Improving the Productivity through Site-Specific Nutrient Management in Cashew through a Mobile App in Coastal India

Shamsudheen Mangalassery[1*], Palpandian Preethi[1],
Bommanahalli Munivenkate Muralidhara[1]
and Mundakochi Gangadhara Nayak[1]

[1]ICAR- Directorate of Cashew Research, Puttur 574202, Dakshina Kannada, Karnataka, India.

Authors' contributions

This work was carried out in collaboration among all authors. Author SM conceptualized, acquired funding for the study, planned the research, designed the mobile app, conducted the participatory research, planned the data collection, conducted laboratory analysis, and wrote the first draft of the manuscript. Authors BMM and PP involved in field level implementation, data collection, review and editing of the manuscript. Author MGN was involved in supervision and administrative support. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Nutrient management plays a key role in the productivity and sustainability of land resources. Balanced application of mineral nutrition to the crops not only helps to realise increased yields but also to prevent land degradation. Cashew is generally grown as a rainfed crop in tropical regions with limited attention on nutrient management. Making an informed decision on the scientific aspects of the nutrient application in terms of the right amount, time and place of application are important for the growers. The mobile apps come handy in this direction because the farmers can themselves find out nutrient management schedule as per the field conditions. A mobile app for nutrient management in cashew was developed which takes care of varied field situations of farmers and was demonstrated in the farmer's fields under participatory research mode. The app helped farmers to devise their own site-specific nutrient management. The field implementation for the site-specific

_____

Corresponding author: E-mail: shamsudheenm@gmail.com, shamsudheen.m@icar.gov.in;

nutrient management with the help of a mobile app showed improvement in soil and leaf nutrient status as well as the raw cashewnut yield. The yield improvement was in the range of 58 to 67% and the BC ratio was increased by 9 to 47% compared to the initial status. The mobile app DCR-Cashew Nutrient Manager was useful to empower the farmers, and field implementation was beneficial to improve the productivity, income and ecosystem sustainability by improving the nutrient balance in the soil.

1. INTRODUCTION

The decline in soil fertility causing the reduction in crop productivity has been largely attributed to the improper soil fertility management [1]. Continuous cultivation in the same piece of land without the addition of nutrients leads to depletion of soil nutrient reserves and causes degradation. As per the crop requirements and soil characteristics, the required supplementary nutrition is to be provided on an annual basis to maintain soil fertility and avoid depletion of nutrients [2]. The indiscriminate nutrient mining is the major cause of land degradation in many tropical countries [3]. The tropical regions are characterised by increased precipitation which facilitates washing away of basic cations and some nutrients and low cation exchange capacity, and these soils are also characterised by low organic carbon status [4]. These characteristics make these regions more vulnerable to the impact of faulty agricultural practices by humans and climatic change. The tropical regions are prone to increased effects of climatic change in terms of increased rainfall events and atmospheric temperature [5,6]. These might further aggravate the land degradation by facilitating the runoff, soil erosion, removal of fertile topsoil and loss of organic carbon [7,8]. The crop cultivation following scientific soil nutrient management practices can arrest soil degradation by maintaining a positive balance of nutrients in the soil. Because of the wide variability in soil characteristics, a universal management strategy suitable for every location cannot be devised. Therefore, nutrient management needs to be site-specific [9]. The application of fertilisers, if not in accordance with the requirement of the soil and crops can adversely affect the ecosystem and productivity. Large scale deficiencies have occurred due to imbalanced use of chemical fertilisers. Meena et al. [10] reported the large scale deficiencies of nitrogen, phosphorus and zinc in the vertisols of Central India due to improper application of fertiliser nutrients.

Cashew is an important tropical nut tree cultivated in nearly 34 countries [11]. The crop is cultivated in 1.06 m ha area mainly along the West Coast and East Coast regions of India [12]. It is largely cultivated as rainfed in red and lateritic soils. Majority of the cashew growing areas in India seldom receives fertiliser nutrients. The studies showed that a grownup cashew tree removes 2.847 kg N, 0.75 kg P and 1.265 kg K [13]. Cashew is a highly fertiliser responsive crop and 50 to 100% increase in yield is reported by adopting proper nutrient management schedule [14]. The general nutrient recommendation for any crop is based on standard cultivation guidelines. The scientific nutrient management is based on region specific fertiliser recommend-dation package developed by conducting research and applying based on soil or leaf nutrient status. But, the condition in the actual field varies from location to location. Different farmers may follow different spacing which leads to the varied number of trees per hectare. Some might adopt the high density or ultra density planting system. For a tree crop like cashew, the age of the tree also important in nutrient management. During the initial stages of the plantation, the tree requires fewer nutrients and as the tree grows, the dose is to be increased [15]. Some farmers may get their soil tested for assessing the soil nutrient status and some may not. It is difficult and not practical for the farmers to approach research institutions or extension personnel every time to get such site-specific nutrient recommendations customised for their plantations.

The reluctance of farmers for adoption of nutrient management practices may be due to several factors such as availability of resources, access to technical know-how, non-easiness of adoption etc [16,17]. It is estimated that almost 60% of the farmers lack access to information on advanced technologies [18]. The information and communication technologies (ICTs) are increasingly becoming popular to provide customised and accurate information to the farmers in a time-bound manner [19]. The usage

of smartphones and availability of internet at affordable prices offered ways to solve such dilemma of farmers through mobile apps. Mobile apps and software are developed for the faster and efficient reach of information to the farmers in the rural areas in various fields by government and private agencies.

This paper present detail about a mobile app on cashew nutrient manager developed considering various field situations of cashew in India, and the results of the impact of its adoption in site-specific nutrient management in the farmer's field under a participatory research mode.

2. MATERIALS AND METHODS

2.1 Mobile App and Experimental Details

A mobile app on nutrient management was developed. It was developed bilingual with both English and local language, Kannada, and was initially made available to the participating farmers only. This study was conducted in farmer's fields in three districts of Karnataka in India, namely, Dakshina Kannada, Uttara Kannada and Udupi (Fig. 1). The experiment was initiated during the year 2018-19. Five cashew growing farmers were selected from each district and were instructed to follow the nutrient management schedule using the mobile app. The soil and leaf samples at the start of the experiment were collected during September 2018. The samples were analysed for the status of essential nutrients as per the procedures outlined in subsequent sections. Soil health cards were developed and made available to farmers in digital format which could be downloaded through the app, by providing their national identification numbers (AADHAR). The financial supports were also provided to farmers for the necessary inputs. The app-based nutrient management was followed by the selected farmers for two years (2018-19 and 2019-20). Soil and leaf samples were collected after the two year period.

2.2 Soil and Leaf Analysis

The soil samples were collected from the top 15 cm layer from each of the cashew plantations. The samples were air-dried in the laboratory and sieved through 2 mm sieve and used for analysis. Soil pH and electrical conductivity were measured in 1:2 soil – distilled water suspension using pH meter, and its supernatant using a conductivity meter respectively [20]. The soil

organic carbon was estimated as per Nelson and Sommers [21]. The available nitrogen content in soil samples was analysed using methods described by Subbiah and Asija [22]. The extraction of available soil phosphorus was carried out using Bray's extractant as per Bray and Kurtz [23] and estimated using a UV-Visible spectrophotometer (Shimadzu UV-1900) [24]. The available potassium, exchangeable calcium and magnesium contents were estimated by extracting with neutral normal ammonium acetate [25] followed by determination using a Microwave Plasma Atomic Emission Spectrometer (MP-AES) (AGILENT 4210 MP-AES). The micronutrient elements such as iron, manganese, zinc and copper were extracted using diethylene triamine penta acetic acid (DTPA) [26] and estimated using MP-AES. The methods used for the analysis of boron and molybdenum contents in soil was as per Dhyan et al. [27] .

The leaf samples from different cashew plantations were collected and processed as per the procedures described by S Mangalassery et al. [28]. The dried and ground samples (about 0.5 g) were digested using a mixture of sulphuric acid and perchloric acid in 10:4 ratio on sand bath for 2-3 hours for nitrogen analysis. The digest so obtained was subjected to distillation using 40% sodium hydroxide using a nitrogen analyser (Pelican – Kelpus Classic DX VATS) to liberate ammonia that was quantitatively absorbed in boric acid and the nitrogen content was obtained by back titration with standard acid. The estimation of all other elements was carried out in the acid extract of leaf samples prepared by digesting the ground leaf samples with a mixture of nitric acid and perchloric acid in 9:4 ratio. The digest were diluted appropriately and analysed for K, Ca, Mg, Fe, Mn, Zn and Cu using MP-AES. The P, B and Mo were estimated using UV-Visible spectrophotometer using methods described by Dhyan et al. [27].

2.3 Cashewnut Yield and Economics

The farmers were instructed to record the data on the yield of raw cashewnuts. The data on raw cashewnut yield were collected from the farmers. The fallen nuts were collected from the field at weekly intervals during the harvest season, the nuts were separated from cashew apple and dried under the sun for 3 days and weighed as raw cashewnut yield. The economics were worked out based on discussion with farmers and considering the cost of various inputs used and the sale price of the produce.

2.4 Farmer's Response

A questionnaire was prepared and farmers were interviewed for recording their views on the
.

usefulness of the developed app, user-friendliness etc. The response was collected on scale 1 to 10, one being extremely unlikely and 10, extremely likely.
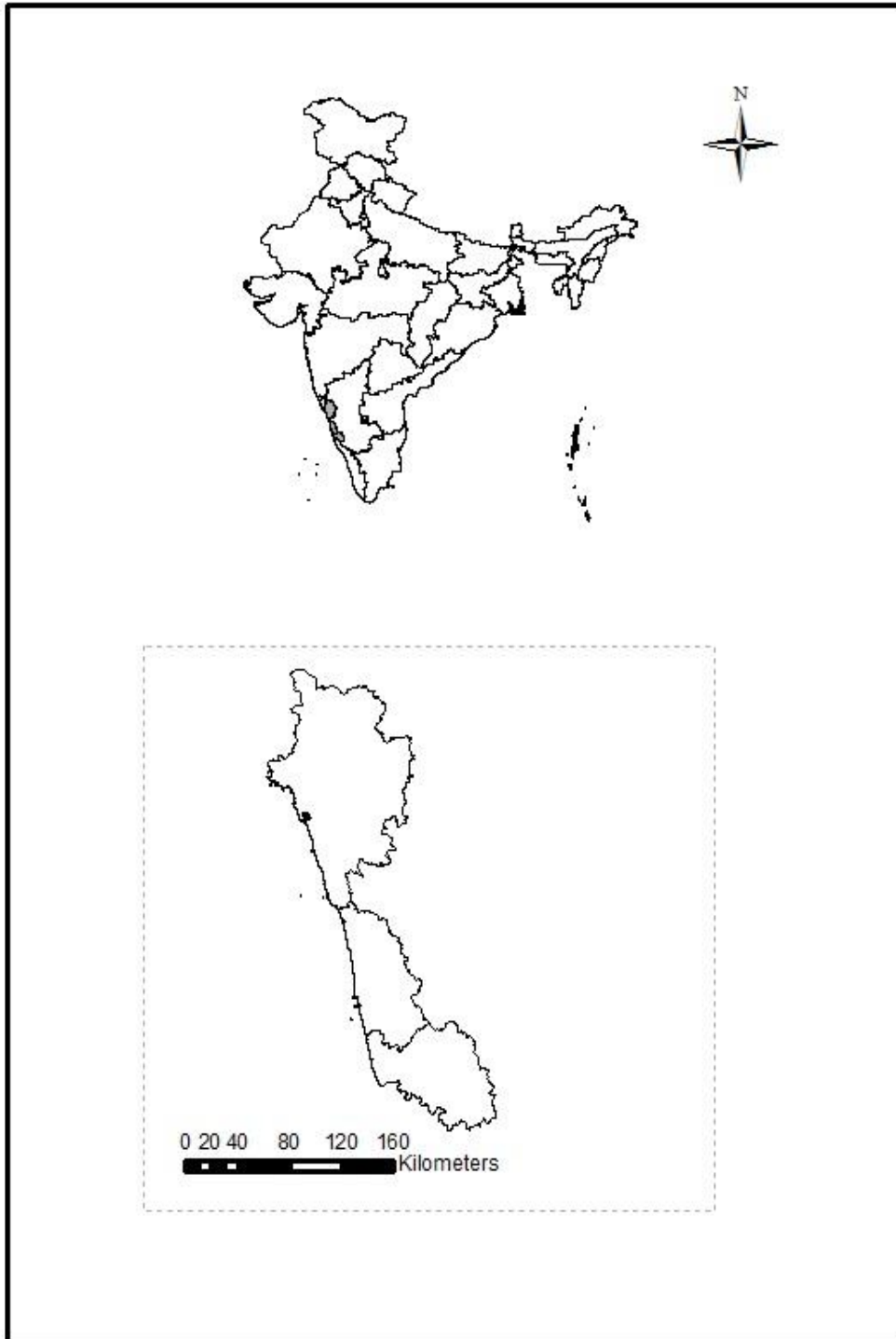

Fig. 1. Location map of the study area

2.5 Statistical Analysis

The statistical analysis was performed in Microsoft Excel. The average values for soil and plant analysis data for each district was computed for the pre and post period of the experiment. The standard error and standard deviation was computed and provided wherever applicable.

3. RESULTS

3.1 Analysis of the Pre-Existing Situation and the Need for a Mobile App

The field conditions of growing cashew vary widely among different farming situations. The soil fertility status in terms of availability of nutrients is one of the determinants which decide the rate of application of fertilisers. In soils that are rich in nutrients, only the nutrition to match the crop removal be given. Whereas, in soils that are deficient in nutrients, the nutrient dose needs to cover the balance of nutrients in the soil to ensure sustainability. Another factor deciding the rate of nutrients is the planting density. The normal planting distance recommended for cashew in India is 7.5 m x 7.5 m. Under high density planting, the spacing needs to be 4 m x 4 m. Whereas, the ultra high density planting recently being popularised, to reduce the pre-bearing period and to increase the profitability per unit of land, follow spacing as low as 2.5 m x 2.5 m. The fertiliser requirements of the trees vary under various planting systems also. Besides, based on the age of the trees also, the quantity of the nutrient to be applied is to be modified. Yet another dilemma for the farmers is the type of fertiliser available in their local market. The scientific recommendations are always on a nutrient basis. However, the nutrient content varies from fertiliser to fertiliser. Sometimes the different nutrient elements are bundled in one complex fertiliser. All these factors make the calculation of fertiliser to be applied for cashew, by farmers a difficult task. They need to approach the learned extension workers or researchers each time for getting the information on nutrient/fertiliser calculations, which may not be feasible every time. Ultimately, the farmers end up applying the fertiliser on a lumpsum without consideration of actual field situations. The fertiliser calculator module of the app was developed to address these issues.

The cashew is predominantly grown in humid tropical regions and the soils are mainly acidic.

Application of liming materials to correct the acidity is important to correct the soil pH to a favourable level so that nutrients are readily available for absorption by plants. No application, under and over-application of liming materials can adversely affect the nutrient availability. The lime calculator module of the mobile app was developed to help the growers in the lime requirement calculations.

The foliar application of nutrients is recommended as a quick way to correct the deficiencies to meet the urgent nutrient requirement during the critical phases of plant growth such as flowering, fruiting and nut development in cashew. It is also helpful to correct the micronutrient deficiencies, as the micronutrients are required in very small quantities and soil application is difficult. The foliar nutrition calculator included in the app is intended to aid the farmers in finding out the correct dosages of nutrients to be used in foliar application.

3.2 Scenarios Available in the Mobile App

The overview of the developed mobile app is given in Fig. 2. The various modules available in the mobile app are listed in Table 1. The fertiliser calculator module helps the growers to find out the site-specific nutrient requirement for their field. The farmers need to input information such as spacing followed, adoption of high density or ultra high density planting, the area under plantations, age of the trees, the recommended fertiliser schedule for their region, information on soil testing and the details thereof, and the type of fertiliser available with them. This app not only permits the calculation of major nutrients but also micronutrients. Another speciality of the app is, it is open-ended, in the sense that if some items such as the fertiliser available with the farmers are not listed in the drop-down menu, they can manually enter the details and nutrient content and calculate the dosage.

The lime calculator module in the mobile app helps the growers to calculate the lime requirement for their field. It works based on the lime requirement method of Woodruff [29]. The grower needs to input the pH of the Woodruff buffer treated soil, the radius of the canopy and the liming material to be used.

The foliar nutrition calculator module in the mobile app indented to help the farmers in calculations related to the foliar application of

major and micronutrients. Farmers can select the required nutrients from the dropdown menu and the dosage as per the prevailing recommendation is taken automatically. The additional inputs required from the farmer are spacing, area, age of the tree and capacity of the tank.

Yet another important module in the mobile app is the deficiency symptoms. The images of the major deficiency symptoms of nutrients in cashew are made available in the app. The farmers can relate the deficiency symptoms of their fields with any of the pictures, and on clicking the image in the app, the information

such as the description of the symptoms and various management alternatives will be displayed.

The other modules in the app include the option to download soil health card, by giving the unique national identification number (Aadhar card number) and year of soil testing. Whereas the paper-based soil health card is difficult to track, this digital soil health card gives the opportunity to download anytime and anywhere. Some useful converters are also included in the mobile app to aid in essential calculations by the farmers. The overview of different modules of the mobile app is given in Fig. 3.
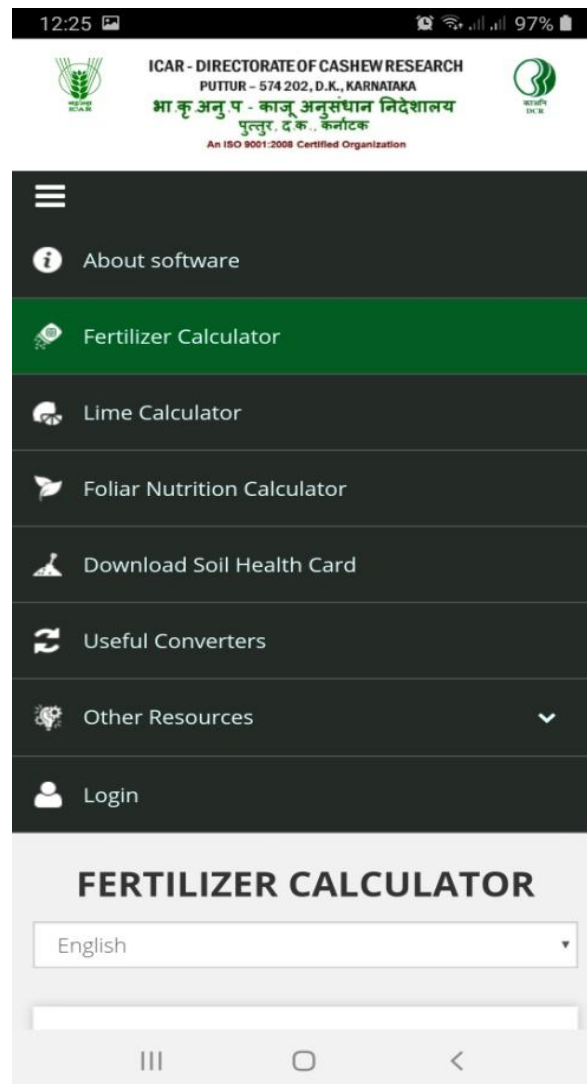

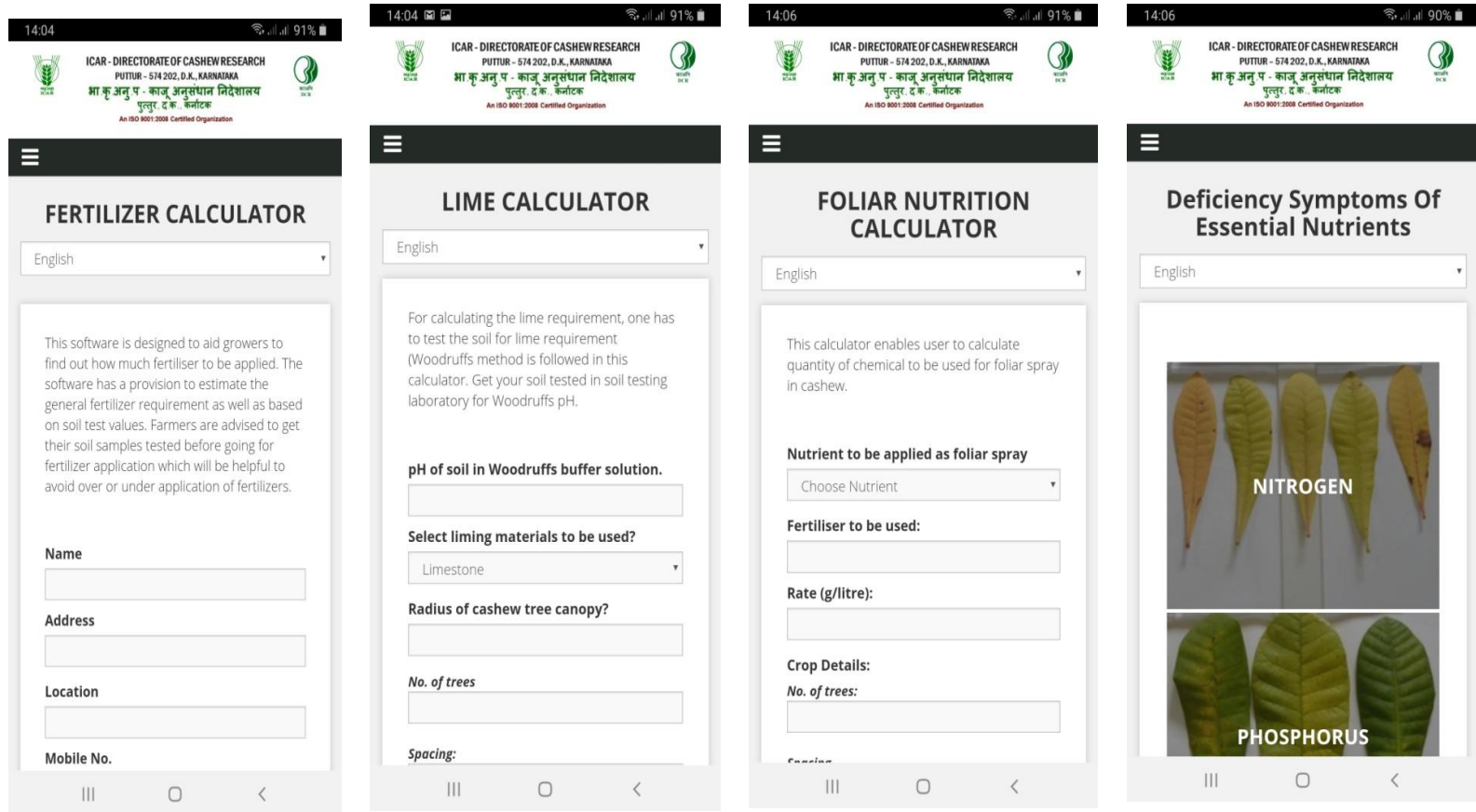**Fig. 2. The overview of the mobile app, "DCR-Cashew Nutrient Manager"**

1.1

Fig. 3. The different modules of the mobile app, "DCR-Cashew Nutrient Manager"

3.2.1 Soil nutrient status

The status of major nutrients such as N, P and K in the soil before initiation of the experiment and two years of implementation is provided in Fig. 4. The available nitrogen content ranged from 174.0 to 326.1 kg ha^{-1} and 189.4 to 358.2 kg ha^{-1} during the pre and post-experimental periods respectively. Among the three districts, the nitrogen status was high for the Udupi, followed by Uttara Kannada and Dakshina Kannada. The per cent improvement in soil status for available nitrogen by following the mobile app based site-specific nutrient management ranged from 7.7 to 15.7%. The range in available soil P status during the pre and post periods of the experiment was 8.5 to 27.1 and 8.9 to 28.6 kg ha^{-1} respectively and the per cent increase due to adoption of the improved management practices was in the range of 4.7 to 8.7%. Similarly, the mobile app-based site-specific management led to a 9.8 to 23.4% increase in soil K status compared to the initial status. The adoption of site-specific nutrient management with the help of mobile app benefitted in improving the soil status of nutrients such as Ca, Mg, Fe and Mn (Fig. 5). The Ca and Mg contents in soil, two years after the adoption of site-specific nutrient management was increased by 4.3 to 6.9 and 7.0 to 10.9% respectively over the initial status. However, the per cent increase was less for Fe and Mn. The Fe and Mn status showed an increase in the range of 1.2 to 4.0% and 1.1 to 3.0% respectively. The status of Zn, B and Mo in soil was decreased by 1.1 to 9.9%, 3.8 to 13.6% and 12.1 to 25.9% respectively (Fig. 6).

3.2.2 Leaf nutrient status

The nutrient status in the index leaves of cashew before the initiation of the experiment and two years after the implementation of site-specific nutrient management using mobile app is given in Table 2. The initial leaf nutrient status with respect to N, P, K, Ca and Mg in different farmers fields varied from 0.53 to 1.51%, 0.04 to 0.18%, 0.27 to 0.62%, 0.41 to 0.96% and 0.27 to 0.48% respectively. The corresponding values for these nutrients, two years after the adoption of site-specific nutrient management ranged from 0.65 to 1.91, 0.04 to 0.21, 0.30 to 0.75, 0.47 to 1.05 and 0.29 to 0.52% respectively. The adoption of improved management practices led to increased plant nutrient status. Compared to the initial leaf status, the post-adoption phase showed 22.2 to 45.5% increase in leaf nitrogen status, 6.2 to 12.5% increase in leaf P status, and 9.2 to 31.7% increase in leaf K status. Similarly, the Ca and Mg status registered a comparative increase of 5.6 to 15.8% and 6.3 to 10.9% respectively. Unlike soil, the leaf status of all the micronutrients found to be increased with the adoption of improved management practices based on site-specific nutrient management followed by farmers with the help of the mobile app. For Fe and Mn, the increment in leaf status in comparison to the initial values was in the range of 8.3 to 12.0 and 2.2 to 6.6% respectively. The leaf nutrient status with respect to Zn, Cu, Mo and B showed an increase in the range of 8.7 to 19.1, 3.1 to 9.0, 0.53 to 2.0 and 5.06 to 11.8% respectively due to the adoption of mobile app based site-specific nutrient management over the initial status where mostly fertiliser application was neglected by the farmers.

3.3 Cashewnut Yield and Economics

The effect of the adoption of site-specific nutrient management practices on yield and the benefit-cost ratio is presented in Fig. 7. In different regions the average baseline raw cashewnut yield recorded was in the range of 0.96 to 2.5 kg tree^{-1} with the baseline benefit-cost ratio of 1.09 to 1.99. The adoption of mobile-based site-specific nutrient management was found to be beneficial to increase the average raw cashewnut yield in farmer's fields in different districts to range from 2.61 to 6.45 kg tree^{-1} and benefit-cost ratio from 1.37 to 2.83.

3.4 Farmer's Response

The response of farmers towards the usefulness of the mobile app technology on 1 to 10 scales is provided in Fig. 8. The average score for the usefulness of the mobile app was 8.8. The farmers found the app very convenient to use (score 7.8) and user friendly (7.1). From the skill enhancement point of view, the average score obtained was 8.1. On average the farmers scored 8.1 out of 10 towards the chance of continued use of the app in future. In the lateral knowledge dissemination, all the participating farmers passed on the information about the mobile app to neighbours and friends with the number of people reached by them in the range of 46 to 92 Nos. About 66.7% of farmers perceived the app require further improvement.

Table 1. The main features of the mobile app "DCR-Cashew Nutrient Manager"

Sl. No.	Module in the app	Usefulness
1.	Fertiliser calculator	It helps to calculate the quantity of fertilisers as per the field situations of farmer and as per the fertiliser availability
2.	Lime calculator	This module enables to calculate the liming materials required to neutralise soil acidity
3.	Foliar nutrition calculator	It aids the growers in calculating the doses of nutrients to be applied as foliar spray
4.	Download soil health card	This module help the farmers to download soil health cards by providing their unique national identification number (Aadhar card number) and year of soil testing
5.	Useful converters	Some basic conversion factors are provided
6.	Deficiency symptoms	The pictures of prominent symptoms of nutrient deficiency in cashew are provided. On clicking each image the description of symptoms and various remedial options are displayed.

Table 2. Leaf nutrient status in cashew before and after implementation of the mobile app based nutrient management

Nutrient	Initial status			Two years after implementation		
Districts	Dakshina Kannada	Udupi	Uttara Kannada	Dakshina Kannada	Udupi	Uttara Kannada
N (%)	0.85±0.17	1.09±0.08	0.96±0.11	1.13±0.21	1.41±0.13	1.29±0.15
P (%)	0.11±0.02	0.07±0.01	0.09±0.01	0.12±0.02	0.08±0.01	0.10±0.01
K (%)	0.46±0.03	0.54±0.04	0.43±0.05	0.54±0.04	0.63±0.05	0.53±0.07
Ca (%)	0.88±0.03	0.64±0.08	0.71±0.08	0.98±0.04	0.71±0.08	0.78±0.08
Mg (%)	0.35±0.04	0.38±0.04	0.40±0.03	0.38±0.04	0.41±0.05	0.44±0.03
Fe (mg kg^{-1})	264.38±38	199.78±46	303.63±46	289.53±41	220.22±50	335.58±51
Mn (mg kg^{-1})	252.20±37	247.54±56	303.14±67	266.12±39	259.73±59	317.21±70
Zn (mg kg^{-1})	24.32±2.3	22.74±4.5	20.98±2.5	28.37±2.7	25.61±4.7	24.13±2.8
Cu (mg kg^{-1})	18.62±3.7	20.48±1.4	18.97±2.2	19.75±3.9	21.87±1.6	19.85±2.2
Mo (mg kg^{-1})	2.07±0.22	2.09±0.27	1.85±0.22	2.09±0.22	2.13±0.28	1.88±0.23
B (mg kg^{-1})	15.33±2.7	12.15±2.2	11.57±3.3	16.72±3.0	13.02±2.4	12.74±3.7

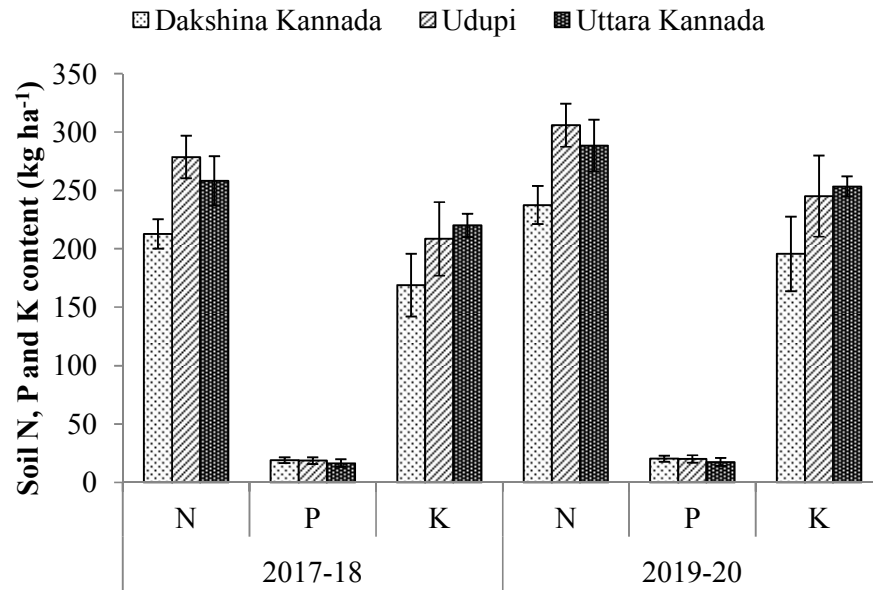*Values are Mean±Standard Error*

Fig. 4. N, P and K content in soil before intimation of experiment and two years after implementation
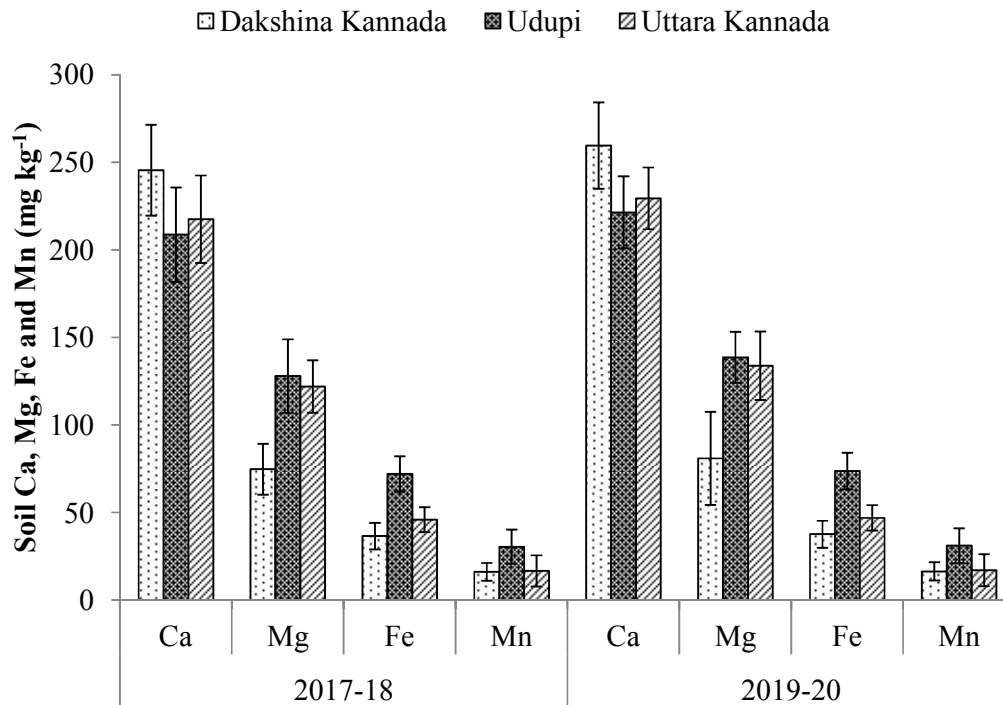

Fig. 5. Ca, Mg, Fe and Mn content in soil before intimation of experiment and two years after implementation
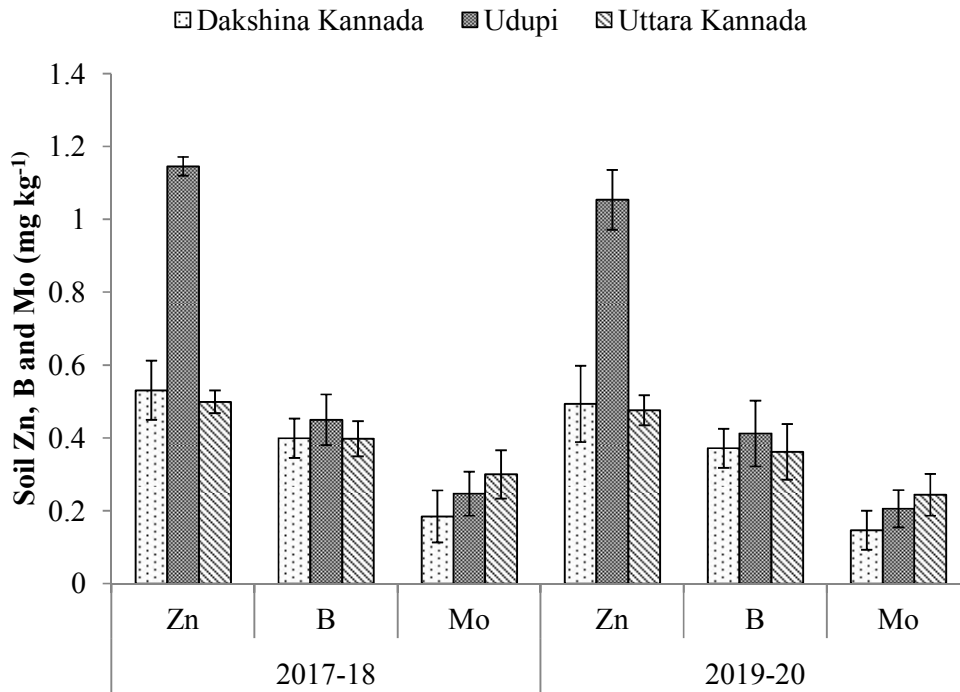
Fig. 6. Zn, B and Mo content in soil before intimation of experiment and two years after implementation
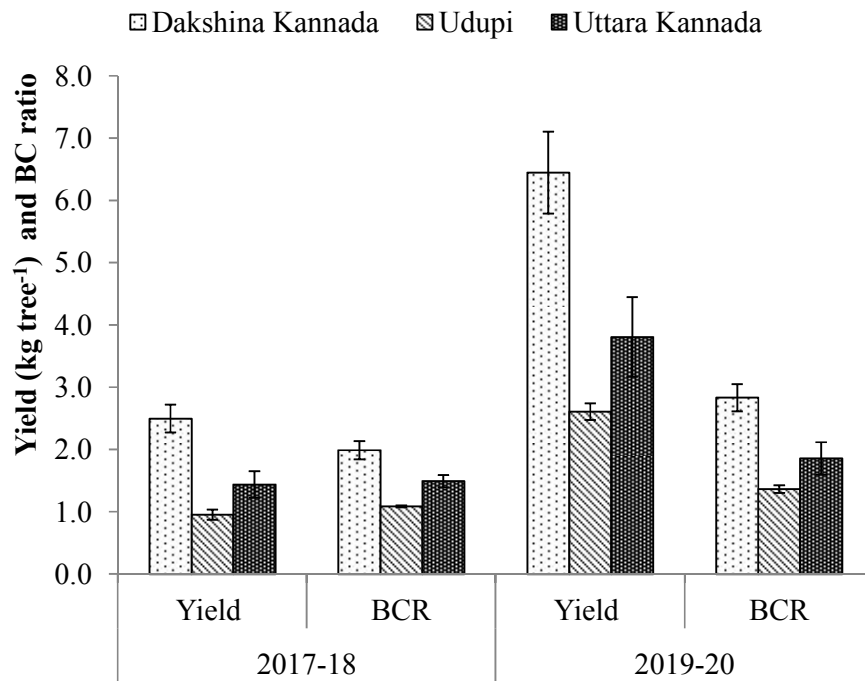

Fig. 7. Raw cashewnut yield (kg) per tree and benefit-cost ratio (BCR) before intimation of experiment and two years after implementation
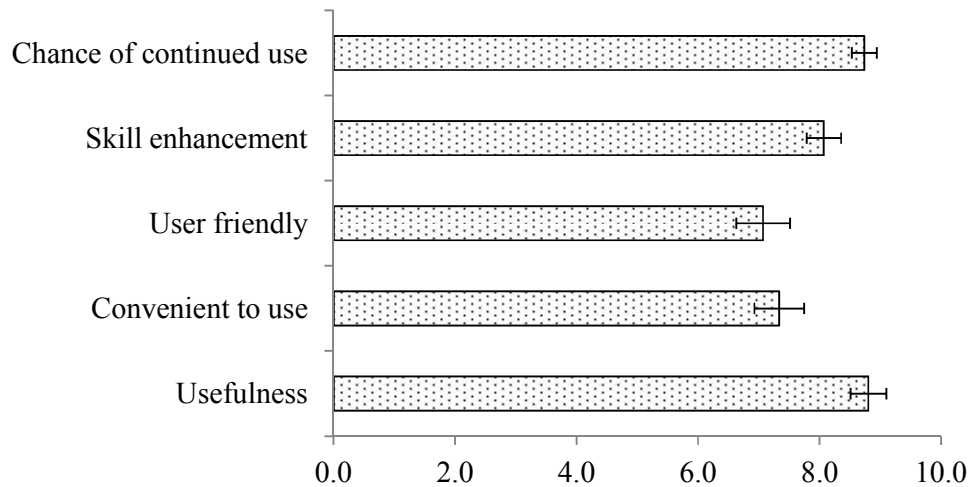
Fig. 8. Farmer's response about the usefulness of the mobile app (on 1 to 10 scale, one being extremely unlikely and 10, extremely likely)

4. DISCUSSION

4.1 Impact of Mobile App Based Nutrient Management on Soil and Plant Nutrient Status

The public extension activities are mainly constrained by limited manpower, burdening the extension personnel with non-extension duties, changes in priorities of the government etc [30]. Moreover, the remoteness of the agricultural farms away from the extension personnel or research institution was one of the hindrance in transfer of technology in agriculture [31]. The lack of resources prevents farmer to reach out to the research or extension functionaries also. Providing farmers with relevant information on advanced technologies in a timely manner is important for the production and economic point of view. Nowadays, information and communication technologies (ICT) are being increasingly used in the dissemination of agricultural technologies in the developing world [32,33]. Among the ICTs, smartphones have become ubiquitous and serve as an effective agent for the dissemination of information to a large number of clients, in cost effective and time-efficient manner [34]. Smartphones are being increasingly used by people around the world. In India, the smartphone users are reported to double by 2022 with an annual compound growth rate of 12.9%. As per Negi and Sharma (2019), the number of smartphone users by 2022 shall be 859 million compared to

468 million in 2017. Increasing penetration of smartphones coupled with availability of cheaper mobile data can be beneficial to reach advanced technologies to the farmer clients at a faster pace and in a form customised to their needs. In this study, a mobile app was developed to fill the extension gap in the area of nutrient management in cashew. The adoption of nutrient management practices by cashew farmers reported to be poor with an adoption index of only 30% [35,36]. The diverse field situation found not to go well with a generalised recommendation. The developed mobile app takes care of varied field conditions and intends to aid the grower in finding out recommendation specific to their field, by themselves.

Site-specific nutrient management envisages to apply only the need-based nutrients based on actual field situation to improve the crop productivity, farm income and to sustain the soil productivity [37,10] The studies on site-specific nutrient management showed its beneficial effects to increase farm income by 100 USD per hectare [33]. Web-based or mobile app based decision support system is being increasingly popular for helping the farmers for self computation of the rate of fertiliser and to assist in its proper application in accordance with his/her field conditions. Some such decision support systems are *Rice Crop Manager* for rice [38] and Quantitative Evaluation of Fertility of Tropical Soils (QUEFTS) [39]. In the present study, the adoption of the mobile app based site-specific nutrient management practices helped to

increase the soil nutrient status with respect to majority of the nutrients. The micronutrients such as Zn, B and Mo was decreased following the adoption of site-specific nutrient management. Plants roots tap more of the limited micronutrients from soil to meet the requirement of increased growth and production stimulated by the increased supply of major and secondary nutrients [40]. This indicates the emerging need for soil application of micronutrients and research efforts to standardise the dosage for soils in this tropical environment.

4.2 Impact on Yield and Economics

The increased response of cashew to applied manures and fertilisers were reported by many workers [41-43,15]. The application of nutrients at the critical stages of plant growth benefits the plant in effective sink development. This is corroborated by the increased leaf nutrient status recorded after the implementation of site-specific nutrient management programme compared to the initial status. The beneficial effects of soil test based nutrient management to improve the yields of a number of field crops were demonstrated in a number of field crops by Wani et al. [44]. They obtained a yield increase to the tune of 30-55% in sorghum and 10-50% in maize. In cashew, 50-100% increase nut yield by the nutrient management alone has been reported by Babu et al. [14]. In the present study, the yield improvement was in the range of 58 to 67% and the BC ratio showed an increase of 9 to 47% compared to the initial status. The study showed that the adoption of site-specific manures and fertilisers was cost-effective.

4.3 Farmers Response

Farmer's knowledge, awareness and perceptions are the key factors deciding the adoption of soil fertility management programmes in their field [45]. Technology adoption by the farmers also depends on the dissemination of information from the research institutions to the clients through effective extension system. However, many factors hinder achieving the desired efficiency in knowledge dissemination [46]. Attanandana et al. [47] stressed the need to empower farmer leaders in dissemination of site-specific nutrient management. Like any other agricultural technologies, the continued use of ICTs and mobile app-based technology dissemination also depends on its convenience and user-friendliness. In the present study, the majority of farmers find the app useful to improve

their self-reliance on scientific nutrient management.

5. CONCLUSIONS

The study presented in this paper elaborated about the mobile app, DCR-Cashew Nutrient Manager, developed to empower the cashew farmers to devise site-specific nutrient management suited to their field conditions. The mobile app take cakes care of most of the possible field situations of a cashew farmer and reduces his/her reliance on scientists and extension workers for nutrient management. The farmer participatory research using the site-specific nutrient management schedule derived using the mobile app by the farmers showed that nutrient status in soil was improved for the majority of the essential nutrients except for zinc, boron and molybdenum. Providing need-based nutrition to the crop was beneficial to increase the nutrient uptake as indicated by the increased leaf nutrient contents. The continued adoption of location-specific nutrient management programme was helpful to improve the nut yield in cashew and net income by the farmers. The study demonstrated the potential of mobile app based site-specific nutrient management to empower the farmers for the effective adoption of advanced scientific technologies with the resultant improvement in income and ecosystem sustainability.

CONSENT

As per international standard or university standard, Participants' written consent has been collected and preserved by the authors.

ACKNOWLEDGEMENTS

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1.   Kome GK, Enang RK, Yerima BPK. Knowledge and management of soil fertility

by farmers in western Cameroon. Geo Derma Regional. 2018;13:43-51.
DOI:https://doi.org/10.1016/j.geodrs.2018.02.001

2. Fageria NK. Soil fertility and plant nutrition research under field conditions: Basic principles and methodology. Journal of Plant Nutrition. 2007;30(2):203-223.
DOI:10.1080/01904160601117887.

3. Lal R. Managing world soils for food security and environmental quality. In Advances in agronomy: Academic Press. 2001;74:155-192.

4. Mangalassery S. Effect of inorganic fertilisers and organic amendments on soil aggregation and biochemical charac teristics in a weathered tropical soil. [Research article]. Soil and Tillage Research. 2019;187:144-151.
DOI:https://doi.org/10.1016/j.still.2018.12.008.

5. Masuda YJ, Castro B, Aggraeni I, Wolff NH, Ebi K, Garg T, et al. How are healthy, working populations affected by increasing temperatures in the tropics? Implications for climate change adaptation policies. Global Environmental Change. 2019;56:29-40.
DOI:https://doi.org/10.1016/j.gloenvcha.2019.03.005.

6. Kharin VV, Zwiers FW, Zhang X, Hegerl GC. Changes in temperature and preci pitation extremes in the IPCC ensemble of global coupled model simulations. Journal of Climate. 2007;20(8):1419-1444.
DOI: 10.1175/jcli4066.1.

7. Siemann E, Rogers WE, Grace JB. Effects of nutrient loading and extreme rainfall events on coastal tallgrass prairies: Invasion intensity, vegetation responses and carbon and nitrogen distribution. Global Change Biology. 2007;13(10):2184-2192.
DOI: 10.1111/j.1365-2486.2007.01425.x.

8. Munodawafa A. The effect of rainfall characteristics and tillage on sheet erosion and maize grain yield in semiarid conditions and granitic sandy soils of Zimbabwe. Applied and Environmental Soil Science. 2012;243815.
DOI: 10.1155/2012/243815.

9. Buresh RJ, Castillo RL, Dela Torre JC, Laureles EV, Samson MI, Sinohin PJ, et al. Site-specific nutrient management for rice in the Philippines: Calculation of field-specific fertilizer requirements by rice crop manager. Field Crops Research. 2019; 239:56-70.
DOI:https://doi.org/10.1016/j.fcr.2019.05.013.

10. Meena BP, Biswas AK, Singh M, Chaudhary RS, Singh AB, Das H, et al. Long-term sustaining crop productivity and soil health in maize–chickpea system through integrated nutrient management practices in vertisols of central India. Field Crops Research. 2019;232:62-76.
DOI:https://doi.org/10.1016/j.fcr.2018.12.012.

11. Mangalassery S, Rejani R, Singh V, Adiga JD, Kalaivanan D, Rupa TR et al. Impact of different irrigation regimes under varied planting density on growth, yield and economic return of cashew (*Anacardium occidentale* L.). Irrigation Science. 2019b; 37(4):483-494.
DOI: 10.1007/s00271-019-00625-7.

12. Anonymous. Area and production of cashew 2017-18; 2019.
Available:https://dccd.gov.in

13. Mohapatra AR, Vijayakumar K, Bhat NT. A study on nutrient removal by the cashew tree. Indian Cashew Journal. 1973;9(2):19-20.

14. Babu V, Reddy MNN, Rajanna KM, Vidya M. Performance of cashew to NPK fertilizers. In*,* 1080 ed. International Society for Horticultural Science (ISHS), Leuven, Belgium. 2015;291-294.
DOI:10.17660/ActaHortic.2015.1080.37.

15. Rupa TR. Nutrient and water management. In P. L. Saroj (Ed.), Cashew: improvement, production and processing New Delhi: Astral International Pvt Ltd. 2017;233-252.

16. Mahajan A, Gupta RD. Constraints in the adoption of INM system. In A. Mahajan, & R. D. Gupta (Eds.), Integrated nutrient management (INM) in a sustainable rice—wheat cropping system. Dordrecht: Springer Netherlands. 2009;185-191.

17. Daxini A, O'Donoghue C, Ryan M, Buckley C, Barnes A, Daly K. Which factors influence farmers' intentions to adopt nutrient management planning? Journal of Environmental Management. 2018;224: 350-360.
DOI: 10.1016/j.jenvman.2018.07.059.

18. Raj S, Bhattacharjee S. Mobile phone applications for agricultural extension in India. In S. Raj (Ed.), Mobile phone for agricultural extension: Worldwide mAgri innovations and promise for future. New

Delhi: New India Publishing Agency. 2014; 1-74.

19. Rohila A, Yadav K, Ghanghas B. Role of information and communication technology (ICT) in agriculture and extension. Journal of Applied and Natural Science. 2017;9: 1097-1100.
DOI:10.31018/jans.v9i2.1328.

20. Jackson M. Methods of chemical analysis. Prentice Hall of India (Pvt.) Ltd., New Delhi; 1973.

21. Nelson DW, Sommers LE. Total carbon, organic carbon and organic matter. In A. L. Page, R. H. Miller, & D. R. Keeney (Eds.), Methods of Soil Analysis, Part 2: Agronomy. 1982;9:539–579.

22. Subbiah B, Asija G. Alkaline method for determination of mineralizable nitrogen. Current Science. 1956;25(2):259-560.

23. Bray RH, Kurtz L. Determination of total, organic and available forms of phosphorus in soils. Soil Science. 1945;59(1):39-46.

24. Watanabe F, Olsen S. Test of an ascorbic acid method for determining phosphorus in water and NaHCO3 extracts from soil. Soil Science Society of America Journal. 1965; 29(6):677-678.

25. Page AL, Miller RH, Keeney DR. Methods of soil analysis, Part 2- Chemical and microbiological properties second edition (Vol. Agrono. Monogr., 9): American Society of Agronomy and Soil Science Society of America, Madison, WI. USA. 1982;1159.

26. Lindsay WL, Norvell WA. Development of a DTPA soil test for zinc, iron, manganese and copper. Soil Science Society of America Journal. 1978;42(3):421-428.

27. Dhyan S, Chhonkar PK, Dwivedi BS. Manual on soil, plant and water analysis: Westville Publishing House, New Delhi; 2005.

28. Mangalassery S, Nayak MG, Adiga JD, Preethi P, Muralidhara BM. Nutrient management in cashew, Technical bulletin No. 1/2019. 2019a;28.

29. Woodruff CM. Testing soils for lime requirement by means of a buffered solution and the glass electrode. Soil Science. 1948;66(1):53-64.

30. Nandi R, Swamikannu N. Agriculture extension system in India: A Meta-analysis. Agricultural Science Research Journal. 2019;10:473-479.

31. Altab AAT, Filipek T, Skowron P. The role of agricultural extension in the transfer and adoption of agricultural technologies. Asian Journal of Agriculture and Food Sciences. 2015;3(5):500-507.

32. Steinke J, Achieng JO, Hammond J, Kebede SS, Mengistu DK, Mgimiloko MG, et al. Household-specific targeting of agricultural advice via mobile phones: Feasibility of a minimum data approach for smallholder context. Computers and Electronics in Agriculture. 2019;162:991-1000,
DOI:https://doi.org/10.1016/j.compag.2019.05.026.

33. Daum T. ICT applications in agriculture. In P. Ferranti, E. M. Berry, & J. R. Anderson (Eds.), Encyclopedia of food security and sustainability Oxford: Elsevier. 2019;255-260.

34. Deichmann U, Goyal A, Mishra D. Will digital technologies transform agriculture in developing countries? Agricultural Economics. 2016;47(1):21-33.

35. Sajeev MV, Saroj PL, Lakshmisha R. Technology impacts on area, production and productivity of cashew in Dakshina Kannada district, Karnataka. Journal of Plantation Crops. 2014;42(1):62-69.

36. Nirban AJ, Sawant PA. Constraint analysis of cashewnut growers. Cashew. 2000; 14(1);45-49.

37. Singh SP. Site specific nutrient management through nutrient decision support tools for sustainable crop production and soil health. In D. G. Panpatte, & Y. K. Jhala (Eds.), Soil Fertility management for sustainable development Singapore: Springer Singapore. 2019;13-23.

38. Banayo NPMC, Haefele SM, Desamero NV, Kato Y. On-farm assessment of site-specific nutrient management for rainfed lowland rice in the Philippines. Field Crops Research. 2018;220:88-96.
DOI:https://doi.org/10.1016/j.fcr.2017.09.011.

39. Dobermann A, Witt C. The evolution of site-specific nutrient management in irrigated rice systems of Asia. In Increasing productivity of intensive rice systems through site-specific nutrient management: Enfield, N.H. (USA) and Los Banos (Philippines): Science Publishers, Inc. and International Rice Research Institute (IRRI). 2004;76-100.

40. Dimkpa CO, Bindraban PS. Fortification of micronutrients for efficient agronomic production: A review. Agronomy for Sustainable Development. 2016;36(1):7.
DOI: 10.1007/s13593-015-0346-6.

41. O'Farrell PJ, Armour JD, Reid DJ. Nitrogen use for high productivity and sustainability in cashew. Scientia Horticulturae. 2010*;* 124(1):19-28.
DOI:https://doi.org/10.1016/j.scienta.2009. 11.016.

42. Grundon N. Agronomy. Overview of Australian cashew literature. Technical Report No 25/99: CSIRO Land and Water, Australia. 1999;12-21.

43. Yadukumar N, Rejani R, Nandan SL, Prabhakar B. Nutrient budgeting and nutrient balance under high density planting system in cashew (Anacardium occidentale). Indian Journal of Agricultural Sciences. 2013;83(1):14-20.

44. Wani S, Chande G, Sahrawat K, Pardhasaradhi G. Soil-test-based balanced nutrient management for sustainable intensification and food security: Case from Indian semi-arid tropics. Communications in Soil Science and Plant Analysis. 2015;46:20-33.
DOI: 10.1080/00103624.2014.988087.

45. Maro G, Mrema J, Msanya B, Teri J. Farmers' perception of soil fertility problems and their attitude towards integrated soil fertility management for coffee in Northern Tanzania. Journal of Soil Science and Environmental Management. 2013;4:93-99.

46. Vandeplas I, Vanlauwe B, Merckx R, Deckers JA. Bridging the gap between farmers and researchers through collaborative experimentation. Cost and labour reduction in soybean production in South-Nyanza, Kenya; 2008.

47. Attanandana T, Yost R, Verapattananirund P. Empowering farmer leaders to acquire and practice site-specific nutrient management technology. Journal of Sustainable Agriculture. 2007;30(1):87-104.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/65312