Interactive effect of irrigation schedules and fertigation levels on fruit yield, quality and plant nutrition of Nagpur Mandarin (Citrus reticulata)

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4 authors:

Parameshwar Shirgure
ICAR-Central Citrus Research Institute, Nagpur, India

Anoop Kumar Srivastava
ICAR-Central Citrus Research Institute (Formerly National Research Centre for Cit…

Ambadas DATTATRAY Huchche
Central Citrus Research Institute (formerly National Research Centre for Citrus)

Prakash Patil
Indian Institute of Horticultural Research

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Interactive effect of irrigation schedules and fertigation levels on fruit yield, quality and plant nutrition of Nagpur mandarin (*Citrus reticulata*)

P S SHIRGURE[1], A K SRIVASTAVA[2], A D HUCHCHE[3] and PRAKASH PATIL[4]

ICAR–Central Citrus Research Institute, Nagpur, Maharashtra 440 010

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ABSTRACT

Water and nutrient-useefficiency, both are considered as pre-requisites for sustained citrus productivity. The interactive effect of irrigation and fertigation levels on growth, yield and quality of 11-year-old Nagpur mandarin (*Citrus reticulata* Blanco) was studied through a field experiment during 2010-13 at ICAR-Central Citrus Research Institute (Formerly NRCC), Nagpur under AICRP Fruits. The experiment was laid out in split-plot design with nine treatment combinations, comprising three irrigation levels (70 %, 80 % and 90 % of daily evaporation replenishment) and three fertigation levels (60 %, 70 % and 80 % RDF based NPK doses) replicated six times. Canopy volume (74.9 m^3) and fruit yield (19.2 tonnes/ha) were observed maximum with the drip irrigation scheduled at 80 % ER combined with 80 % RDF fertigation. The fruit quality parameters, such as fruit weight (129.2 g), juice percentage (45.05 %), TSS (10.27^o Brix) and lowest acidity (0.81) were observed favorable with irrigation at 80% and fertigation at 80% RDF, in addition to maximum nutrient concentration in index leaves (2.38 % N, 0.12 % P and 1.50 % K) duly supported by changes in available pool of nutrients in soil (123.8 mg/kg N, 14.8 mg/kg P_2O_5 and 261.2 mg/kg K_2O). Interestingly yield efficiency computed as fruit yield per unit canopy volume was also observed maximum (0.26) with treatment carrying irrigation at 80% ER and fertigation with 80% RDF. The sustained productivity of Nagpur mandarin can be achieved with irrigation scheduled at 80 % ER along with fertigation technology at 80 % RDF without any potential nutrient mining.

Key words: Citrus, Drip irrigation, Fertigation, Fruit quality, Irrigation schedule, Leaf nutrient uptake, Nagpur mandarin, Productivity, Yield per unit canopy volume, Yield

Nagpur mandarin (*Citrus reticulata* Blanco**)** is an important commercial citrus cultivar, mainly grown in Vidharbha region of Maharashtra and adjoining states like Madhya Pradesh, Chhattisgarh and Rajasthan in the northwest India. The crop is grown in 0.148 M ha area (Area of productive orchards, 0.086 M ha) with a production of 0.875 M tonnes, but the average productivity is hardly 7-8 tonnes/ha, distinctively lower than the other mandarin cultivars due to faulty irrigation and multiple nutrient deficiencies (Shirgure 2012). These two major production constraints warrant right amount of water and nutrients to be added across different growth stages to enhance the growth, yield and fruit quality of Nagpur mandarin (Bielorai *et al.* 1984, Shirgure *et al.* 2014, Shirgure and Srivastava 2014a). The water need for 6-year-old Kinnow mandarin, varied from 539 -1276 mm depending upon the level of irrigation with average consumptive use from 66.7-132.5 cm for Kinnow mandarin (Mageed *et al.* 1988), in contrast to under clean cultivation the water requirement of young, middle age and mature mandarin trees was 651.9, 849.0 and 997.3 mm/year respectively under clean cultivation (Ghadekar *et al.* 1989). Past research work on irrigation scheduling and fertigation in citrus indicated the irrigation at 65% field capacity caused drought injury symptoms, excessive defoliation and less water consumption compared to irrigation at 85% field capacity in citrus. It was observed that partial fertigation of N and K resulted in lower N content in leaves with higher total soluble solids and acid concentration in juice and the yield remained unaffected in Valencia orange (Koo and Smjstrala 1984, Smajstrla *et al.*1986, Ferguson 1990, Smajstrla 1993, Panigrahi *et al.* 2008). Fouche and Bester (1987) observed highest yield with fertigation of NPK through *Triosol* or by complete broadcasting of NPK fertilizers, without any significant difference in fruit size, acidity, percent juice content and total soluble solids. Highest yields and the largest average fruit size with irrigation at a crop factor of 0.9 gave better results than drip irrigation schedule.

The incremental plant growth, yield and fruit quality

[1] Principal Scientist (Soil and Water Conservation Engineering) (e mail: shirgure@gmail.com), [2]Principal Scientist (Soil Science) (e mail: aksrivas2007@gmail.com), [3] Principal Scientist (Hort.) (e mail: ambadas.huchche@gmail.com), [4]Project Coordinator (e mail: pcfruits@gmail.com), AICRP (Fruits), ICAR-IIHR, Bengaluru.

of Nagpur mandarin were observed much higher with the irrigation scheduled at 20% depletion of available water content combined with 500 N: 140 P_2O_5: 70 K_2O g/plant as fertigation dose (Shirgure *et al.* 2001, Srivastava *et al.* 2003). While in acid lime, the growth, fruit yield and quality were significantly higher with irrigation at 30% depletion of available water content along with 500 N: 140 P_2O_5: 70 K_2O g/plant in form of fertigation (Shirgure *et al.* 2003, Shirgure *et al.* 2013a). Irrigation scheduling and optimum fertilizer requirements are two important components affecting yield and quality fruit production are mainly dependent on the constant soil moisture and fertilizer management, right from fruit set to fruit maturity of citrus cultivars. Various micro-irrigation systems in citrus have established their superiority over traditionally used surface irrigation (Panigrahi *et al.* 2012, Shirgure and Srivastava 2014b, Shirgure and Srivastava 2015). Fertigation has shown good responses on growth, yield, quality and uniform distribution pattern of applied water as well as nutrients within the active rootzone compared to band placement involving localized fertilization (Shirgure and Srivastava 2013a, 2013b). With the objective to study the interactive effect of different levels of irrigation schedules based on 70-90% Evaporation Replenishment and along with different 60-80% RDF fertigation doses on growth, yield and fruit quality of bearing Nagpur mandarin grown under central Indian locations.

MATERIALS AND METHODS

A field experiment was conducted on eleven-year-old bearing Nagpur mandarin trees (average canopy volume 5.40 - 5.80 m^3) at ICAR-Central Citrus Research Institute (Formerly known as National Research Centre for Citrus), Nagpur (Maharashtra) during 2010-13. Different treatments involved drip irrigation system with three main irrigation treatments based on evaporation replenishment (ER), viz. I_1, irrigation scheduling at 70% ER, I_2, irrigation scheduling at 80% ER and I_3, irrigation scheduling with 90% ER with three sub-treatments of fertigation levels, viz., F_1, fertigation at 60% RDF, F_2, fertigation at 70 % RDF and F_3, fertigation at 80% RDF under six replications through split plot design. The average depth of soil was 53 cm underlined by weathered basalt (Typic Ustochrept). Volumetric soil moisture content at field capacity (FC), the permanent wilting point (PWP) and soil moisture characteristics curve were determined using pressure plate method. The FC and PWP of the experimental soil were observed as 28.14% and 19.1%, respectively, with available water content of 8.15%. White water holding capacity of the soil was worked out to be 12.23 cm/m depth of soil considering soil bulk density as 1.5 g/cc, determined using core sampler having 100 cm^3 volume. The drip irrigation system consisting of 4 lph drippers as 4 per plant at 4 different points on the lateral arrangement, were installed in the field along with the fertilizer dispenser. The soil moisture status under tree basin was measured frequently using neutron probe at 30 cm depth. Irrigation was scheduled as per the treatments. Based on the recommended dose of fertilizers (600g N: 100 g P_2O_5: 200 g K_2O/plant). Various fertigation treatments were fertigation, started from month of October to June at fortnightly interval, given on 2nd and 16th day of month. All N, P and K were applied during every October to June.

The biometric parameters of Nagpur mandarin plants in terms height and spread (E-W × N-S), expressed as in canopy volume according to standard formula suggested by Castle (1983). The soil and leaf samples were collected as per the treatments following the standard leaf and soil sampling method proposed by Srivastava *et al.*(1994). The collected leaf samples were digested in diacid mixture of H_2SO_4 : $HClO_4$ in 2.5:1 ratio (Chapman and Pratt 1961). The leaf N was determined using Auto Nitrogen Analyser, P by vanadomolybdophosphoric acid yellow colour method and K flame photometrically. Fruit quality analysis was performed as per procedures described by Ranganna (1986). Data on growth, fruit yield and quality attributing to the different irrigation schedules and fertigation levels for 3 years were statistically analysed through Analysis of variance following the procedural steps as outlined by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Depth of water use

Depth of water use is a function of water requirement of plant canopy. The total depth of irrigation used with 70% evaporation replenishment (ER) irrigation was 834.5 mm, 743.2 mm and 711.4 mm during 2010-11, 2011-12 and 2012-13, respectively. While, with 80% evaporation replenishment (ER), irrigation was from 953.3 mm, 849.5 mm and 812.9 mm during 2010-11, 2011-12 and 2012-13 respectively. The water use was 1072.6 mm, 955.8 mm and 914.6 mm during 2010-11, 2011-12 and 2012-13 respectively in the different irrigation scheduling involving 90% ER. The optimum total depth of irrigation based on plant growth, yield and fruit quality of bearing Nagpur mandarin was observed as 953.3 mm, 849.5 mm and 812.9 mm in irrigation scheduled at 80% ER schedule. The depth of irrigation was more during the summer months due to higher temperature and less relative humidity. The optimum water requirement of Nagpur mandarin from November-December to June months varied from 36.4 to 200.6 mm. From the pooled data the average water requirement of Nagpur mandarin is 871.9 mm during October to June *Ambia* fruit growing period.

Bio-metric growth and yield response

Response of varying levels of irrigation, fertigation and their interaction, all three showed a significant effect on canopy volume, fruit yield and yield efficiency in terms of yield per unit canopy (Table 1). With exception of irrigation at 90% ER, the canopy volume increased from 71.18 to 74.2 m^3 and from 72.8 to 74.9 m^3 by increasing levels of fertigation from 70% RDF to 90% RDF, with irrigation at 70% ER and 80% ER, respectively. However,

Table 1 Effect of irrigation and fertigation schedules on growth and yield of Nagpur mandarin (Pooled data : 2010-13)

Treatment		Canopy	Yield	Yield/unit
Irrigation levels	Fertigation levels	volume (m^3)	(tonnes/ha)	of canopy (tonnes/m^3)
I_1	F_1	71.8	8.4	0.12
	F_2	71.3	9.9	0.14
	F_3	74.2	10.9	0.15
I_2	F_1	72.8	11.0	0.15
	F_2	72.3	14.8	0.20
	F_3	74.9	19.2	0.26
I_3	F_1	74.1	12.6	0.17
	F_2	73.8	15.4	0.21
	F_3	74.4	17.6	0.24
LSD	Irrigation (I)	0.95	1.2	
(*P=0.05*)	Fertigation (F)	0.24	0.71	
	Interaction (I×F)	0.14	023	

I_1, Irrigation at 70% ER; I_2, Irrigation at 80% ER; I_3, Irrigation at 90% ER; F_1, Fertigation at 60 % RDF; F_2, Fertigation at 70 % RDF and F_3, Fertigation at 80 % RDF.

the response on growth of canopy volume was on part with each other 90% RDF with irrigation at either 70% ER or at 80% ER. Interestingly, the average response on canopy volume was significantly higher with irrigation at 80% ER (73.3 m^3) than at 70% ER (72.4 m^3), regardless of fertigation levels. The maximum canopy volume was recorded with irrigation at 80% ER plus fertigation at 80% of RDF (74.9 m^3) followed by irrigation at 70% ER plus fertigation at 90% RDF (74.2 m^3). While the lowest canopy volume (71.3 m^3) was observed with irrigation scheduled at 70% ER plus fertigation level of 70% RDF.

The fruit yield is predominantly a function of constant optimum availability of soil moisture nearest to field capacity level coupled with optimum available nutrients within the root zone, right from fruit set stage to fruit maturity stage (Srivastava *et al.* 2003). Fruit yield was observed significantly affected by irrigation as well as fertigation levels (Table 1). Fruit yield of Nagpur mandarin at all the three irrigation levels, increased from 8.4 to 10.9 tonnes/ha, 11.0 to 19.2 tonnes/ha and from 12.6 to 17.6 tonnes/ha with increase in fertigation levels from 70% of RDF to 90% RDF with irrigation at 70% RE, 80% and 90%, respectively. However, the average response on fruit yield was observed to 9.7 tonnes/ha, 15.0 tonnes/ha and 15.2 tonnes/ha with irrigation at 70% ER, 80% ER and 90% ER, respectively, irrespectively fertigation. But, yield response optimised with irrigation at 80% ER and fertigation at 90% of RDF (19.2 tonnes/ha). These responses commensurated well with the pattern of response with regard to yield/unit canopy volume, often termed as yield efficiency, eventually was maximum with irrigation at 80% ER combined fertigation at 90% of RDF. Such a magnitude of response was far superior to different treatments involving irrigation at 70% ER combined with fertigation ranging from 70% to 90% RDF or irrigation at 90% ER combined with fertigation at 70% RDF and on par fertigation rates at 80-90% RDF equivalent. Our earlier experiments on irrigation schedules showed higher plant growth and fruit yield with irrigation scheduled at 20% and 30% depletion of soil available moisture content in Nagpur mandarin and acid lime (*Citrus amantifolia* Swingle) with 20% reduction in fertilizer doses over conventional RDF (Shirgure *et al*. 2004a).

Response on soil fertility and leaf nutrient composition

Changes in soil fertility and consequent response on leaf nutrient composition in citrus are, often irrelated, to guide towards yield-based interpretation (Srivastava *et al.* 2001). Leaf N content was observed to be 2.07%, 2.17%

Table 2 Leaf and soil nutrient composition of Nagpur mandarin in various treatments of irrigation schedules and fertigation levels (Pooled data : 2010-13)

Treatment		Changes in leaf nutrition and soil fertility					
Irrigation levels	Fertigation levels	Leaf nutrient composition (%)			Plant available nutrients (mg/kg)		
		N	P	K	N	P	K
I_1	F_1	2.03	0.08	0.92	115.8	11.8	241.3
	F_2	2.07	0.08	0.97	115.8	11.1	243.3
	F_3	2.10	0.09	0.98	116.8	11.8	246.3
I_2	F_1	2.15	0.09	1.00	117.1	11.3	251.8
	F_2	2.16	0.10	1.07	119.3	13.0	231.8
	F_3	2.21	0.10	1.17	123.8	14.8	261.2
I_3	F_1	2.16	0.09	0.98	121.1	14.1	248.1
	F_2	2.16	0.09	1.03	120.2	14.0	241.1
	F_3	2.17	0.08	1.08	122.3	14.2	252.3
LSD	Irrigation (I)	0.04	0.006	0.04	1.2	0.70	1.2
(*P=0.05*)	Fertigation (F)	0.03	NS	0.02	0.8	0.64	1.8
	Interaction (I×F)	0.06	NS	0.07	2.1	1.40	3.2

I_1, Irrigation at 70% ER; I_2, Irrigation at 80% ER; I_3, Irrigation at 90% ER; F_1, Fertigation at 60 % RDF; F_2, Fertigation at 70 % RDF and F_3, Fertigation at 80 % RDF.

and 2.16% with irrigation at 70% ER, 80% ER and 90% ER, respectively. Likewise leaf P concentration displayed maximum value of 0.10% with irrigation at 80% ER, which was significantly higher than either irrigation at 70% ER (0.08%) or at 90% ER (0.09). Same pattern of leaf K accumulation was observed, maximum (1.08%) being with irrigation at 80% ER followed by irrigation at 90% ER (1.03%) and 80% ER (0.96%). These observations suggested best treatment of irrigation at 80% ER. Leaf N increased from 2.03 to 2.10% and from 2.15 to 2.21% with increase in irrigation levels from 60% ER to 70% ER and fertigation levels from 60% RDF to 80% RDF, without any significant effect further with irrigation at 90% ER and increasing fertigation from 80%. However, the response on leaf P concentration was non-significant in relation to different fertigation levels. While leaf K increased from 1.00 to 1.17%, 0.98 to1.08% and from 0.92 to 0.98% with increasing fertigation level from 60% RDF to 80% RDF in combination with irrigation at 80% ER, 90% ER and 70% ER, respectively. The magnitude of response on increase in leaf K was maximum with increasing fertigation levels from 60% RDF to 80% RDF, proportionately much higher with irrigation at 80% ER than at either 70% ER or 90% ER.

Plant available nutrients in soil displayed significant changes in response to different irrigation treatments. $KMnO_4$-N was maximum (121.2 mg/kg) with irrigation at 90% ER, statistically on par with irrigation at 80% ER (120.1 mg/kg), but significantly inferior to irrigation at 70% ER (115.8 mg/kg). On the other hand, Olsen-P registered maximum (14.1 mg/kg) with irrigation at 90% ER followed by irrigation at 80% ER (13.0 mg/kg) and 70% ER (11.6 mg/kg). NH_4OAc-K followed the similar pattern, registering maximum (248.3 mg/kg) and minimum (243.6 mg/kg) with irrigation at 80% ER and 70% ER, respectively. A significant response of joint application of irrigation and fertigation levels was observed on plant available nutrients in soil. Highest available soil N, P and K was observed with irrigation at 80% ER and 80% RDF fertigation (123.8 mg/kg, 14.8 mg/kg and 261.2 mg/kg) followed by irrigation at 90% ER plus 80% RDF fertigation (122.3 mg/kg, 14.2 mg/kg and 252.3 mg/kg) and 70% ER plus 80% RDF fertigation (116.8 mg/kg, 11.8 mg/kg and 246.3 mg/kg). Increasing fertigation levels, from 60% RDF to 90% RDF with irrigation at 70% ER and 80% ER showed more distinctive changes in concentration of N, P and K in index leaves, compared to different fertigation levels with irrigation at 90% ER.

Plant available nutrients as $KMnO_4$-N, Olsen-P and NH_4OAc-K observed similar changes in response to different fertigation levels. Increasing fertigation levels from 60% RDF to 80% RDF, produced a much higher response on changes in soil fertility with irrigation at 80% ER compared to rest of the other two levels of irrigation, 70% ER or 90% ER. Maximum increase in $KMnO_4$-N was observed to increase from 117.1 to 123.8 mg/kg, Olsen-P from 11.3 to 14.8 mg/kg and NH_4OAc-K from 251.8 to 261.2 mg/kg as the fertigation level increased from 60% RDF to 80% RDF coupled with irrigation at 80% ER.

Response on fruit quality changes

Fruit quality development is claimed to be a function of both water- and nutrient-useefficiencies. All the fruit quality parameters, except juice acidity, were significantly affected by different levels of both, irrigation and fertigation (Table 3) influenced by the interactive effect of irrigation schedule. The average fruit increased from 102.3 to 119.7 g with increase in irrigation level from 70% ER to 90% ER. While, total soluble solid increased at irrigation only up to 80% ER, beyond that, both the treatment were statistically same. The juice content on the other hand improved from 39.4% with irrigation at 70% ER to as high as 43.4% with irrigation at 90% ER. These observations strongly warranted the impact of irrigation treatments on fruit quality

Table 3 Fruit quality of Nagpur mandarin under different irrigation schedules and fertigation levels (Pooled data : 2010-13)

Treatments		Fruit quality parameters				
Irrigation levels	Fertigation levels	Avg. fruit weight (g)	Total soluble solids (°Brix)	Juice(%)	Acidity(%)	TSS/acidity ratio
I_1	F_1	95.8	9.7	39.1	0.82	11.90
	F_2	102.3	9.7	39.4	0.82	11.95
	F_3	108.7	9.8	39.8	0.82	11.95
I_2	F_1	106.8	9.8	39.7	0.80	12.30
	F_2	112.0	10.0	40.1	0.82	12.25
	F_3	129.2	10.3	45.0	0.81	12.60
I_3	F_1	113.7	10.1	42.7	0.83	12.35
	F_2	119.6	10.1	43.4	0.83	12.25
	F_3	125.8	10.2	44.2	0.82	12.40
LSD	Irrigation (I)	1.4	0.1	0.18	NS	
(*P=0.05*)	Fertigation (F)	1.8	0.2	0.31	NS	
	Interaction (I×F)	3.1	0.3	0.60	NS	

I_1, Irrigation at 70% ER; I_2, Irrigation at 80% ER; I_3, Irrigation at 90% ER; F_1, Fertigation at 60 % RDF; F_2, Fertigation at 70 % RDF and F_3, Fertigation at 80 % RDF.

developments. Increasing fertigation levels also aided in better fruit quality development. The fruits per plant ranged from 463 to 764 during 2011-13. More number of smaller fruits and lesser fruits with higher weight were observed in 2011-12, due to climatic conditions and hailstorm during fruit setting. However fruit quality parameters have shown a significant response to irrigation as well as fertigation treatment combinations. Out of different fruit quality parameters average fruit weight, TSS and juice content showed a significant response due to different ER irrigation scheduling and RDF fertigation levels. The acidity was found insignificant may be due to the internal fruit quality attribute.

Best fruit quality parameters were recorded with irrigation at 80% ER (Fruit weight 129.2 g, TSS 10.3 ^{o}Brix, juice content 45.0% and acidity 0.81%) coupled with fertigation at 80% RDF at significantly better than either irrigation at 70% ER along with fertigation at 80% RDF (Fruit weight 108.7g, TSS 9.8 ^{o}Brix, juice content 39.8% and acidity 0.82%) or a irrigation at 90% ER with fertigation at 80% RDF schedule (Fruit weight 125.8 g, TSS 10.2 ^{o}Brix, juice content 44.2% and acidity 0.82%). However, the treatment involving fertigation at 60% RDF produce the poorest response on different fruit quality parameters (Fruit weight 95.8 g, TSS 9.7 ^{o}Brix, juice content 39.1% and acidity 0.82%) were recorded with irrigation at 70% ER. The higher TSS to acidity ratio is the indicator of sweetness of the fruit of *Ambia* flush. The TSS/acidity ratio was analysed, the highest TSS to acidity ratio (12.3 to 12.6) was found in the irrigation schedule with 80% ER irrigation scheduling in combination with 60-80% RDF fertigation followed by the irrigation schedule with 90% ER with 60-80% RDF fertigation (12.25 to 12.40). The lowest TSS to acidity (11.90-11.95) was observed the drip irrigation schedule with 70% ER with 60-80% RDF fertigation levels. Studies in the past showed the improvement in fruit quality in response to irregular schedule based on evaporation replenishment in Nagpur mandarin (Shirgure and Srivastava 2012) as well as acid lime (Shirgure *et al.* 2004 b).The highest fruit yield, coupled with juice percentage, sugar to acidity ratio (12.7) and lower acidity (0.61%) were observed with irrigation at 80 % ER during stages I-V (January-October) and 30% ER during stage VI (November-December) (Shirgure *et al.* 2014, 2016).

The present investigation clearly showed a significant interactive effect of irrigation schedule along with fertigation level on growth, soil-leaf nutrient build up, higher yield and fruit quality of Nagpur mandarin. The optimum total depth of irrigation based on plant growth, yield and fruit quality of bearing Nagpur mandarin was observed as 953.3 mm, 849.5 mm and 812.9 mm in irrigation scheduled at 80% ER schedule during 2010-2013. The incremental plant height, canopy volume and yield was more in irrigation scheduled with 80% Evaporation replenishment (ER) along with 80% RDF fertigation level due to combined effect of irrigation scheduling and fertigation technology. The soil-leaf nutrient composition was also superior in irrigation with the 80% ER schedule along with 80% RDF fertigation in bearing Nagpur mandarin. The higher fruit yield and superior fruits can be obtained with irrigation scheduled with 80% ER in combination with 80% RDF fertigation compared to rest of the treatments combinations.

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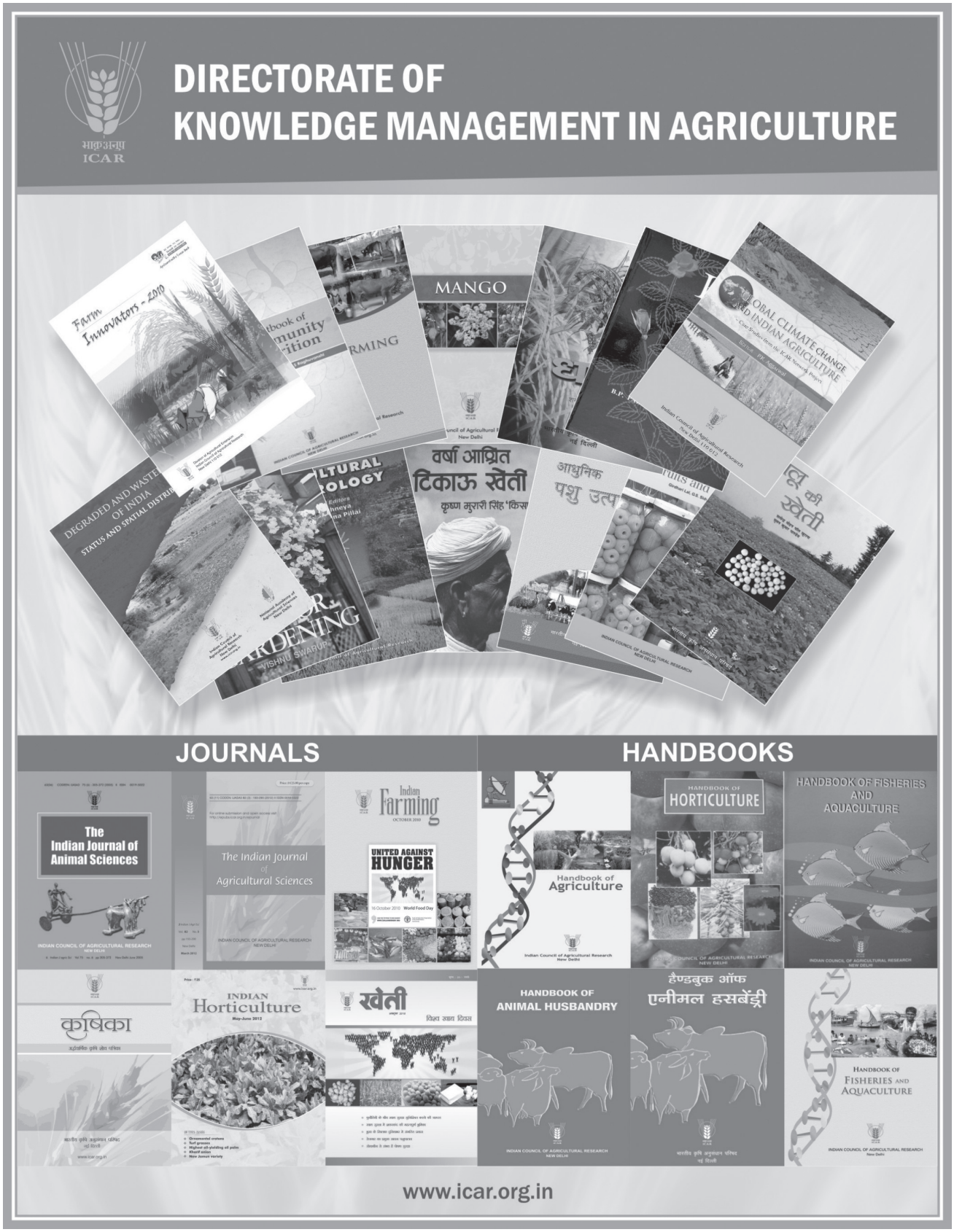
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Nominations of outstanding agricultural scientists of Indian nationality are invited from the Secretaries of Science Department of Government of India, Vice-Chancellors/Directors of Agricultural Research Institutes of national importance and Presidents, National Academies for the VIth Rao Bahadur B. Viswanath Award. The award carries a sum of Rs. 1,00,000/-, a medal and citation. The nominee should not be less than 50 years of age and with a standing of 25 year's contributions in the concerned field of agricultural sciences while working in India. The awardee will be required to deliver a lecture based on his/her research contributions. Nominations (10 copies) complete in all respects as per proforma available at Post Graduate School. IARI/Institute website ***www.iari.res.in*** should reach the **Registrar, Post Graduate School, Indian Agricultural Research Institute, New Delhi-110012 latest by 5th December, 2016.** The Insitute will not be responsible for any postal delay. The nominations received after the due date will not be entertained.

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