# Maize-Nutrient-Manager

## A mobile phone application for field-specific, balanced nutrient management advisory

(version 1.0 for Songwe region Tanzania)

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***in collaboration with the Crop Nutrient Gap Project***

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## Short summary

To increase productivity and profitability, while limiting nutrient losses and related GHG-emissions, African smallholders need more tailored fertilizer advice. Yet, such advice critically hinges upon – largely lacking – field-level management data, as management is key to efficient fertilizer use. The **Maize-Nutrient-Manager (MNM)** mobile phone application enables collection of such data at scale, and directly converts this data into actionable advice for the farmer. Focusing on field-level management data, MNM can identify those management practices that are currently imperative for enhancing smallholder farmers' efficient use of fertilizers in their locality, thereby increasing productivity while reducing greenhouse gas (GHG) emissions. This document describes the background, design principles and development process of then MNM mobile phone application, as well as its pilot use in advisory practice in the Mbozi and Momba districts of Songwe region, Tanzania.

# 1. Introduction

This document describes the background, design principles and development process of the mobile phone application **Maize-Nutrient-Manager (MNM)**, as well as the deployment of version 1 of the application in the Mbozi and Momba districts of Songwe region, Tanzania, in Nov.-Dec. 2019.
**MNM** is an application for service providers (currently, agricultural extension workers) and smartphone owning smallholder farmers. It generates nutrient management advice for one maize field, based on the farmer's current management practices. MNM records agronomic management data to off-line generate:

(1) investment-based, balanced nutrient (NPK) advice, and;
(2) nutrient management advice (timing, application, application method, splitting, etc.).

The aim of this field-specific advice is to help smallholder maize growers to enhance the use efficiency of the fertilizers they can afford to use. The focus on enhancing nutrient use efficiency is a deliberate and key design principle of the MNM application. First, it means a shift of emphasis in agricultural advisory towards the farmers' (field) conditions and her/his available resources. Rather than prompting – often resource-constrained – farmers to invest more capital and labour in order to increase profitability and production, the main focus becomes how to increase fertiliser use efficiency based on smallholders' current (or preferred) spending. Second, a focus on improving nutrient use efficiency simultaneously helps to decrease related greenhouse gas (GHG) emissions. Applying the right balance of nutrients at the appropriate time of the crop's development not only increases yields, but also reduces losses, particularly $N_2O$ emissions that are associated with unbalanced NPK use.

**MNM** is both an application and a learning system for farmers, knowledge service providers and researchers. It alerts knowledge service providers and farmers to record those field conditions and management practices that are most likely to be relevant for increasing nutrient use efficiency. It thus stimulates MNM-application users to systematically record field conditions and management practices, thereby setting up a field-based 'business administration'. This record of management practices and their outcomes is crucial as well as innovative as it enables farmers and advice providers to evaluate and learn from the field-specific advice provided by MNM.

As MNM collects field-level agronomic management data (data that is currently scarce as it is typically not collected through surveys), and does so at scale, it allows researchers to identify the key yield-determining factors in a particular geography. Comparative analyses of management practices and their outcomes, that is, comparisons between large numbers of fields and farms and across seasons, can help to identify the critical management practices and field-conditions for enhancing nutrient use efficiency. Yet, to identify these critical management factors and to develop appropriate advice for them, requires a flexible approach with regard to application design; contents needs to be changeable.
Therefore, MNM is written in Open Data Kit (ODK), a free and open-source software package for mobile data collection in resource-constrained environments (https://opendatakit.org). While ODK consists of a suite of applications (for handheld devices, computers and servers), its main advantage for content development for agricultural advisory applications is that it enables users to quickly develop content in Microsoft Excel®, and to test this at scale on mobile phones that can be operated with ease by advice providers.

This document is organized as follows: First, we outline the background and rationale of field-specific nutrient management advisory. Then, we discuss the design principles and advice logics for such advisory, focusing on user needs, scaling potential, and effectiveness. Lastly, a pilot conducted with the MNM app in advisory practice in the Mbozi and Momba districts of Songwe region, Tanzania is described, and the way forward is explained.

# 2. Background

## 2.1 From blanket fertilizer recommendations to field-specific advisory

Fertilizer advice for African smallholder farmers generally takes the form of crop-specific blanket, high-input recommendations targeted at specified agro-ecological zones or administrative areas. These recommendations are based on average nutrient responses as measured in multi-locational crop-dose response experiments. Thus, for the Southern Highlands zone of Tanzania, the nutrient recommendations for maize are: 120 kg N and 20 kg P per hectare (and no recommendation for K as response to K was apparently minimal in the conducted experiments).

Targeted at agro-ecological zones, large scale differences in climatic conditions and soil types are currently shaping fertilizer recommendations. Yet, crop responses to nutrients are also shaped by lower level differences in soils and climatic conditions within one agro-ecological zone, as resulting from soil forming processes and topography (soil texture, landscape position, slope). In addition, crop yields are also shaped by field-level conditions (such as soil pH) and farmers' management practices (such as manure and nutrient management). A specific field's soil fertility, as well as a crop response (yield) to fertilization, is an outcome of three categories of factors – agro-ecological, field conditions and farmer management factors – that are strongly interdependent (Figure 1). As a consequence, blanket fertilizer recommendations (the same across an entire agro-ecological zone) can result in rather different outcomes (See Figure 2; red line).

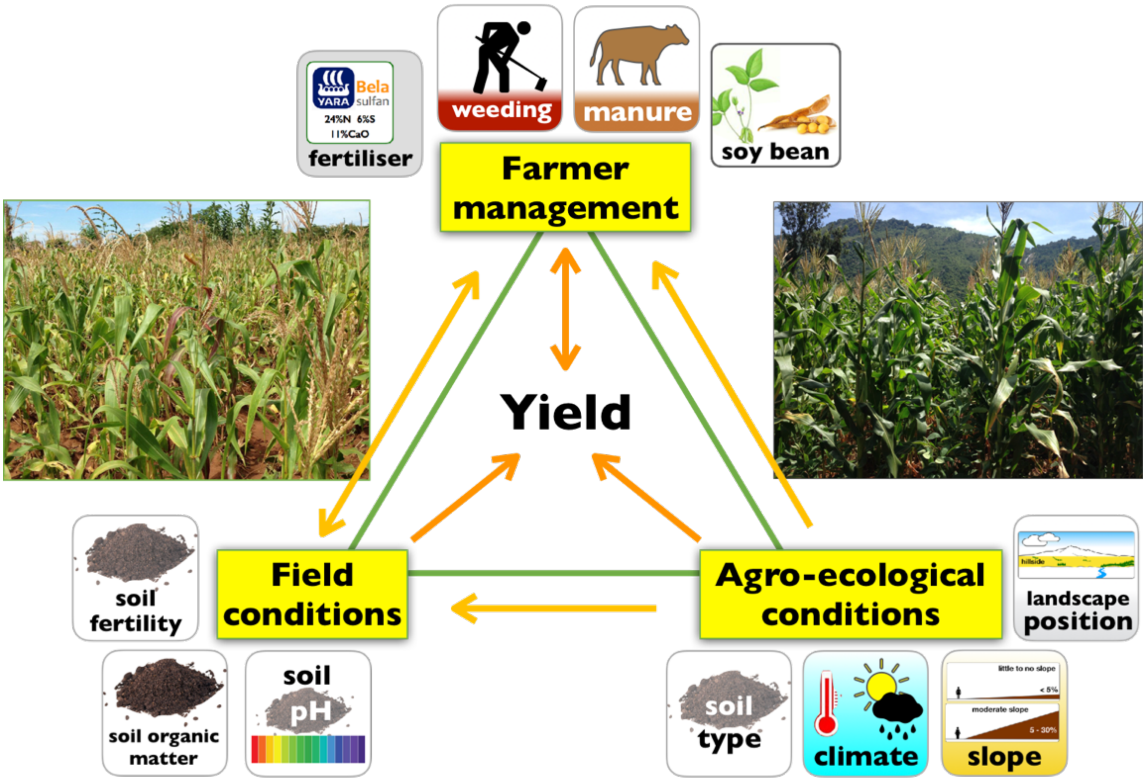


*Figure 1: Similar nutrient input levels result in different outcomes (cf. maize field pictures), as crop responses to fertilizer applications (yields) are a product of agro-ecological factors, field conditions and farmer management (some examples of each category of factors included).*

A further problem of blanket fertilizer recommendations is that they do not take account of changing market situations and farmer behaviour. For instance, low grain prices often limit the profitability of maize production, and therefore limit farmers' cash and labour investments in maize production. Agronomic considerations and profitability are therefore not likely to be the main drivers of fertiliser use. Smallholder farmers are often cash-constrained, which restricts their capacity to invest in expensive inputs such as fertilizer; while their livelihood composition is likely to structure resource allocations (capital and labour) on the farm. As a consequence, most farmers do not or cannot apply the recommended nutrient rates (Figure 2); Apart from economic and social considerations, the uptake of blanket recommendations is also hampered by the fact that many farmers do not know the exact size of their maize fields.

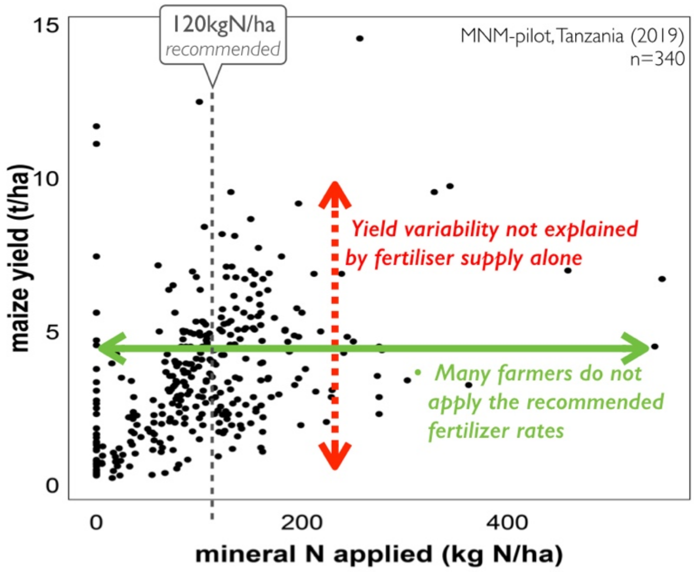


*Figure 2: Example of smallholder maize growers' reported Nitrogen use on their maize field, converted to N-use per hectare (field areas GPS-measured, production farmer estimated; outliers not-removed), Songwe region, Tanzania, 2018-2019 season.*

As similar nutrient rates result in rather different yield levels (Figure 2), even within geographies of limited extend (e.g. Mbozi and Momba districts of Songwe region), there appears to be room for improving smallholder farmers' nutrient use efficiency. If so, productivity can be increased, and fertiliser losses – such as greenhouse gas (GHG) emissions – be reduced. In order to achieve this, fertilizer advice needs to become more farmer and field-specific, and more encompassing – not only focusing on nutrient types and quantities, but also on management that improve nutrient use efficiency.

## 2.2 Fertilizer advisory and the 'data revolution': The lack of field-level management data

Capitalizing on rapidly expanding and increasingly detailed remote sensing-, soils- and climatic-data, data-driven approaches have taken the lead in the development of geo-spatially explicit, field-specific advisory. This is exemplified by tools such as Nutrient Expert® and Fertilizer Optimizer® (Figure 3).

The QUEFTS (Janssen *et al*. 1990; Smaling & Janssen 1993) model-based Nutrient Expert®[1] tool links (1) experimentally-derived, soil nutrient supply data to model the soil's nutrient supply and, (2) a limited set of indicators of a field's soil fertility status to adjust the model-derived estimation of the soil's nutrient supply, to generate field-specific fertilizer advice. The advice is based on a farmer-set target yield. Fertilizer Optimizer®[2] uses (1) nutrient-response experiments to establish crop-nutrient response functions, which are then used to generate farmer-specific advice that maximizes net returns to fertilizer for financially constrained fertilizer investment.


*Figure 3: Examples of field and farmer-specific fertilizer applications: Nutrient Expert® and Fertilizer Optimizer®.*

While both tools build on fertilizer and grain price data, either to calculate profitability (Nutrient Expert) or to maximize net returns (Fertilizer Optimizer), both tools build on averages – soil nutrient supply, and crop-nutrient responses – derived from multi-locational agronomic experiments. While the needed sample size and representativeness of these experiments is open to discussion, a major question remains: how to adjust the modelled average soil nutrient supply or crop nutrient response to the specific field for which an advice needs to be generated?

Most often, the answer is sought in the 'data revolution', which provides increasingly detailed and real-time, geo-spatially explicit soils and climatic data, can help to characterize field conditions. However, such data often remains too coarse to adequately characterize the often small (<0.5 ha) and discontinuous plots of smallholder farmers. In addition, data-driven approaches towards field-specific advisory often assume that these (remotely sensed or interpolated) geo-spatially explicit data on agro-ecological conditions are key determinants of field conditions and yield. Yet, as a growing body of agronomic literature on management-induced soil fertility gradients exemplifies (Mtambanengwe & Mapfumo, 2005; Tittonell *et al.* 2007a,b), field conditions and yields are to a large degree shaped by (past) farmer management of a field. Field-level management data is, however, largely lacking as it is not usually collected in agricultural surveys.

[1] Nutrient Expert® is a tool of the International Plant Nutrition Institute (IPNI). See: http://software.ipni.net/article/nutrient-expert

[2] Fertilizer Optimizer® is a tool of CABI, developed in collaboration with the University of Nebraska. See: Jansen *et al.* (2013).

Our research exemplifies this need for field-level, farmer management data. For instance, analyses of agronomic experiments distributed over agro-ecologically diverse landscapes in Ethiopia showed that the observed variability in experimental outcomes was not so much shaped by differences in soil types, climate or rainfall, but foremost by field-level factors (Andersson *et al*. in prep.; Figure 4b). Similar analyses of nutrient omission trials distributed over major maize growing areas in Tanzania suggest the same (Figure 4a). This shows that most variability in yield responses to N, P or K is explained at farm or field-level. Consequently, yield responses in one field have very little predictive value for other fields.

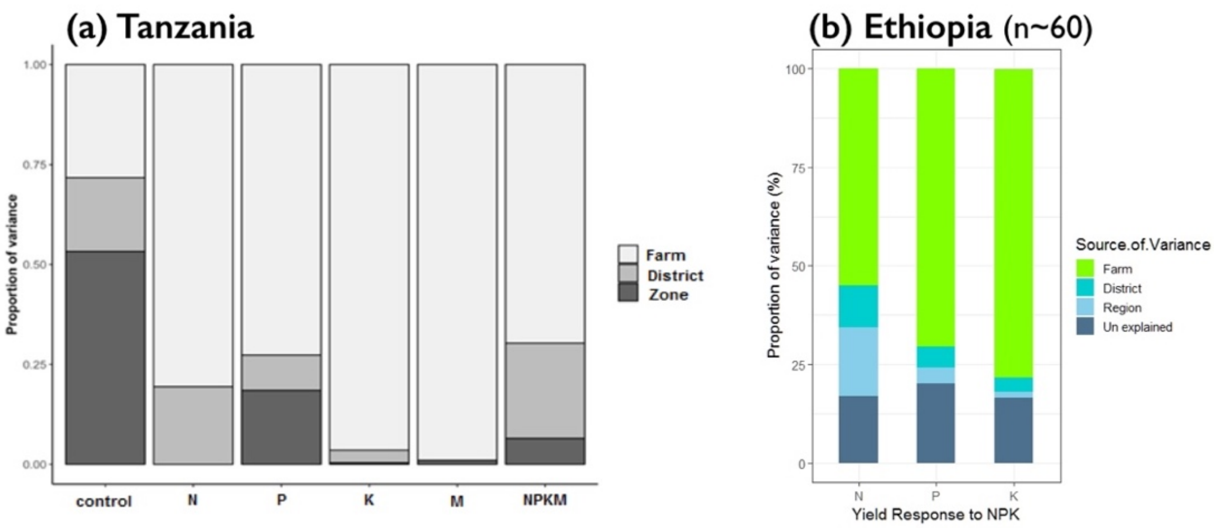


*Figure 4: Source of variance in yield responses to fertiliser application. (Note: Yield response data was derived from Nutrient Omission Trials (NOTs), that used one (high) level of nutrient inputs (i.e. NOTs are not the same as crop-nutrient response trials). (a) Tanzania (source: Delaune 2018). (b) Ethiopia.*

## 2.3 Collecting field-level management data at scale: developing a learning system

Acknowledging that field-level management is a key determinant of smallholder farmers' yields, the challenge becomes: How to collect this largely lacking management data at scale? And subsequently, how to translate this field-level management data into actionable field-specific advice that can be delivered at scale? The Maize-Nutrient-Manager (MNM) mobile phone application addresses these two challenges, by combining data collection with advice provision. Using an easily programmable mobile phone-based survey package – Open Data Kit (ODK) – it collects data on field conditions, field-level management and obtained yield of large numbers of smallholder farmers who farm in relatively similar agro-ecological circumstances and market conditions. This enables comparisons between fields in the same location and across seasons.

First, field characteristics – such as field size (GPS-measured) and agro-ecological conditions resulting from soil formation processes are captured: field location in the landscape, field slope, and soil texture These factors, which are known to influence nutrient availability and uptake, are recorded through simple visual representations (Figure 5).


*Figure 5: Field conditions recorded by Maize-Nutrient-Manager*

Second, management practices – of the past season – that are known to influence field conditions and yields are recorded These include:

- **crop(s) grown** – *e.g. yield benefits of crop rotation (especially with legumes) (Franke et al. 2018)*
- **land preparation and seeding practices** – *e.g. plant density and yields (Ciampitti & Vyn, 2011).*
- **manure use** (frequency and last season's use) – *e.g. effects on Soil Organic Matter (SOM), nutrient uptake, yields (Zingore et al. 2007)*
- **seed use** (variety, quantity used, recycled seed, seed spacing)
- **timing of planting** (plant date) – *e.g. yield penalty of late planting (Tittonnel et al. 2008)*
- **fertilizer use** (types, quantities, timing of application and method of application)
- **weeding practices** (pre- and post-emergence herbicides use, number of weedings)
- **observed nutrient deficiencies** in maize (P and K deficiencies)
- **observed pest and disease prevalence**

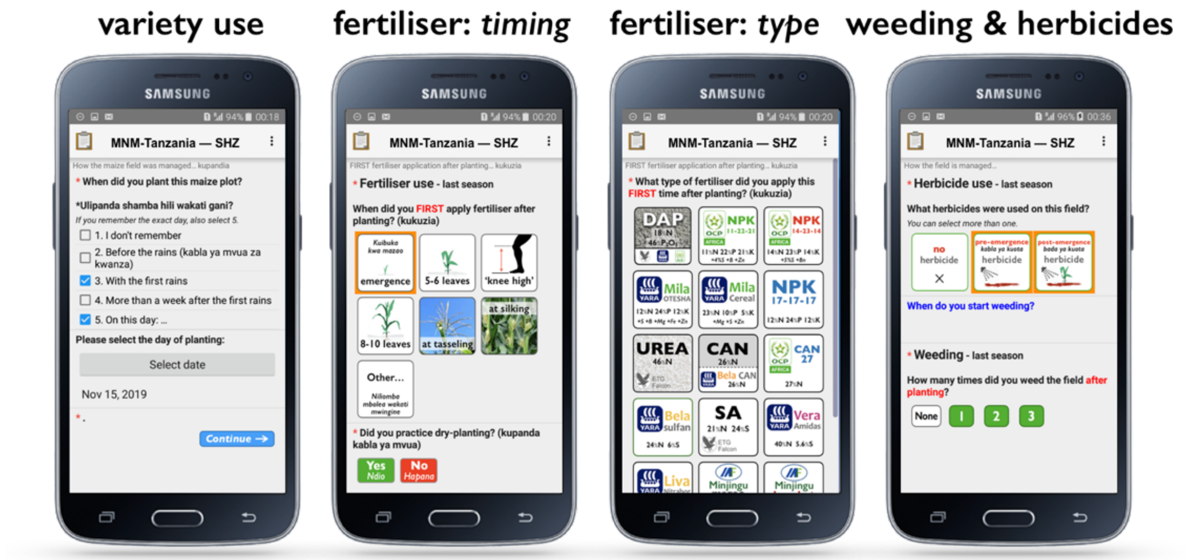


*Figure 6: Examples of field-level management data recorded in Maize-Nutrient-Manager*

Third, achieved yields are recorded in 'gunia', commonly used bags for grain that hold 108-112 kg of maize grain. (As many farmers do not keep the harvests of their different maize fields separate, MNM also records whether fields are harvested separately, as a measure for data quality assessment).

Exploratory research in Songwe region, MNM's operational area, informed what and how management practices are recorded. Locally available fertilizer blends, packet sizes and prices are included and MNM uses as much as possible the local terminology and units of measurement. For instance, as it was found that many farmers in Songwe region recycle hybrid seeds to save costs, MNM includes questions on seed recycling in order to establish whether such practices affect yields and nutrient use efficiencies. Using visualizations, local terms and units of measurement – such as acres and 'gunia' – not only serves to improve data quality, but most importantly, to speed up advice provision and to enable non-expert users to use the application. Thus, the scaling potential for field-specific advisory is enlarged.

### *2.3.1 Maize-Nutrient-Manager as a learning system for farmers and advice providers*

In recording field-level management data, the MNM-application stimulates farmers to be observant and keep a record of how they managed their maize field. In the 2019/20 pilot in Songwe region, farmers' recording of field-level management data is further stimulated by handing-out combined advice and field-record sheets to farmers. On one side the extension worker writes the MNM-advice, and on the flipside the farmer records types and quantities of fertilizers used, timing and method of application, observed nutrient deficiencies in the field, etc. (Figure 7).

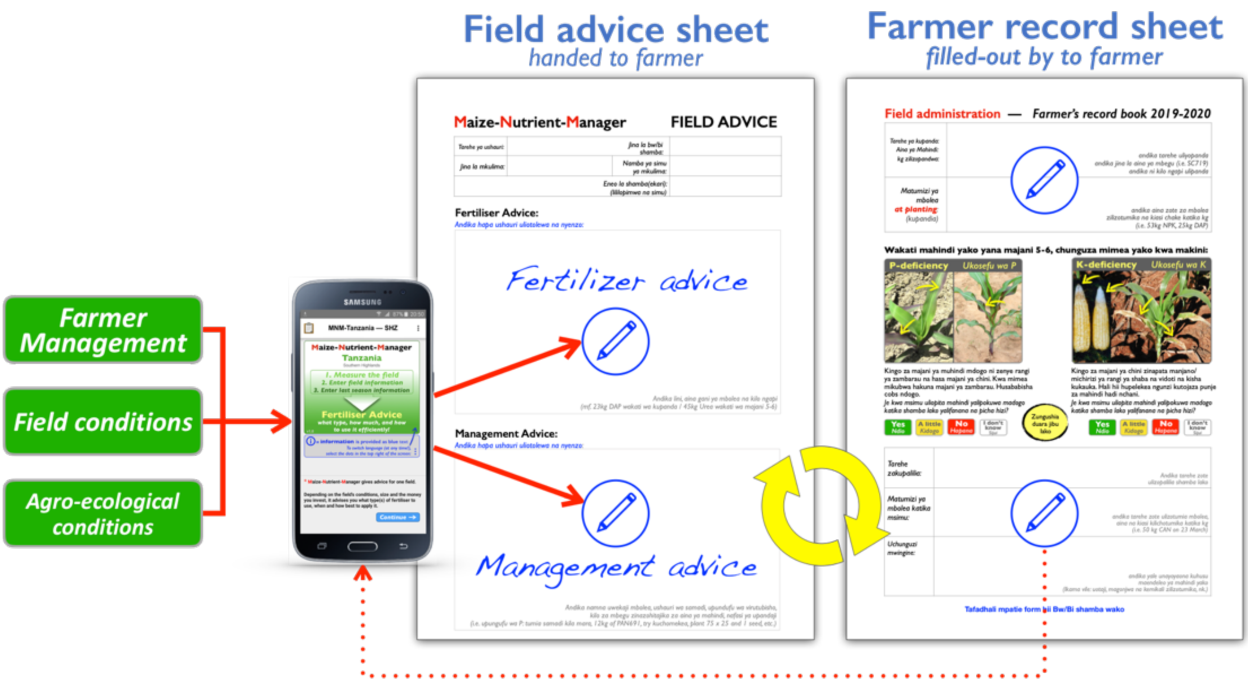


*Figure 7: Flow diagram of management recording, MNM-advice provision and farmer record-keeping*

### *2.3.2 Maize-Nutrient-Manager as a learning system for placed-based agronomy*

While the recorded field conditions and farmer management data are immediately transformed into tailored, field-specific advice (see next chapter) and handed to the farmer, the collected agronomic management data is aggregated and used for analyses. The MNM collected data focuses on three types of analyses:

1) the identification of management practices that enhance nutrient use efficiency in a particular locality or region;
2) diachronic analyses of fertilizer use and nutrient use efficiencies at different scales (field, locality, region);
3) advice uptake monitoring and impact evaluation through multi-season analyses of field-specific data.

These analyses, which centre on nutrient use efficiency, inform MNM-application updates: data collection on management practices that are commonly applied in the region, or that do not appear to have any (positive or negative) effect on nutrient use efficiency when assessed at different scales (field/locality/region), may be dropped from the application, in order to reduce the time required to generate an advice. Alternatively, found diversity in management practices or apparent effects of particular management practices may instigate further investigations and additional fieldwork in order to (re)-formulate new questions to be included in the application. For instance, MNM use in 2019/20 revealed the importance of intercropping and crop rotation with legumes (groundnuts, beans) in the Songwe region (see also section 4). Consequently, new data collection will also need to focus on recording legume cultivation related management practices to enable: (1) analysis of the potential effects of legume rotations on nutrient use efficiency, and subsequently; (2) the development of advisory for intercropping/rotated fields.

# 3. MNM design principles and advice logics

Targeted at African smallholder farmers who are often cash and labour constrained, yet constitute the vast majority of farmers in Africa, MNM design is informed by three main considerations. First, only actionable advice is scalable. Second, for advice to be actionable for generally resource-poor smallholder farmers, it should not require substantially higher cash and/or labour investments. Third, for field-specific advisory to be scalable within a large population of smallholder farmers, a large user base is needed. Therefore, advice generation should not require expert knowledge, take little time, and preferably, be location independent. In the discussion of main design principles below, these considerations will become recognizable.

## 3.1 Investment-based advisory and 4R principles: from Right rate to Right balance

As already noted earlier, African farmers' investment in fertilizers for maize production is often low and highly variable, due to low investment capacity (especially among the poor), volatile grain market prices, low and variable profitability. Yet, as maize is the main staple food for most (cash-constrained) farming households, all farmers do invest in maize production for food security purposes and, following the theory of the normal surplus production (Allan, 1965), are likely to invest more labour and capital than is needed to meet subsistence needs in an average year. Investment in fertilizer for maize is therefore not necessarily a function of profitability, nor simply a function of subsistence requirements. Farmer investment in a particular crop or field needs to be understood within the context of the farming households' livelihood strategy. Maximizing maize production is therefore not likely to be the aim of smallholder maize growing farmers.

Consequently, a focus on a single crop's nutrient needs, as outlined in the 4R nutrient stewardship approach (www.nutrientstewardship.org), is only likely to impede advice uptake and thus, limit the scaling potential of nutrient management advice. In situations of high fertilizer prices, as prevailing in many areas in Africa, a focus on crop nutrient needs or a set target yield (as in existing applications) may lead to social exclusion in advisory practice; Advice providers may target only those farmers who are able to invest in fertilizer, while resource-poor farmers may ignore advice that requires investments beyond their means. In order to enlarge the user base (scaling potential) for field-specific nutrient management advisory, MNM therefore adopts an investment-level design principle, replacing the notion of 'right rate' with 'right nutrient balance' (Figure 8).

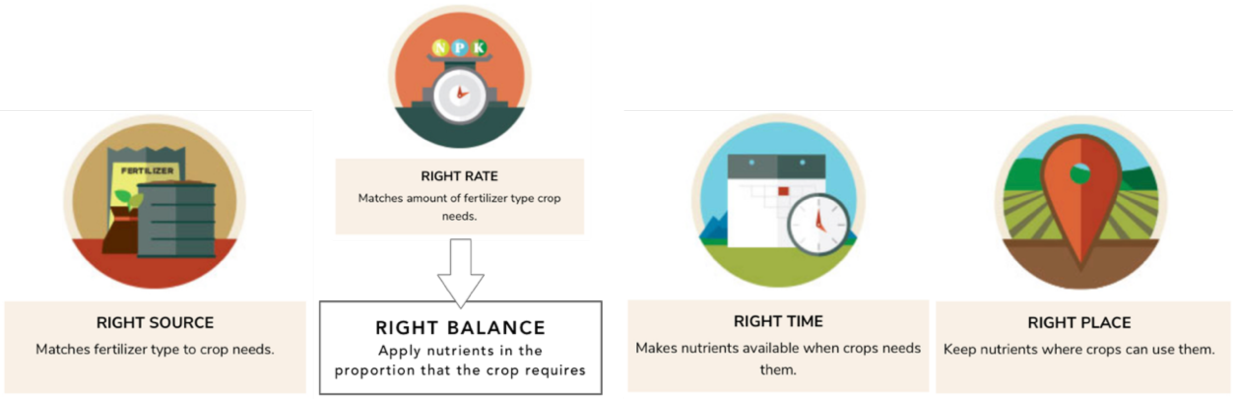


*Figure 8: 4R nutrient stewardship stresses, Right source of fertiliser, Right amount to match crop needs (in MNM replaced by Right balance), Right timing of fertiliser application, and Right placement (adapted from: www.nutrientstewardship.org)*

Based on the recording of fertilizer use in the previous season, the MNM-application estimates a farmer's investment in fertilizer for maize production. This estimate forms the basis of different advisory options (Figure 9):

1) Similar investment-level advice;
2) A farmer preferred – higher or lower – level of investment in fertilizer

Field research on farmer's nutrient management practices revealed that a substantial number of maize farmers in the Songwe region already starts to purchase seeds and (basal) fertilizers for the next season upon selling their harvest in September (Kilakila, 2020). Therefore, MNM also incorporates an advisory option for farmers who:

3) already have bought (some) fertilizer

*3.1.1 Investment-based advisory and the scaling potential of field-specific advisory*

As farmer-reported field areas are often biased (Carletto *et al.* 2013, Kilic *et al.* 2013), farmer reported yields – production per area – are often inaccurate too. In order to asses current yield levels and agronomic efficiency of current fertilizer use, the MNM application therefore starts with a protocol to measure the field-area using the phone's in-build GPS (global positioning system). However, as MNM-advisory is investment-based rather than target-yield based, field advice can also be generated without an accurate estimation of the field area for which the advice is generated. Consequently, MNM-advice generation does not necessarily require the application user to be present in the field. Investment-based -advice thus drastically enlarges the scaling potential of field-specific advisory, as it enables off-farm advice generation – for instance, by agro-dealers – and thus the user base. (Although MNM version 1 does enable off-farm advice generation, pilot use has thus far been restricted to extension workers visiting farmers in their fields).

*3.1.2 Investment-based advisory: Price per kg nutrient and farmers' fertilizer blend preferences*

An exploration of fertilizer blends and prices in the Songwe region in November 2019 further informed application design, building on the principle of investment-based nutrient advisory. It appeared that prices per kg nutrient, differed substantially between different blends. For instance, for basal fertilizers, prices per kg P varied from TSh 5,900 (for DAP and TSP) and TSh 6,800-7,800 (for NPS fertilizers), to TSh 15,000 or higher (for NPK fertilisers). Similarly, prices per kg N for top-dressing fertilizer varied between TSh 2,400 (for Urea) and TSh 3,000-3,500 (for CAN fertilizers), to TSh 3,600-4,200 (for SA and other N-based fertilizers).

As DAP and Urea are the cheapest and most widely available sources of respectively P and N, investment-based advice in MNM generates initial advice in kg DAP and Urea. However, many farmers also apply other top-dressing fertilizer types than Urea, as is evidenced by the wide availability of CAN and SA fertilizers. Such preferences for CAN and SA may be informed by lower volatilization risks in dry soils ('burning'), or by their (claimed?) rapid and efficient uptake by plants. Whatever farmers' exact considerations, MNM provides the option to replace standard, Urea-based advice with a maximum two different types of top-dressing fertiliser (Figure 9). Fertiliser quantities advice in MNM is provided in kg.

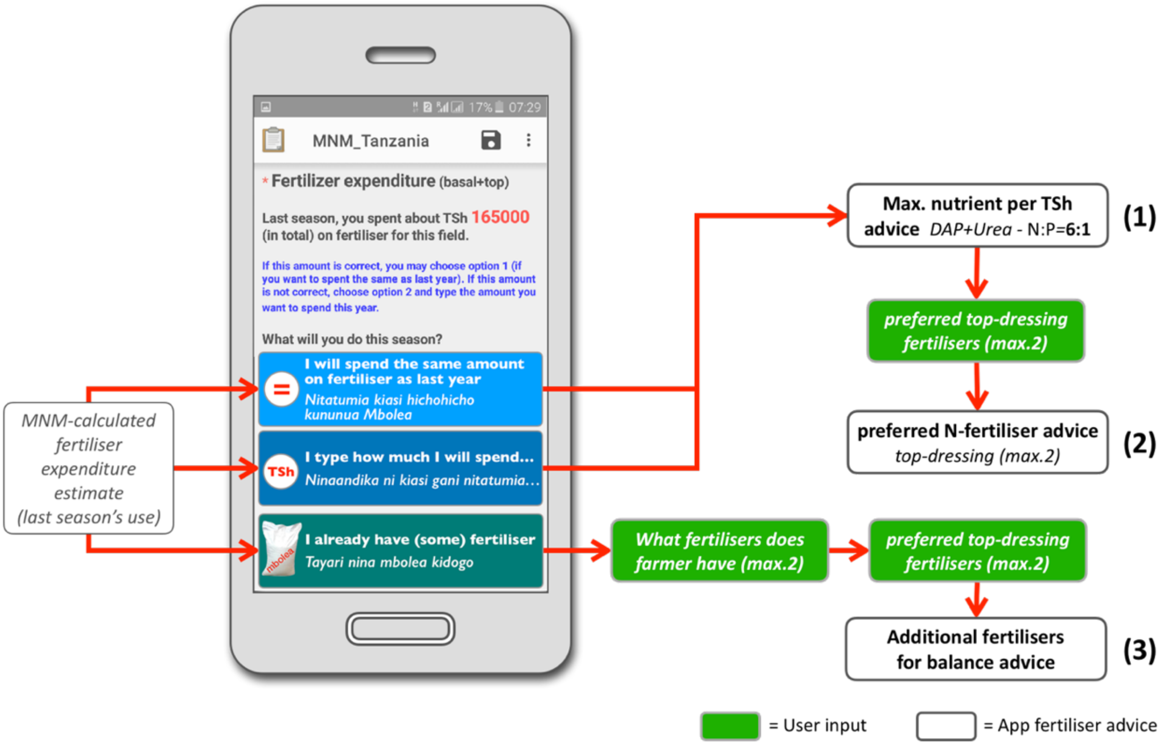


*Figure 9: Flow-diagram for nutrient source type decisions in MNM to arrive at balanced nutrition, based on: (1) farmer-preferred fertiliser expenditure; (2) preferred expenditure and preferred type of topdressing fertiliser, or (3) in addition to already purchased fertilisers. DAP and Urea constitute the cheapest nutrient solutions (kg nutrient per TSh invested).*

## 3.2 Towards balanced nutrient advice using available sources

Adopting a slightly revised interpretation of the 4R principles – adjusting only the nutrient *balance*, rather also the rate – to the crop's needs, MNM focuses on achieving an appropriate N:P ratio in the fertiliser applied. While this focus seems at odds with the principle of balanced nutrient supply, it is informed by the institutional environment in which field-specific advisory is to operate.

First, as in many areas, in Songwe region soils are generally regarded as not K-deficient. Hence, current blanket recommendations for maize do not include K, which may have shaped the availability of K-fertilizers in the region. Second, establishing the soil nutrient supply for N, P and K is a huge logistical challenge as (past) farmer management strongly influences nutrient supply and uptake. It is also questionable whether large-scale and repeated soil testing is a useful strategy in establishing the soil fertility status of smallholder's generally small maize fields. This is because there are indications that standard soil parameters are not always an accurate indication of the soil's fertility status, and that agronomic models – such as the QUEFTS model – may not adequately estimate crop yield responses to fertilizer applications under variable soil fertility conditions (Njogore, 2019). (Nevertheless, geo-spatially distributed nutrient response experiments for different fertilization rates could be helpful in generating a more are or site specific standard nutrient balance)[3]. Third, K-fertilizers are more difficult to obtain, more expensive, and only available in blends, impeding the possibilities of applying different balances of nutrients in response to field conditions.

[3] The reference nutrient balance used in the current version of MNM is based on current blanket fertilizer recommendations in Tanzania.

Unlike other field-specific advisory applications, which adopt the principle of soil nutrient replenishment – and therefore use maintenance rates for each macro-nutrient – MNM adopts a hybrid approach. Since establishing appropriate field-specific nutrient balances is not possible, in absence of (accurate) field-level soil fertility data, MNM uses a standard balanced nutrient approach for N and P. This standard balanced advice is combined with a field-specific approach focused on correcting apparent imbalances in soil nutrient availability. Visual farmer assessments of nutrient deficiencies in the field result in adjustments in the N:P ratio in the field-specific advice, and/or K-fertilizer application advice (Figure 10).

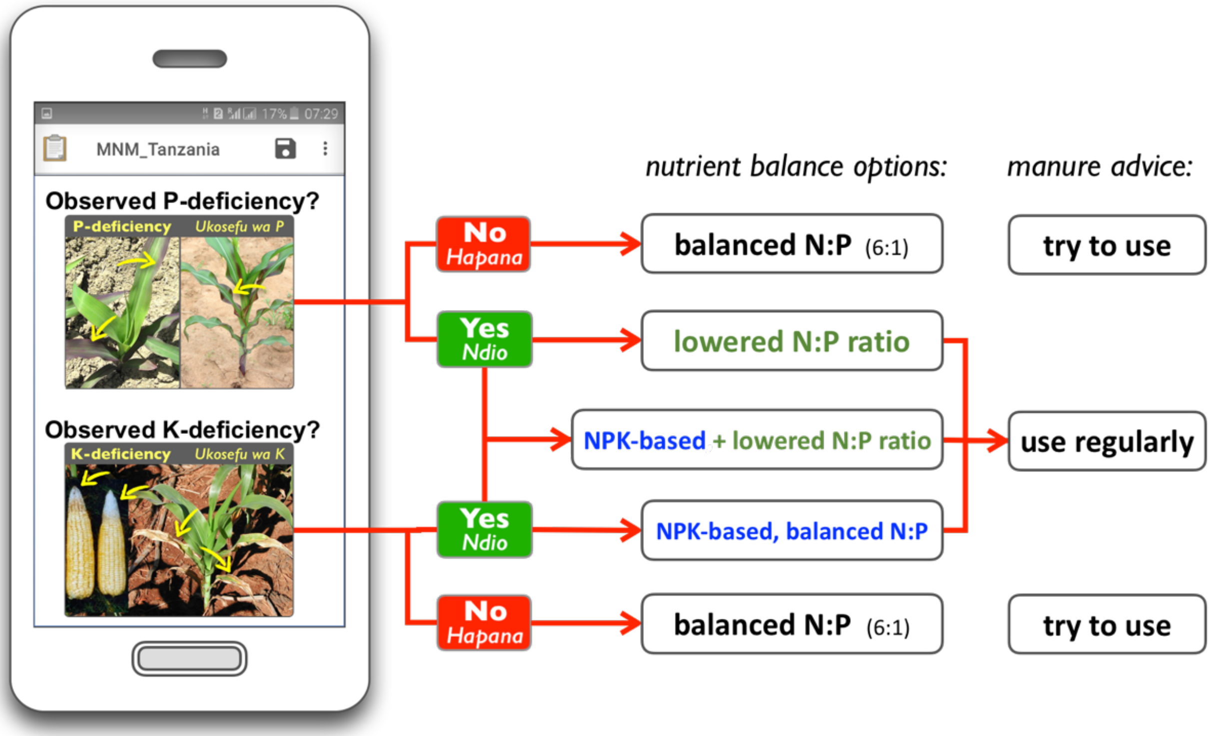


*Figure 10: Flow-diagram for adjusted nutrient balance decisions in Maize-Nutrient-Manager-based on farmer-observed deficiencies in previous season.*

### 3.3 Farmer nutrient management practices: Types, timing and application methods

As the timing of fertilizer application has a significant effect on nutrient use efficiency, yields and nutrient losses, MNM focuses both on recording existing diversity in nutrient management practices – to enable the identification of nutrient use efficiency enhancing practices – and the provision of farmer-specific advice. Next to recording types and quantities of fertilizer used, the focus is on:

- timing of fertiliser applications (top-dressing)
- application method (placement)

*3.3.1 Manure use advisory*

Next to inorganic fertilizer application, nutrient availability in smallholder farmer's fields can be strongly influenced by manure use, which provides nutrient and enhances soil organic matter in the soil. Yet low and uneven stocking rates (manure availability), and different manure management (collection, storage, transportation and on-farm distribution practices), make the assessment of the effects of manure use on yields difficult.

Research in smallholder farming systems has shown that manure quality and application rations are highly variable and often low, while in-field application methods differ. For instance, in Songwe region, farmers may spread their available manure across the field or, when there is little manure available, spot apply it to planting stations. In addition, manure use may replace the use of basal fertilizer (DAP), or be preferentially allocated to fields closer to the cattle kraal (boma), or to crops that have a higher returns than maize, such as coffee (Kilakila, 2020). Next to differences in manure quality, distribution and application methods, quantification of manure use has proven to be difficult; farmers often use different means to carry manure to the field and often do not keep track of amounts.

Many farmers apply manure on their maize fields, yet quantities and frequency often appear to be variable and difficult to establish. This also appeared to be the case in Songwe region, where both cattle-owning and non-cattle owning farmers could apply manure (Kilakila, 2020). The implications of these observations for field-specific nutrient advisory are not straightforward. Although manure application is generally beneficial, advising farmer to preferentially apply it to their maize field, may increase labour requirements (e.g. a when the maize field is far from the cattle kraal), or go at the expense of other crop production, or be less or not profitable when viewed from a farm-scale perspective. MNM-advice on manure use is therefore limited at present; it advices farmers to 'try to use manure' and those who observed nutrient deficiencies in their fields to 'apply manure regularly' (seasonally) (Figure 10). With a view on improving manure use advisory in the future, MNM collects information on manure use practices, including frequency of use, and whether manure was used in the previous season. (manure application methods – broadcast, spot-application – may also be included).

*3.3.2 Nutrient management advice (1): Basal fertilizer*

In the current version of MNM nutrient management advice is still limited, as detailed and quantitative data on farmer's management practices is still largely lacking. Building on farmer's input of last season's practice, basal fertiliser related advice in MNM currently consists of:

| **Last season's practice:** | | **MNM-advice:** |
|---|---|---|
| No basal fertiliser used | → | 'Try to use this season' |
| Basal fertiliser applied after planting *(DAP/NPK/NPS/TSP)* | → | 'Apply basal fertiliser at planting'<br>'Dry-planting?' *(i.e. seeding before rains)*<br>'Try *kuchomekea* at emergence'<br>*(kuchomekea = to place in a hole next to plant)* |

*3.3.3 Nutrient management advice (2): Top-dressing fertilizer*

MNM-advice related to top-dressing fertilizer use is equally limited at present, due to lack of detailed field-level data. However, explorative research in Songwe region suggested that some farmers start applying top-dressing fertilizer rather late in the growing season (Kilakila, 2020). Hence, the current version of MNM already includes advice on the timing for top-dressing fertiliser. When MNM is recording that the first time application of top-dressing fertiliser is late, the farmer is advised to apply their first top-dressing fertilizer earlier, at 5-6 developed leaves.

Building on farmer's input of last season's management practice, top-dressing related management advice in MNM currently consists of:

| **Last season's practice:** | | **MNM-advice:** |
|---|---|---|
| No top-dressing fertilizer used | → | 'Try to use this season' |
| < 25 kg top-dressing fertilizer used & field size > 0.5 | → | 'You may split apply, but you can also all at once before maize has 8-10 leaves' |
| > 25 kg top-dressing fertilizer used & applied at once | → | 'Split apply top-dressing fertiliser, about half the first time (5-6 leaves), the remainder the second time.' |

### 3.4 Identifying nutrient use efficiency enhancing conditions and practices: Adopting a farming and agricultural systems perspective

As mentioned before, in absence of field-level management data, the current version of MNM necessarily centres upon recording those management practices that are potentially shaping crop nutrient responses and enhancing nutrient use efficiency. What practices to include in the MNM application is informed by:

1) An extensive academic literature that has delineated field conditions and management practices factors that may affect nutrient availability and uptake in specific situations;
2) Local explorative research into farmer's current farming practices to establish whether these field conditions and management practices apply in the application's operation area;
3) A mapping and quantification of the diversity in field conditions and management practices in the application's operational area.

For instance, while in the agronomic literature it has been well-established that crop rotation with legumes can improve soil nutrient supply, local research is required to establish what rotations are practiced in order to estimate possible effects and their magnitude. Yet, for the development of relevant field-specific advisory it is not only necessary to map the different crop rotation practices, but also to establish the frequency by which these occur within the farming population. Rare practices, or practices that are applied by all, do not warrant the development of specific advice protocols, or numerous questions in the application.

Next to mapping relevant but diverse field conditions and management practices at field-level, it is important to understand farming practices within the context of the local farm household system and the agricultural system at large. For example, whereas questions on crop rotations with nitrogen-fixing legumes are included in MNM in order to enable analyses of their impact on soil nutrient supply and nutrient use efficiency, rotations with non-nitrogen fixing cash-crops may have similar effects due to farmers' preferential allocation of resources (i.e. fertilizers) to such cash-earning crops. (Input-providing contract-farming arrangements may shape similar impacts). Explorative research in Songwe region suggests the importance of such preferential allocations of resources within the farm; coffee growing farmers were found to preferentially allocate their available manure to this cash crop, rather than to their maize crop (Kilakila, 2020). In addition, within farm manure allocations may appear to be a function of the distance of the field to the farmer's homestead and cattle kraal (boma); analysis of the MNM-collected field data is to establish whether such distances reflect management gradients and soil fertility gradients (Zingore *et al.* 2007).

# 4. MNM-Tanzania pilot, 2019-2020: Initial findings and next steps

In the Mbozi and Momba districts (Songwe region), Tanzania, a first version of MNM is currently piloted (~1,000 farmers advised) (Figure 11). Its use is monitored and will be evaluated in 2020. Initial impacts of MNM advisory will also be assessed in 2020. This chapter presents some initial findings and outlines possible next steps in the development and institutionalization of the MNM application. As data analyses is ongoing and application use, advice uptake and impact is still being monitored, these are merely preliminary explorations.

*4.1 Initial findings on nutrient use, timing, agronomic efficiency and investment-based advisory*

The 2019/20 MNM-Tanzania pilot builds on advice provision by government extension workers in in Momba and Mbozi district. Thirty-two extension workers who were already familiar with smart-phone use, received a half-a-day training in MNM use in November 2019. Given a target of 35 advices per extension worker, they generated approximately 1,000 advices within a period of two months (Figure 11).

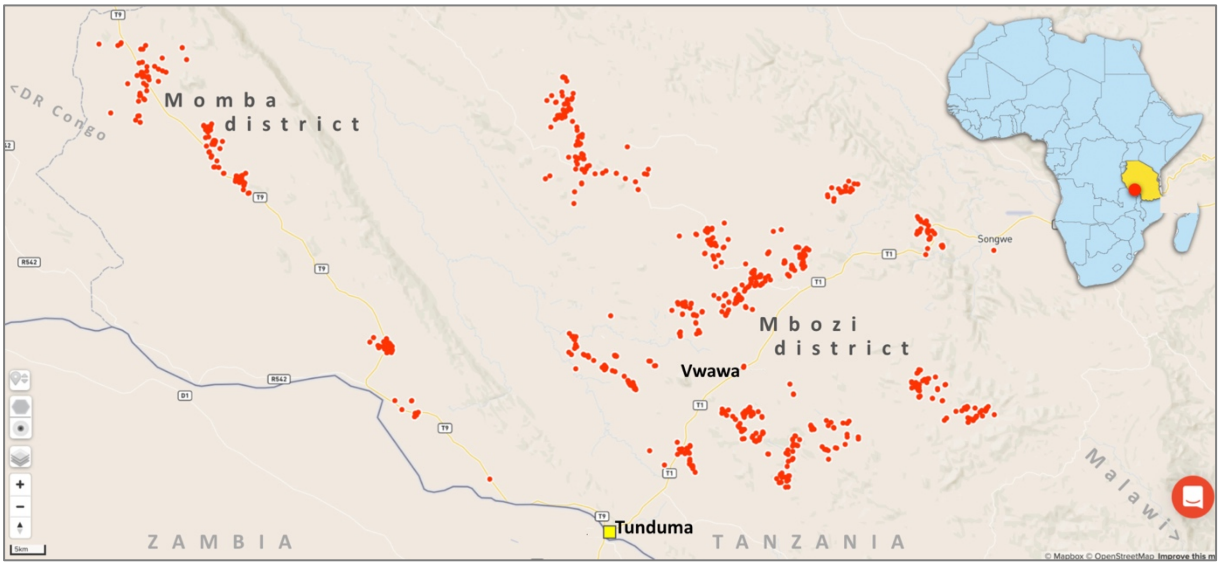


*Figure 11: Location of MNM-advices provided by 32 government extension workers Songwe region, Tanzania (n~1,000 farmers)*

*Is there a need for more balanced nutrient advice?*

Figure 12 shows actual N and P use by maize growing farmers in the 2018/19 season on the plot targeted for MNM-advice in the 2019/20 season. The figure shows that whereas a number of farmers did not apply any fertilizer (blue arrow), most did apply both basal (P) fertilizers and top-dressing (N) fertilizers. Yet, the more kg fertilizer a farmer applied, the higher the N:P balance appears to become (slope of the N area, no slope P area), suggesting there is space for more balanced nutrient advisory.

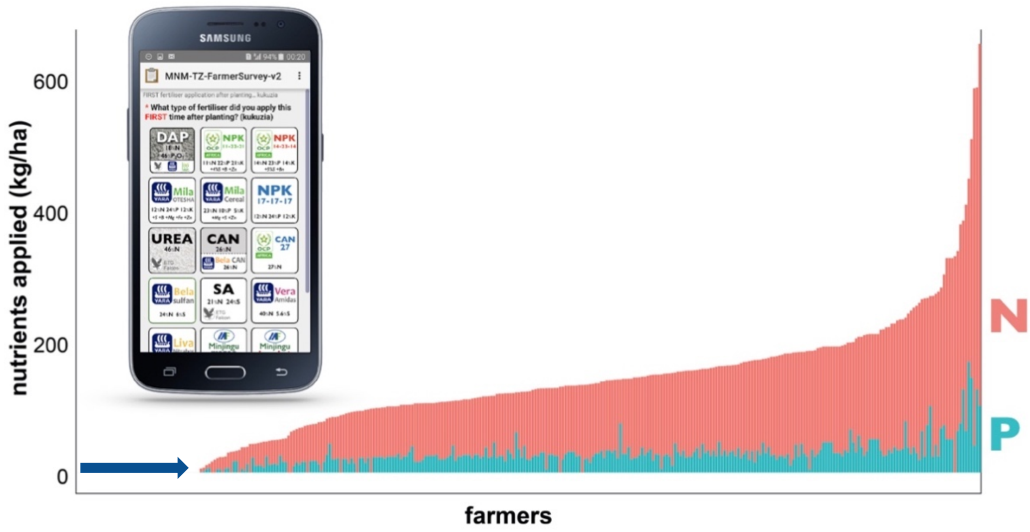


*Figure 12: Total kg N and P used per targeted maize plot, 2018/2019 season (n=349). Note that a substantial group of advised farmers did not use any fertilizers. N:P ratio increases as fertiliser use increases - scope for balanced advice?*

*Nutrient management advice: Incorporating farmers' fertilizer preferences and timing advice*

Initial explorations of maize farmers' fertilizer use confirmed that many farmers also apply other top-dressing fertilizer types than Urea (CAN and SA are the most commonly used top-fertilisers after Urea; accounting respectively for 13, 12 and 67% of all the fertiliser used among n=312 farmers; basal fertilizer used is predominantly DAP).

A substantial number of smallholder farmers does not appear to apply fertilizers to their maize, or only apply top-dressing fertilizers. In Songwe region, about 14% of maize growing farmers (n=347) reported not to have applied any fertilizers (18% no basal fertilizer, 15% no top-dressing fertilizer) to their maize in the 2018/19 season. Explorative research (Kilakila, 2020) in November 2019 yielded different figures of non-use of fertilizers (40% no basal fertilizer, 4% no top-dressing use; n=102), but also that:

- maize plots dedicated to the production of maize for household consumption tended to receive less attention and inputs;
- farmers that apply manure to their maize field may reduce or not use any basal fertilizer;
- maize plots close to the homestead are more likely to receive manure inputs;
- different fertiliser application methods are used by farmers using hand hoes or animal draught power at planting;
- some farmers apply basal fertilisers (long) after planting

Recording of farmer practices through MNM use confirmed the latter practice; It was found that about a third of the fertilizer-using maize farmers tend to apply top-dressing fertilizer for the first time only at 8-10 developed leaves or later (Figure 13).

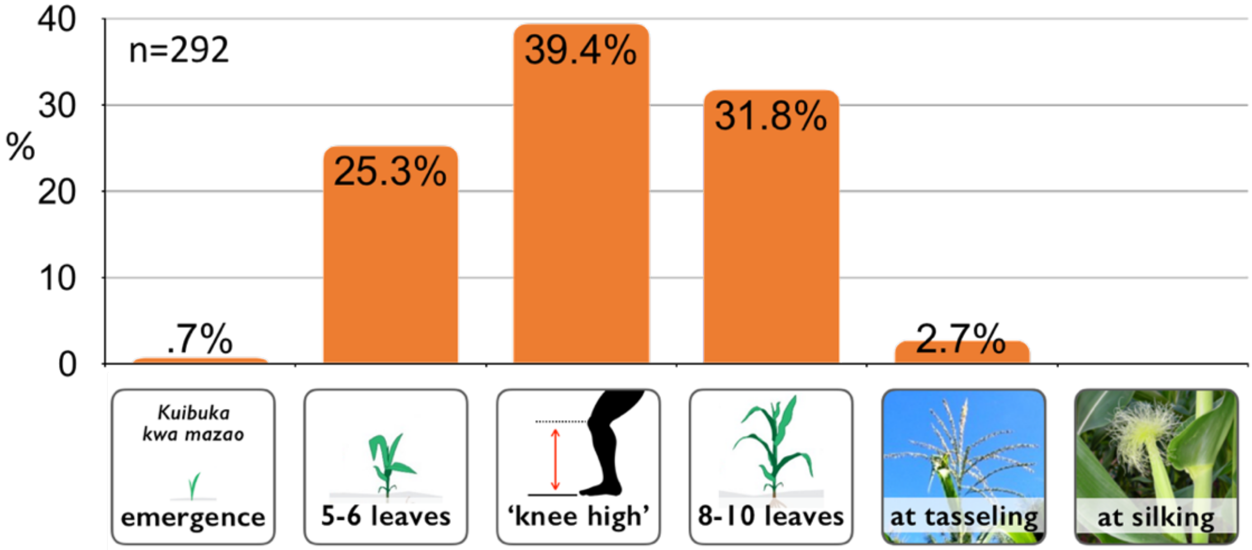


*Figure 13: Timing of first top-dressing application by Songwe region farmers, 2018/19 season (n=292; non-applying farmers excluded). Note that 5-6 leaves and 8-10 leaves does not correspond with V6 and V8 crop development stages. Farmer who split applied topdressing fertiliser, tended to apply their first fertiliser application earlier (at 5-6 leaves or knee-high).*

*Agronomic efficiency of fertilizer use*

An initial exploration of Agronomic Efficiency (AE) related to N application (outliers not removed) suggests that maize farmers harvest at least an extra 8 kg grain for each kg N applied. On average, this efficiency is 12 kg additional grain for each extra kg N applied (Figure 14).

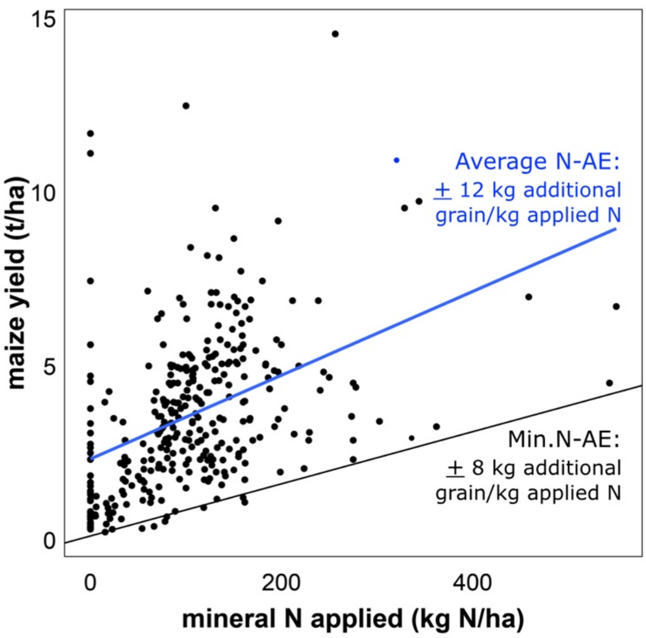


*Figure 14: Observed Agronomic Efficiency related to N application (n=330): Minimum agronomic efficiency (N-AE): 8 kg additional grain per kg N applied. Average agronomic efficiency (N-AE): 12 kg additional grain per kg N (P<<0.00001).*

*Understanding farmers' fertilizer investment behaviour to enlarge MNM's scaling potential*
Initial explorations of the MNM-application's principle of investment-based advice, suggests the value of providing both cash-based options *and* an 'already-purchased' option. Figure 15 evidences the existence of different fertilizer purchasing practices among maize growing farmers: some buy early, others only shortly before the season starts. These different options enlarge the time-window for advice provision, enabling advice provision from the moment farmers have harvested their maize, up to the time time farmers start planting their next crop.

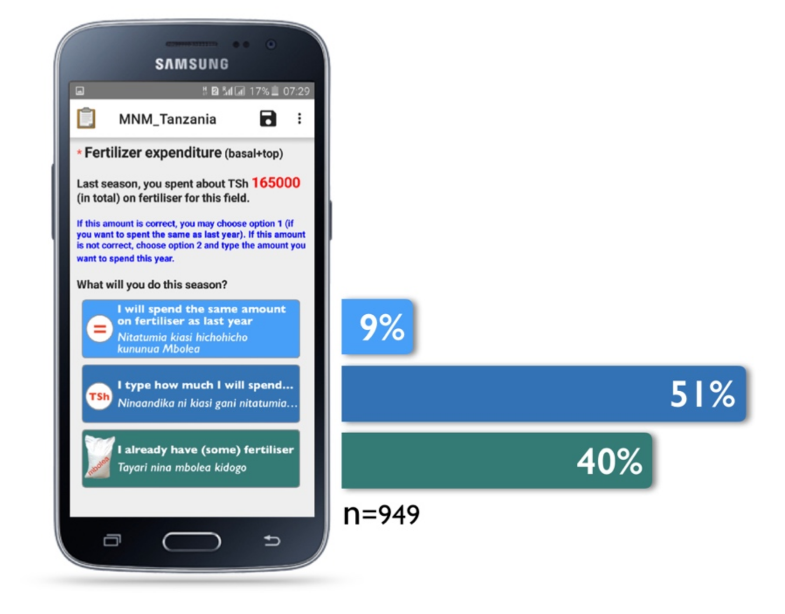


*Figure 15: Number of farmers opting for different investment-based advisory options.*

*4.2 Next steps in the analyses, development and institutionalization of the MNM-application*
In 2020, as the agricultural season progresses, research will initially focus on monitoring advice uptake and impact analyses. Field advice and Farmer record sheets (Figure 7) will be collected to analyse:

- App-provided MNM-advice and MNM advice provided on the hand-outs;
- Farmer records of management practices
- Behavioural change in nutrient management

In addition, MNM use will be evaluated through interviews (and workshops) with farmers and extension workers. These interviews will inform adjustments in the user interface and application's options and advice protocols.

Later in the season, after farmers' have harvested, analyses will focus on early impacts of MNM-advice provision, including comparative analyses of the performance of:

- MNM-advised farmers and a control group of non-advised farmers
- MNM-advice followers and non-followers

More extensive data analyses, aiming to identify nutrient management practices that enhance nutrient use efficiency, will result in the development of new field-specific advisory to be included in MNM, and the identification of new data collection protocols (for future learning). A lack of observed diversity in measured management practices, or data collection on nutrient management practices that do not appear to have had any impact on nutrient use efficiency, may be dropped from the application.
An updated version of MNM will be made available for uptake by the Tanzanian government's regional agricultural research institute (TARI-Uyole), and the district agricultural extension service operating in the Southern Highlands of Tanzania by mid to late 2020.

# 5. Acknowledgements

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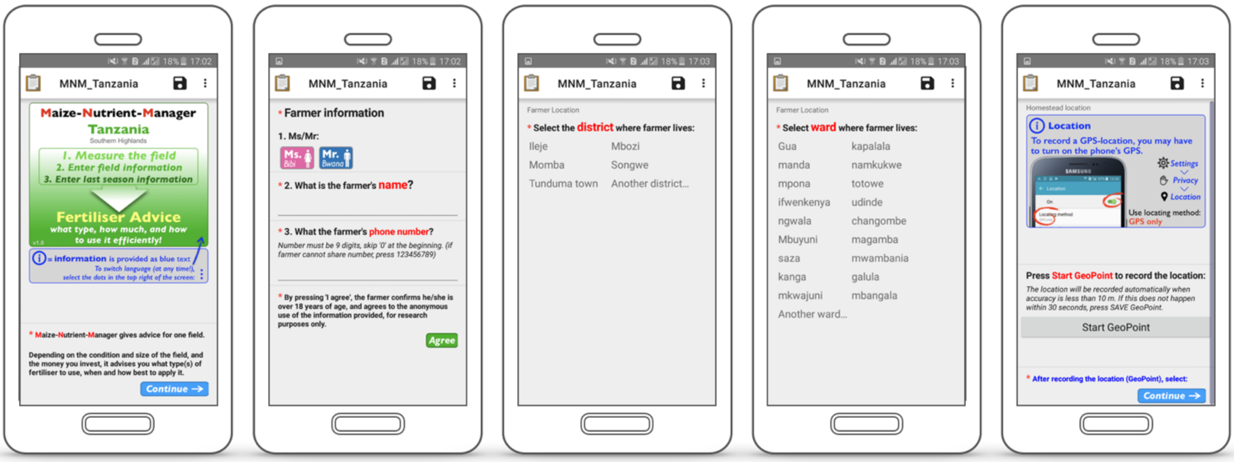
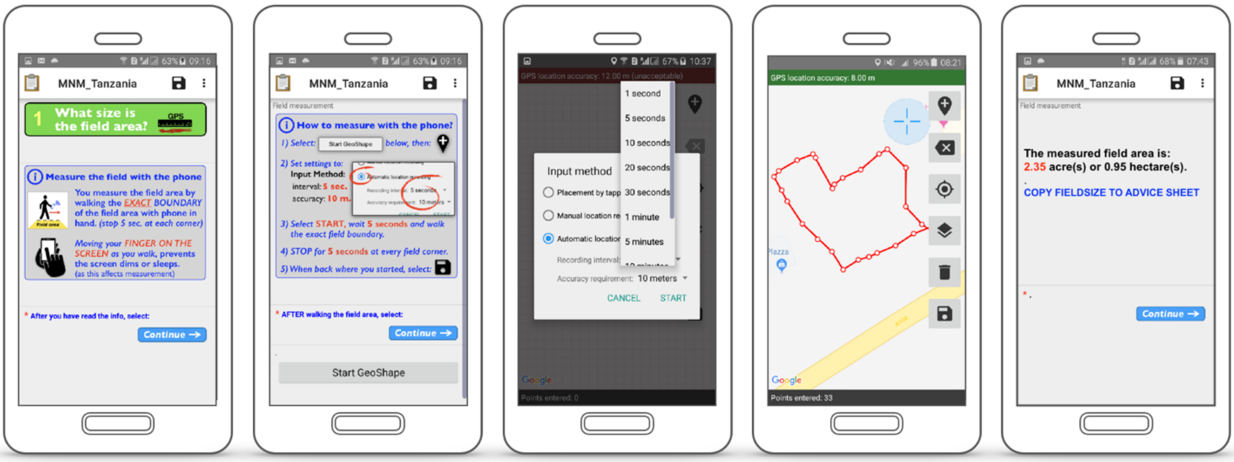
# 7. Appendix: *Screenshots of Maize-Nutrient-Manager application*

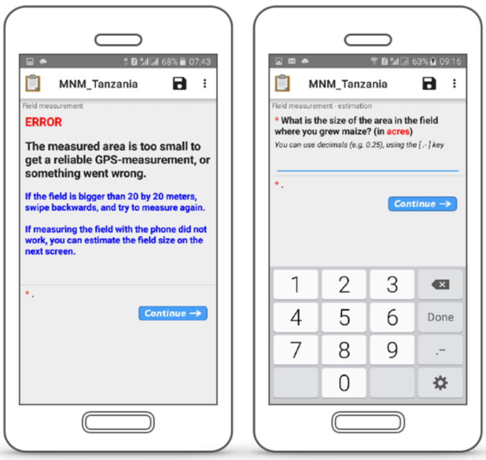
## Farmer registration    Farmer location



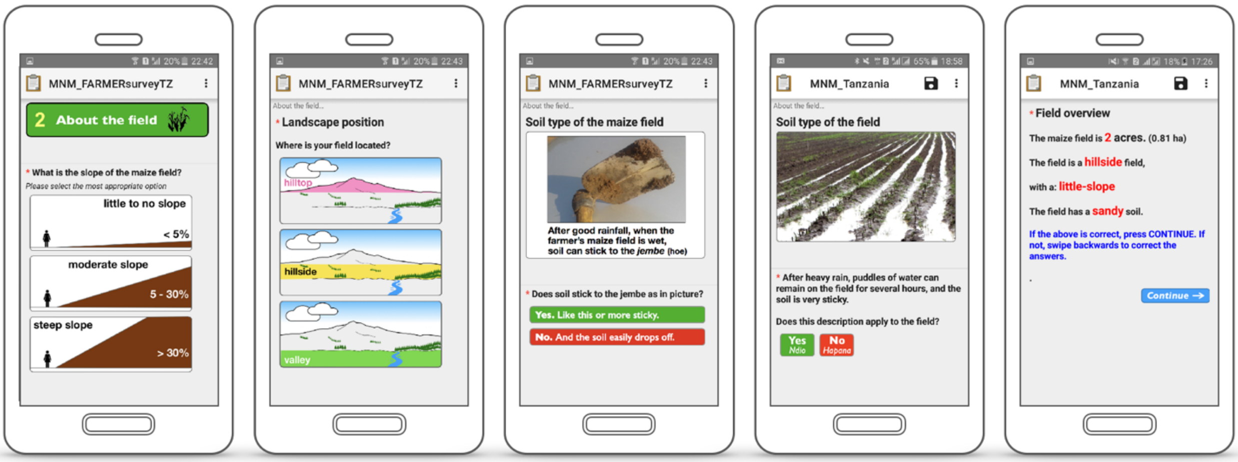

## Field Measurement




## Field Estimation *If the field area is too small (< 20 x 20 meter)*

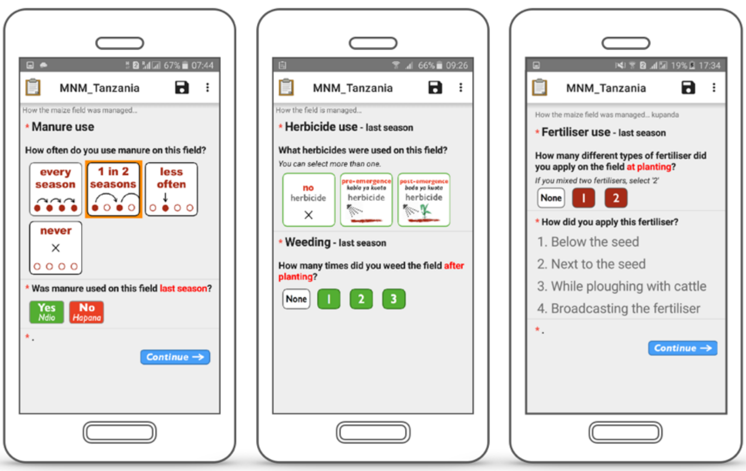


# Field characteristics




# Farmer management - LAST SEASON


# Farmer management - LAST SEASON

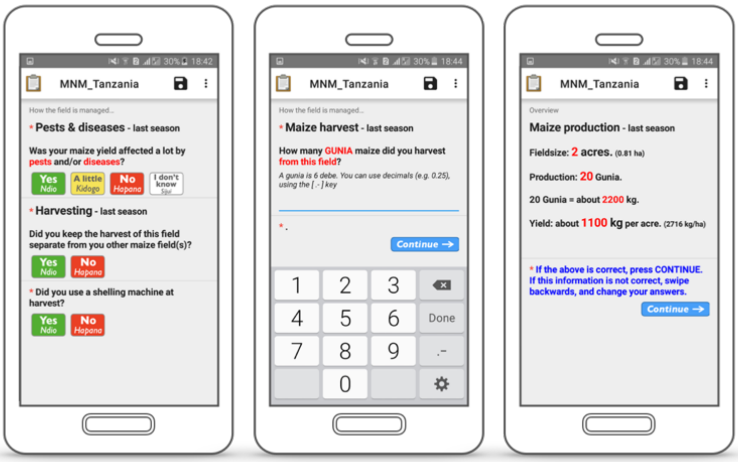


## LAST SEASON - basal fertiliser *(max. 2)* deficiencies


## LAST SEASON - top-dressing fertiliser - *1st application (max. 3 times x max. 2 types)*

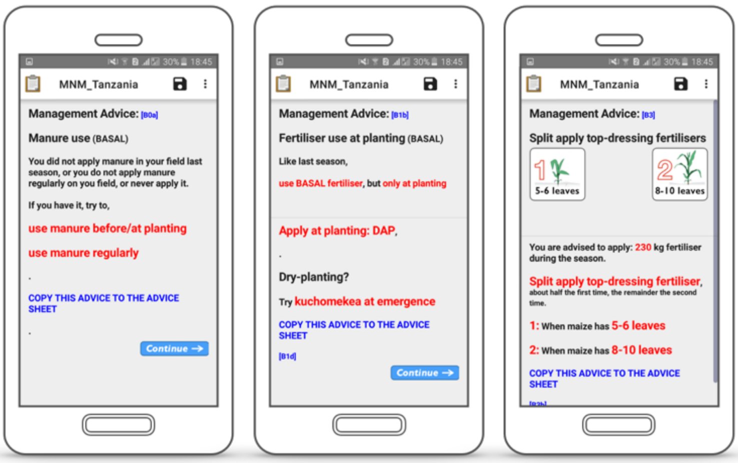

## LAST SEASON - top-dressing fertiliser - *2nd application (max. 3 times x max. 2 types)*

## LAST SEASON - harvest




## Advice type 1: Fertilizers *max. nutrient option, preferred top-dressing option*


## Advice type 1: Management



# Advice type 1: Management


# Advice type 2: Additional fertilisers


# Advice type 2: Management