sidlaghatta, Chintamani, Mulbagal, Kolar, Malur and Bangarpet (Kolar), Devanahalli and Hoskote (Bangalore)	Deep alluvial clayey (4.0) (salinity in patches), Moderately deep red gravelly clay (3.55), Deep red clay (3.4), Deep lateritic clay (1.95), Deep red gravelly clay (1.34), Deep red loams (1.24)
	150–180	Gauribidnur (Kolar), Doddaballapur, Nelamangala, Magadi, Ramnagaram, Anekal and Kanakapura (Bangalore), Kunigal, Gubbi and Tumkur (Tumkur)	
Southern dry zone	90–120	Gundlupet and Chamarajnagar (Chamarajnagar)	Deep red clay soils (3.53), Very deep alluvial clayey (2.92), Moderately deep red gravelly clay (2.9), Deep red gravelly clay (0.92), Deep black soils (0.62)
	120–150	Yellandur, Kollegal (Chamarajnagar), K.R. Pet, Maddur, Mandya, Srirangapatna, Malavalli (Mandya), Nanjangud, Mysore, K.R. Nagara and T. Narsipur (Mysore)	
	150–180	Channarayapatna (Hassan), Nagamangala (Mandya), Turuvkere (Tumkur)	
Southern transitional zone	150–180	H.D. Kote and Hunsur (Mysore), Channagiri and Honnali (Davangere), Shikaripur, Shimoga and Bhadravathi (Shimoga), Tarikere (Chikamagalur)	Moderately deep red gravelly clay (3.10), Deep alluvial clay (2.76), Moderately deep red clay (2.47), Deep red gravelly clay (1.52), Very deep red clay (1.0), Deep black (0.66)
	180–210	Belur, Hassan, Alur and Holenarsipur (Hassan)	
Northern transitional zone	120–150	Byadgi, Ranibennur (Haveri), Shirhatti (Gadag), Kundgol (Dharwad), Bailhongal (Belgaum)	Deep black soils (5.30), Moderately deep red gravelly clay (2.0), Shallow loamy soils (1.5), Moderately deep red clay (1.20)
	150–180	Chikodi, Hukkeri, Belgaum (Belgaum), Dharwad and Hubli (Dharwad), Shiggaon, Savanur, Haveri and Hirekerur (Haveri)	

(*Contd*)

Table 1. (*Contd*)

NARP zone	Crop growing situations and their geographic distribution		Dominant soils of the area (lakh ha)
	LGP* (days)	Crop growing situations (taluk/district)	
Hilly zone	180–210	Khanapur (Belgaum), Kalghati (Dharwad), Hangal (Haveri), Supa, Haliyal, Yellapur, Mundargi, Sirsi and Siddapur (U. Kannada), Sorab, Sagr, Hosanagar and Tirthahalli (Shimoga), N.R. Pura (Chikmagalur)	Deep lateritic clay (2.58), Moderately deep red clay (1.58), Moderately deep red gravelly clay (0.83),
	210–240	Koppa and Sringeri (Chikmagalur)	Shallow red clay (0.72),
	>270	Mudigere and Chikmagalur (Chikmagalur), Sakaleshpur (Hassan), Virajpet, Madikeri and Somvarpet (Kodagu)	Deep black soils (0.70), Very deep alluvial loam (0.50)
Coastal plain	180–210	Karwar, Ankola, Kumta, Honnawar and Bhatkal (U. Kannada), Kundapur and Udupi (Udupi), Mangalore	Deep lateritic gravelly clay (2.08), Moderately deep lateritic gravelly
	210–240	Karkala, Belthangady, Bantwal and Puttur (D. Kannada)	clay (1.80), Deep alluvial sandy soils (1.10)

*LGP, length of growing period.

Table 2. Soil heterogeneity, fertility status and recommended fertilizer level for different crops in northern dry zone (NARP zone III) of Karnataka

	Area		Fertility status					
	(lakh ha)	%	OC (%)	P (kg/ha)	K_2O (kg/ha)	Zn (kg/ha)	Recommended fertilizer dose (kg/ha)	Crops
Red gravelly loam soils	1.6	3.5	0.3	4.9	452.3	0.3	100–75–37.5 (Kh)	Sorghum
Red loam soils	1.7	3.6	1.1	6.1	718.7	0.6	100–62–37 (R)	
Red gravelly clay soils	7.9	16.3	0.7	6.2	395.2	0.5		
Red clay soils	2.9	6.0	0.7	7.1	348.0	0.4	25–25–12 (LRF)	Cotton
Alluvio-colluvial clayey soils	1.2	2.5	0.6	6.5	356.7	0.3	30–15–15 (MRF)	
Deep black soils	16.3	33.8	0.7	6.3	471.6	0.4	80–40–40 (HY)	
Medium deep black soils	3.6	7.6	0.7	4.5	372.1	0.4		
Shallow black soils	4.8	10.0	0.6	6.5	356.0	0.4	50–25–0	Pearl millet
Alluvio-colluvial clayey soils (partly saline-sodic)	6.8	14.1	0.8	5.8	407.3	0.4		
							250–75–190 (I)	Sugarcane
							315–75–190 (Ratoon)	

Kh, Kharif; R, Rabi; I, Irrigated crop; LRF, Low rainfall conditions; MRF, Medium rainfall conditions; HRF, High rainfall conditions.
HY, I Hybrid (irrigated).

constitutes maximum area of 24 lakh ha (33.8%) followed by red gravelly clay soils (7.9 lakh ha), alluvio-colluvial clayey soils which are partly saline and sodic (6.8 lakh ha), shallow black soils (4.8 lakh ha), medium deep black soils (3.6 lakh ha), red clay soils (2.9 lakh ha), red loam (1.7 lakh ha) and red gravelly loam soils (1.6 lakh ha). This zone receives mean annual rainfall in the range of 494–759 mm, indicating that the length of crop growing period within the zone varies (<90–180 days). Due to this variation, the same crop variety cannot be recommended uniformly throughout the zone (Table 1). This shows that this zone comprises productive lands as well as degraded and problematic soils, which need different management packages.

Soil-fertility variations: Organic carbon content of different soils in northern dry zone varied from 0.3% to 1.1% (Table 2). Red gravelly loam soils are poor in organic carbon content (0.3%), whereas red loam soils (1.1%) and alluvio-colluvial clayey soils (0.8%) are comparatively rich in organic carbon. The remaining soils have medium level of organic carbon content (0.6–0.7%). Soil phosphorus content is low and varied from 4.5 to 7.1 kg P/ha (Table 2). Soils of northern dry zone are rich in potassium, which varied from 356 to 718 kg K_2O/ha. Zinc content of all soils in general is low except in red loam soils. In general, the soils of northern dry zone are medium in organic carbon, poor in phosphorus and zinc, and rich in potash.

Management units: Within the zone, seven management units (sub-zones) are delineated, which require different nutrient management options. Sugarcane is predominantly being grown in three management units (alluvio-colluvial clayey, deep black soils and alluvio-colluvial soil partly saline-sodic). Since phosphorus and potash content of all soils within the zone are similar, keeping these two as constant, three different fertilizer recommendations are required to be made by taking into consideration, organic carbon and zinc requirement of sugarcane crop.

In Nellore District of Andhra Pradesh, two fertilizer recommendations are suggested for paddy based on soil

Table 3. Soil fertility status and nutrient requirement of sugarcane crop in different management units in northern dry zone

Management area	Avg. cane yield (t/ha)	Fertility status of soils				Nutrient requirement as per target yield approach				Application rate error (+/–)			
		OC (%)	P (kg/ha)	K_2O (kg/ha)	Zn (kg/ha)	N (kg/ha)	P (kg/ha)	K_2O (kg/ha)	Zn (kg/ha)	N (kg/ha)	P (kg/ha)	K_2O (kg/ha)	Zn* (kg/ha)
Whole zone	117.0	0.6	6.0	430.9	0.4	555.0	260.0	275.0	–	–305.0	–185.0	–85.0	–20
Alluvio-colluvial clayey soils	151.0	0.8	6.5	356.7	0.3	713.0	336.5	416.0	–	–463.0	–261.5	–226.0	–25
Deep black soils	139.0	0.5	6.3	471.6	0.4	692.0	309.5	385.6	–	–442.0	–234.5	–195.6	–20
Alluvio-colluvial clayey soils (partly saline-sodic)	89.0	0.6	5.8	407.3	0.4	401.0	196.5	155.0	–	–151.0	–121.5	+35.0	–20

Recommended fertilizer dose for sugarcane: 250–75–190 kg NPK/ha. *Application rate of Zn is indicated based on soil fertility status.

variability as against currently followed single recommendation[10].

Present fertilizer recommendations: At present, fertilizer recommendations for different crops are uniform throughout the zone except for cotton crop, where fertilizer recommendations varied with the quantity of rainfall but not with soil (Table 2). Soil fertility variations within the zone indicate that there is a need to formulate three fertilizer recommendations for sugarcane. Several studies indicated an increase in profits from applying plant nutrients based on soil nutrient status than a general application for the whole area[11–13]. Therefore, fertilizer application according to soil status should form the basis for farming to achieve precision[14].

Performance of sugarcane crop: The productivity of sugarcane crop (Table 3) indicated that alluvio-colluvial clayey soils which are rich in organic carbon and potash yielded higher cane yield (151 t/ha). But poor content of soil P and Zn limited the yield of sugarcane, whereas alluvio-colluvial soils having problems of salinity and sodicity were found to produce cane yield of 89 tonnes/ha. This indicates that though both the soils were the same except for the limiting factor of saline-sodicity in one case, they needed to be addressed separately to improve the productivity. Studies conducted elsewhere also showed that groundnut crop performed differently on red (35.6 q/ha) and black (14.5 q/ha) soils of ICRISAT farm at Hyderabad[15]. Cotton is being grown on three soil types within the zone in Nagpur District with uniform fertilizer recommendation. The highest seed cotton yield (10.0–15.2 q/ha) was recorded in deep black soils followed by medium deep soils (5.0–7.4 q/ha) and shallow black soils (2.6–3.7 q/ha). Similar trend of varied crop performance was recorded in soybean[16,17] in Nagpur District. Similarly, wide variation in wheat grain yield and response trend was observed in different soil types namely, sandy (20.4 q ha^{-1}), coarse loamy (27.8 q ha^{-1}) and fine loamy (34.6 q ha^{-1}) soils in Delhi territory and parts of Haryana under similar level of management[18]. The above results clearly demonstrate that crop adaptability and yield potential varied with soil type.

Refinement of fertilizer recommendations based on soils: The data on nutrient requirement in different management units in comparison to current zonal recommendation for application efficiency is presented in Table 3. With respect to fertilizer application efficiency in sugarcane, examination of the soil test data of whole zone and management units indicate that management units differed from the whole zone. To improve the fertilizer application efficiency of sugarcane (targeted yield approach), alluvio-colluvial clayey soils require more NPK (463–261–226 kg/ha) than the current recommended dose (250–75–190 kg NPK/ha). Deep black soils require additional dose of NPK (442–234–195 kg/ha) than the present level of recommendation. Special attention needs to be given to manage the alluvio-colluvial clayey soils as these are highly fertile soils but being partly saline-sodic could limit the productivity (Table 3). However, these soils require additional dose of NP (151–122 kg/ha) while currently K is applied in excess (35 kg/ha). There is a need to include Zn (20–25 kg/ha) application for all the management units. The results indicated that in all the management units, nitrogenous, phosphatic and potashic fertilizers are recommended and applied in less than required quantity, which leads to nutrient mining and fertility degradation. Though it is believed that Indian soils are rich in available potash, accordingly K nutrient was recommended less than the required and not given sufficient emphasis. The yield decline or stagnation of productivity is observed due to long-term imbalanced fertilizer use[19].

The present study also revealed that besides P, zinc is the most widespread deficient nutrient in all the soils and hardly supplemented to crop. An average sugarcane crop of 100 tonnes removes 1.2 kg Fe, 1.2 kg Mn, 0.6 kg Zn and 0.2 kg Cu (ref. 20). Current zonal Zn recommendation is to apply zinc if plants show deficiency symptoms. But, secondary nutrients and micronutrients are not included in general recommendations.

Due to continuous nutrient removal by crops in most of the soils, deficiency of secondary nutrients and micronutrients are emerging recently[7,21,22]. The fatigue in crop productivity of major crops is not only because of imbalanced application of NPK but also due to hidden hunger of crops for secondary nutrients and micronutrients. Incidence of multiple nutrient deficiencies has become common due to mismatch in nutrient addition and crop nutrient removal over a period of time. Therefore, there is an urgent need to apply secondary nutrients and micronutrients for balanced fertilization.

In view of wider NPK ratios of nutrients applied by farmers, hidden hunger of secondary nutrients and micronutrients and decades old fertilizer recommendations, strategies are to be developed to increase the productivity of crops in a sustainable manner without degrading the soil health. Strategies that need to be developed to achieve precision in nutrient management are:

- Identifying distinct management units with the help of soil resource maps.
- Instead of chemical fertilizers alone, integrated nutrient management (INM) approach needs to be emphasized by including biofertilizers and organic sources. It will not only help in mitigating the deficiency of major and micronutrients, but also in improving the nutrient use efficiency. At present, information on soil status of secondary and micronutrient levels is limited and target yield approach has limited applicability. In this context, soil-based integrated nutrient management approach can take care of the hidden hunger of secondary nutrients and micronutrients. Besides, INM is a step towards organic farming, which is being emphasized by the state governments.
- During recent years, natural and organic farming concept is catching up among the farmers. So, research efforts need to be made to monitor response of crops in different soil units to organic farming approach and soil-based recommendations need to be developed specially for plantation and high value crops.
- Precision farming in India as such is difficult owing to many limitations but recommending soil or management unit based technologies like fertigation, drip irrigation, etc. can improve the productivity of crops and reduce the cost of production.
- To promote precision farming technologies, farmers' associations need to formed at village level. Institute (R&D institutes/centres)–village linkage programmes should be initiated to educate, guide and develop the skills of the farmers for precision farming.

Conclusion

The present study revealed that the NARP agro-climatic zones are found to be geographically broad units for fertilizer recommendation. Soils within the agro-climatic zone vary widely in their potentials, behaviour and response to management. The NARP zonal fertilizer recommendations are very generalized and not specific to soil type. Fertilizer use efficiency varies within the zone and management units. Fertilizer application by zonal recommendation resulted in insufficient nutrient application. There is a continuous nutrient removal of secondary nutrients and micronutrients in all farming situations and the chances of replenishing them are very limited. All these suggest, use of soil-based fertilizer recommendations to maximize crop production, maintain soil health and minimize fertilizer misapplication. It also has socio-economic and environmental dimensions in terms of reducing the cost of production, and pollution of soil and water due to excessive use of fertilizers. With the availability of soil and fertility maps at watershed, mandal, district, state and national levels, it is possible to identify different management units to prescribe required fertilizer dose. Such recommendations based on soil and fertility variability form the basis for precision farming.

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MEETINGS/SYMPOSIA/SEMINARS

International Conference on Biotechnological Solutions for Environmental Sustainability (Icon-BSES)

Date: 21–23 October 2009
Place: Vellore, India

Scope: The Conference would encompass guest lectures, paper presentations and poster presentations from India and abroad, on a wide spectrum of topics in Environmental Biotechnology. The thrust areas include: Bioremediation, bioresource and energy, ecoinformatics, aquatic resources, ecofriendly agriculture environmental engineering and public health, environmental ethics and regulation, environmental instrumentation, environmental monitoring, food security and environment sustainability, greenhouse effect, forest biotechnology and wildlife, and environmental genetics.

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6th International Summer School on Immunology and Immunogenetics

Date: 16–19 November 2009
Place: New Delhi, India

Themes include: Basic Immunogenetics; MHC – General features and nomenclature; HLA and disease; Antigen presentation; MHC restriction; Non classical HLA and pregnancy; Role of T cells in immune surveillance; Hematopoeitic stem cell transplantation; Allorecognition and transplant rejection; Role of non MHC genes in transplantation; Histocompatibility needs and requirements – Case studies, unrelated marrow registries; HLA typing technologies and chimerism monitoring; Organ transplantation; Role of antibodies in transplantation; Genetic polymorphisms and databases; Statistics for population genetics; Linkage disequilibrium.

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