

Research Paper

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Production and use of homemade dry manure-based tea in fertigation systems in North Africa

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Abstract

Organic matter water extract, or so-called ‘tea’, may be used to correct nutrient deficiencies in crops or enhance their defense systems. Such tea mixtures are prepared locally by Mediterranean farmers to offset a multitude of constraints, particularly a scarcity of organic manure or high synthetic input costs. However, the diverse range of tea production and usage practices and farmers’ underlying rationales have yet to be thoroughly studied. Yet locally they constitute real alternatives that allow farmers to maintain their income levels while reducing reliance on chemical inputs. The main objective of this study was to gain insight into farmers’ rationale and practices regarding the production of homemade dry manure tea (HMT) in North Africa, while also highlighting the benefits perceived by farmers. Nearly 50 interviews with farmers were thus conducted in three irrigated cropping areas in Morocco, Algeria and Tunisia. Our results showed that HMT is widely used in intensified family horticultural cropping systems that usually rely on drip irrigation and chemical fertilization. The analysis of farmers’ practices revealed that HMT was generally made from aged manure that was pure or consisted of a mixture of sheep, cow or poultry dung. The production protocol varied in terms of drenching techniques, maceration time, container volume and type, and filtration techniques. Farmers applied the derived tea via the drip irrigation system, regularly or with a limited number of applications. The analysis of farmers’ rationales and perceptions regarding HMT clearly highlighted that they felt that these practices played a positive role. HMT was considered to improve vegetative growth, yield and, to a lesser extent, soil properties. These benefits could in turn lead to decreased use of synthetic fertilizers by farmers, while boosting their income. The increased understanding of HMT and the underlying rationales showcased in this study could help scientists better analyze and assess these practices in the future. The findings could also facilitate improvement and wider dissemination of these practices to achieve more sustainable irrigation systems in the intensified irrigated cropping areas that abound in North Africa.

Introduction

Compost tea—the result of water extraction from composted organic matter of different origins and of known properties and age (Brinton *et al.*, 1996)—has long been used in agricultural applications (Eden, 1938; Rodale, 1967; Koepf, 1992). This tea has more recently become popular for use in organic farming systems (Scheuerell and Mahaffee, 2002). Compost tea usage is broad in scope, ranging from pathogen control to correcting crop nutrient deficiencies. It may also be an interesting agricultural alternative to synthetic input use, thereby contributing to the development of more sustainable farming and food systems.

Many effects of compost tea application have been investigated, such as improving the crop nutrient and defense system status. Studies have documented the impacts of compost and vermicompost tea in suppressing pests and diseases (Scheuerell and Mahaffee, 2002). This tea can also have positive effects on crop physiology, growth and yield (Benitez *et al.*, 1996; Pant *et al.*, 2009; Gutiérrez-Miceli *et al.*, 2011; Chaichi *et al.*, 2018; Arancon *et al.*, 2019; Ibrahim *et al.*, 2019, and many others). Pant *et al.* (2012) directly linked increased pak choi plant growth

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with the mineral N and gibberellin content of compost tea. Negative effects have also been reported, e.g., high volume tea application may have an inhibitory effect on seed germination and plant growth (Gutiérrez-Miceli *et al.*, 2011).

Homemade dry manure tea (HMT) can be prepared on the farm, like other agricultural inputs such as homemade botanical insecticides (Dougoud *et al.*, 2019). HMT production can be considered as a ‘do it yourself’ operation (Benouniche *et al.*, 2014), with available local material and knowledge acquired through experimentation being the main innovation factors. HMT can therefore be made from a variety of materials, ranging from plant biomass to different types of manure or various mixtures. It is widely acknowledged that the impacts of compost tea are highly dependent on the initial material, as well as the production and application methods (Scheuerell and Mahaffee, 2002). Concerning the HMT production protocol, the fermentation method is often considered to be a crucial factor, alongside other variables such as the compost/water ratio and extraction time (Islam *et al.*, 2016). The options open to farmers include foliar or soil application, the dilution ratio, equipment, timing, rates and spray or microorganism adjuncts (Scheuerell and Mahaffee, 2002). Researchers have tested some of these variables, often in randomized experiments undertaken in controlled conditions. For example, Gutiérrez-Miceli *et al.* (2011) noted a maximum root dry weight at 15% tea/water dilution doses of sheep-manure vermicompost tea applied on radish. Islam *et al.* (2016) reported optimum extraction conditions of 1:2.5 compost/water ratio (w/v) with a 2-day extraction time for tea prepared from compost consisting of pruning residues, bovine manure and straw. Yet homemade tea mixtures, particularly of manure origin, have seldom been studied, especially with respect to production protocols, impacts and farmers’ understanding of the best ways to use these mixtures and their potential benefits.

One reported example of a North African farmer’s innovation concerned the preparation of tea solely from dry manure (Dugué *et al.*, 2015; Aneur *et al.*, 2020; Akakpo *et al.*, 2021). Moroccan farmers call this *ossaret l’ghbar* (i.e., ‘manure juice’), which they use for organic fertilization, resembling the compost tea mixtures described in the scientific literature. It differs, however, by the fact that it is made solely from animal manure and is specifically applied in irrigated horticultural cropping systems. Who uses this tea? How are the mixtures produced and applied? Why do farmers use this product? This study was carried out to obtain answers to these questions, while describing the origins, production and application methods, as well as the benefits of homemade manure-based tea perceived by farmers. This review of current practices could help farmers understand how fellow farmers produce their tea mixtures; show managers that this novel product could enhance the sustainability of farming practices; and lastly enable scientists to design experimental protocols to gain insight into the effects of this specific innovation. After describing the methodological approach in section ‘Methodology’, the results are focused on characterizing the farm and cropping systems in which this practice is implemented, on HMT production and application techniques, and on the perceived benefits of HMT. Finally, the scientific interest of conducting research on HMT for agricultural applications, the importance of the origin of the organic matter used, and the potential of HMT for enhancing the sustainability of irrigation systems in North Africa are discussed.

Methodology

Study sites

This study focused on three intensively irrigated agricultural zones in North Africa: the Saiss plain in Morocco, the Upper-Cheliff plain in Algeria, and the Merguellil plain in Tunisia (Fig. 1). All three sites produce a wide range of horticultural, cereal and tree-based products, with irrigation and fertilization mainly undertaken through localized drip fertigation. A thorough description of these study sites can be found in Aneur *et al.* (2020).

Farmer interviews

In total, 46 farmers, mostly in Morocco and Tunisia, were interviewed concerning their HMT use. Twenty-three and 21 farm visits and semi-directive interviews were respectively undertaken in March 2018 in Morocco, and in January, April and May 2018 in Tunisia. These were supplemented by two interviews in Algeria. The semi-directive interviews—which lasted between 1 and 3 h each—were undertaken in two phases, sometimes requiring two visits to the farm. First, they focused on a systemic analysis of the farming system (short historical component to understand the evolution of the farm, total cropped area, crops and livestock keeping activities, agricultural equipment, allocation of labor between family members and employees, etc.). Second, questions were centered on HMT origin, preparation, use and impacts. Questions concerned origins (‘since when do you use HMT?’, ‘how did you learn about HMT?’), crops upon which HMT was applied and HMT production protocols (type of manure used, manure/water ratio and preparation time, additional adjuncts, containers used, filtration system, etc.). The HMT technical system was assessed visually during the field visit, when it was implemented at time of interview. In this phase, application methods were also characterized (doses, application frequency and method). Interests and constraints of HMT were finally discussed, as well as the impacts on the cropping system, including the agronomic interest, technical and economic advantages and inconveniences. Interviews were undertaken in a semi-directive manner, allowing to construct a trusted relationship and involve farmers in the discussion. Interviews were undertaken by three researchers, each intervening in at least two of the three countries. Interviews were recorded, then their transcript was analyzed in a tabular format, to insure consistency. These surveys were supplemented by detailed monitoring of technical management routes regarding 11 chili pepper crop fields in Tunisia in 2019 (for detailed description, see Akakpo, 2021) and five onion crop fields in Morocco. For these technical management routes, all technical operations concerning soil preparation, irrigation, weed control, fertilization, phytosanitary applications and use of HMT were noted in best detail possible through weekly interviews and observations of monitored fields.

Results

Homemade dry manure-based tea: a widespread practice in family irrigated horticultural farming systems

Origins of the practice

In North Africa, manure application in cropping systems is widespread, including punctual applications under fruit trees or

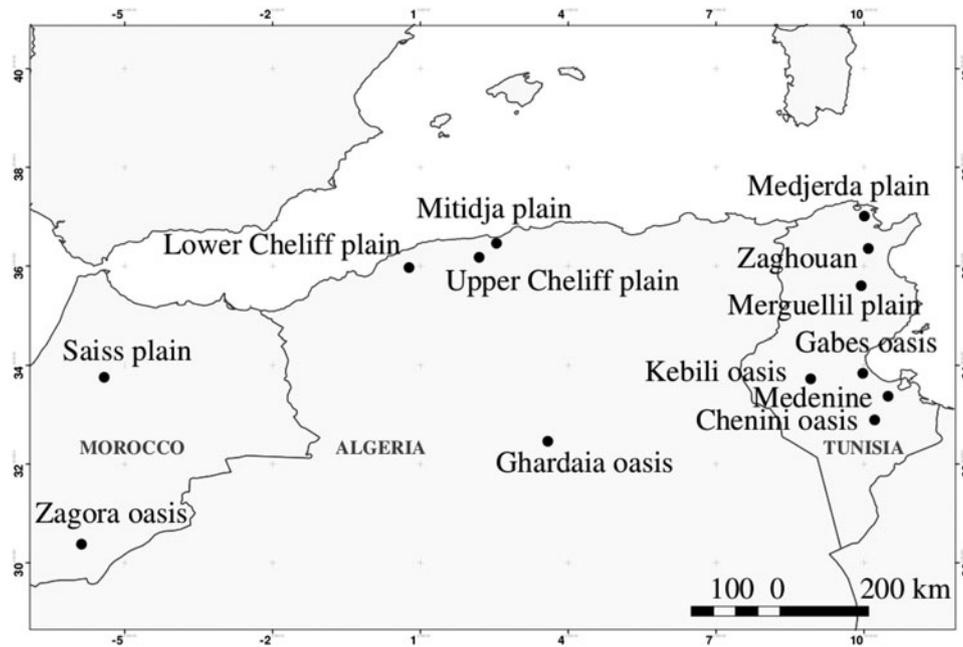


Fig. 1. Map of locations where homemade dry manure tea was observed in this study.

regular basal dressings for more demanding crops. This manure sometimes replaces synthetic starter fertilizers, such as diammonium phosphate. In particular, application of manure in an irrigation bowl at the base of fruit trees followed by gravitational irrigation and basal applications in regularly irrigated green market gardening systems is widespread. This hydrates the manure and facilitates its decomposition and the gradual supply of soluble elements to plants—unlike chemical fertilizers which rapidly leach below the root zone when the crop is regularly irrigated.

The development of drip irrigation in past decades completely transformed irrigation management, with a switch from gravitational irrigation to localized irrigation for tree and vegetable crops. The advantages of drip irrigation for farmers can include decreased irrigation labor time, easier fertilization management and improved water-use efficiency at the field scale. In particular, crop fertilization through drip irrigation may be adjusted according to the plant requirements. The transition to drip irrigation systems increased the crop plantation density, consequently boosting yields in many cases. This, in turn, led to a greater chemical fertilizer use. As the prices of these latter fertilizers have increased in recent years, organic fertilization has enabled farmers to reduce their production costs. Organic fertilization has also become essential for soils fragilized by intensive cultivation practices. Farmers without livestock often buy manure as they are aware of the importance of organic fertilization for soil fertility. Drip irrigation has also led to increased use of organic fertilizers of different types, particularly commercial liquid fertilizers, or so-called *bidoun* (i.e., ‘container’ in French). Some farmers associate manure-tea application with traditional manure uses in cropping systems, particularly the practice whereby olive trees are irrigated by drenching the roots with manure. Most of them, however, associate the origin of its use with two factors: the development of drip irrigation, and the availability of commercial liquid organic fertilizers. Drip irrigation is the medium that has fostered this practice, while the rising cost of commercial liquid organic fertilizers seems to have given farmers the idea to

manufacture their own fertilizers from local readily available organic matter, i.e., mainly sheep manure.

The exact origin of this modern practice of HMT use in drip irrigation systems is, however, not clear and many farmers boasted of being the first innovator. Indeed, innovative farmers either considered the practice as being their own invention—‘I thought of it myself’—while others mentioned seeing neighbors practicing it, after which they decided to test it themselves. For the latter early majority adopters, as defined in innovation theory, the decision to risk adopting this practice was not taken rapidly, and was generally triggered after observing positive results on their neighbor’s plots. Appropriation via agricultural extension agents was only mentioned twice in the interviews. Internet or educational programs were mentioned by young farmers who were more willing to use information technology tools and who sought information to better tailor the practice to their own needs. The widespread use of HMT in different North African regions suggests that it is a long-standing practice and/or that it generally emerged independently as a result of the inventiveness of many farmers, and of the rapid information dissemination.

Farming and cropping systems using HMT

HMT preparations were found in various locations throughout North Africa (Fig. 1), where irrigation is widely practiced, mostly in family-based farming systems in both intensively irrigated croplands (e.g., Saiss, Upper-Cheliff, Medjerda and Kairouan plains) and oases (Zagora, M’zab valley, Gabels and Kebili). The fact that its use was widespread suggests that HMT is likely also used in many other North African regions. Interestingly, its use was not found to be directly linked to any certification label, such as organic farming.

HMT has been applied to a wide range of commercial crops, mostly green market crops, such as onion (*Allium cepa*), potato (*Solanum tuberosum*), chili pepper (*Capsicum annuum*), tomato (*Solanum lycopersicum*), watermelon (*Citrullus lanatus*), melon (*Cucumis melo*), and less commonly fruit trees (e.g., orange

Table 1. List of crops, where application of manure-based tea was observed

Country	Perennial crops	Green market produces
Morocco	Peach, plum, vine	Onion, potato, chili-pepper
Algeria	Pear, apple	Tomato, water-melon mint ^a , parsley ^a , carrot ^a , radish
Tunisia	Orange, olive, pomegranate	Chili-pepper, tomato, water-melon, melon, bush-okra

^aProduced for family consumption.

Citrus sinensis, olive *Olea europaea* or pomegranate *Punica granatum*), but also to crops in small family gardens in which produce is grown for home consumption (Table 1). No applications to cereal crops were observed. HMT use on these commercial crops was linked to the use of drip irrigation systems, allowing easy application of HMT through the fertigation system, but also to the high nutritional requirements of these crops. In home gardens, where HMT could be applied through the drip system or with a watering can, farmers expressed that the limited cropped areas rendered its application rapid and easy to implement.

Preparation of homemade dry manure-based tea

Type and origin of organic matter used in HMT

The studied HMT preparations were all made from dried manure. The vernacular expression *ossaret l'ghbar* encompasses the terms juice (*ossarat*) and dust (*ghbar*) which refers to dry manure. Fertilizers were sometimes incorporated in the mixture, but no other organic matter (e.g., leaves, home organic waste) was incorporated. HMT could be made from a single manure source (sheep, cow or poultry dung) or be a mix of different manures. In most cases, it was prepared from sheep or cow manure, both of which are readily available. A disadvantage of cow dung, according to some farmers, was its acidity. Poultry manure had a strong repelling odor. Applied manure was usually over 1 year of age, after going through a decomposition stage, as described in Ameur *et al.* (2020). Manure could be reused up to three to four times until the color of the produced manure tea became clear, indicating that the organic matter source should be changed. Applied manure could originate from the farm, i.e., livestock rearing involving one to two cows or a dozen or more sheep is common, or be the outcome of a commercial transaction with another farmer. In this case, large quantities of manure were often purchased for basal dressings of green market crops, with a limited quantity reserved for HMT production.

HMT production protocols

The general HMT production protocol was to drench manure in water for a certain length of time, filter the resulting liquid using different techniques, and then apply this product on crops through a drip fertigation system (Fig. 2). Additional fertilizers (ammonium nitrate, diammonium phosphate) were sometimes incorporated in the mixture during the preparation stage. The production protocol varied among farmers in terms of drenching techniques, manure/water maceration time, container volume and type (permanent or non-permanent), and filtration system (Fig. 3). First, manure was placed either in woven plastic bags (Fig. 3(c)) or directly in the container with water (Fig. 3(d)). The overall maceration time ranged from 2 to 20 days, but was generally 2–6 days. The container type and size varied, with

production volumes ranging from 200 L to several cubic meters and depended on the available equipment and the required HMT quantity. The container structure was either permanent, e.g., a basin which was often located close to the fertilization station or the irrigation basin (Fig. 3(f, h)) and used for the sole production of HMT, or non-permanent, e.g., plastic barrels (Fig. 3(a)), or holes dug in the soil waterproofed by plastic (Fig. 3(b)) or a rectangle of bundles of hay (or crates filled with soil) covered with plastic (Fig. 3(g)). These non-permanent structures were mainly used by mobile farmers, i.e., leasees. This choice also depended on the proximity of a permanent water source and the crop rotation conditions.

Concerning the filtration techniques, filtration was always required to avoid clogging the drip irrigation system, especially for market garden crops with a drip system equipped with small drippers. There was less of a risk when the drip system was set up for irrigation of fruit tree crops, where the water flow through the drippers was greater. In most cases, when plastic barrels were used as the container, manure was inserted in woven plastic bags, which served as a first physical barrier (Fig. 3(a)), and then HMT was further filtered through cloth after preparation prior to its incorporation in the irrigation system. In larger container systems (both permanent and non-permanent structures), manure could be directly incorporated in the water. In such cases, the drip system was often subsidized and therefore sized and installed by design offices, while being equipped with a filtration station (sand and/or disc filter) originally designed for filtering sand contained in the pumped water. This was indispensable when no prior filtration technique was used (Fig. 3(b)). An intermediary physical barrier was sometimes installed using locally available material (sand bags or polystyrene blocks and small gravel) (Fig. 3(e, f)). Some farmers also placed bagged manure in these larger-scale systems.

HMT application methods in diverse technical management routes

HMT application is one of many technical operations undertaken for crop management throughout the whole crop cycle (Fig. 4). For green market crops, HMT applications were typically begun from around a dozen days to a couple of weeks after planting. There were two different HMT application frequency modes. Some farmers carried out regular applications, as observed on the Merguellil plain with tomato and chili pepper crops. These farmers applied HMT every one to two irrigations, with doses of around 400 L ha⁻¹, and the doses were increased with crop growth. Otherwise, a limited number of applications were conducted throughout the crop cycle, as noted for onion crops grown on the Saiss plain in Morocco (Fig. 4). Most farmers used HMT as an alternative to commercially available organic liquid fertilizers—to the extent that these were suppressed. In some cases, farmers also decreased their use of synthetic fertilizers but without giving them up entirely, as shown by the fertilizer applications in Figure 4 (see also Akakpo *et al.*, 2021 for detailed technical management routes). For permanent crops, applications were started in the spring and continued until harvest. HMT was also applied on young fruit trees to boost their growth.

All HMT preparations were applied through the drip irrigation system and hence directly above the root system of each plant. No foliar applications, as sometimes recommended, were noted. This could be associated with the fact that farmers considered HMT as a fertilizer or biostimulant rather than as a pest control option.

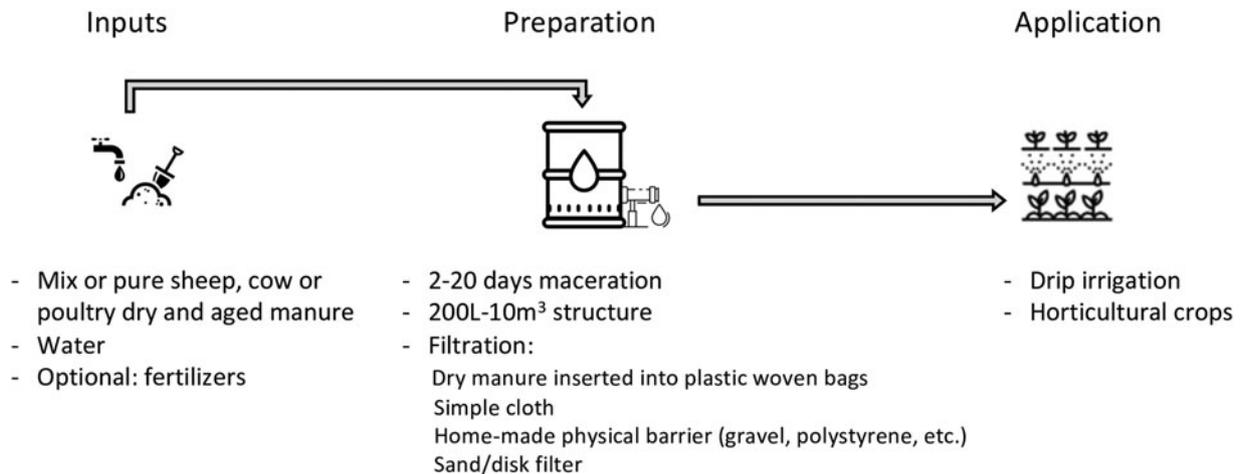


Fig. 2. Homemade dry manure-based tea production protocol.

HMT was manually poured into the drip irrigation system or sucked into the irrigation pipes through the fertigation station. HMT could be applied alone or combined with any other type of fertilizer. It was often applied just before irrigation termination, so that it would not seep to deep soil horizons inaccessible to crop roots, but irrigation was nevertheless continued for 10–15 min after HMT application in order to ‘clean the drip irrigation pipes’. At the end of each irrigation session, and sometimes even at the beginning, some farmers injected a commercial acid-based product into the drip system via the fertigation station to further clean the drip irrigation system. Manure remaining in the container was then either left and another batch of HMT prepared, or it was thrown away or spread on the surrounding field, but the quantities were negligible.

Farmers’ evaluation of the HMT effects

This section describes the advantages and shortcomings of HMT perceived by farmers. Many stressed its benefits, saying HMT was ‘the best product that can be used’ in agriculture. Different properties were put forward, concerning the crop, soil and irrigation systems, which in turn determine the economic value of HMT.

Concerning crop growth, the main impact mentioned was the improvement of vegetative growth, including increased leaf, stem and root growth and greener leaf coloration. Concerning fruit production, HMT was reported to improve fructification, hence the fruit number, increase the fruit diameter and improve the taste. Changes in fruit color were not reported. Farmers claimed that poultry manure-based tea decreased watermelon fruit quality (taste and tissue structure). Visible responses of crops to HMT application were reported at best after 3–4 days. Farmers also stated that HMT could enrich the soil, making it ‘more fertile’, and enabling it to support improved crops and harvests the year following HMT application. Drawbacks were also mentioned, especially concerning the drip fertigation system. Farmers stressed the risk of degrading the irrigation system if proper filtration techniques were not used. When filtration methods were lacking or inefficient, they could clog the drippers, thereby degrading the irrigation tubes on the long run, but also leading to intra-field irrigation heterogeneity and increased pumping costs. To avoid these risks, most farmers carefully filtered their HMT before application, with whatever equipment was available, and some

cleaned the irrigation tubes. Another mentioned disadvantage was the long preparation time as compared to ready-made commercial liquid fertilizers.

Farmers mentioned that these agronomic benefits in turn led to economic benefits, although these were not quantified. According to some farmers, direct application of HMT decreased production costs. Indeed, HMT replaced costly ‘synthetic manure’ (i.e., commercial liquid organic fertilizers). Decreases of one to four 20 L containers of liquid organic fertilizers were mentioned—while some farmers completely stopped using commercial liquid organic fertilizers—thereby further reducing transport costs. Farmers sometimes also reduced the number and dosages of synthetic fertilizer applications. Otherwise, HMT use was also said to increase crop production compared to fields upon which commercial liquid organic fertilizers were applied. Some farmers also mentioned enhanced self-sufficiency as they were able to produce their own HMT. This was partly done to reduce transactions with input suppliers, who tended to take advantage of farmers’ limited financial resources.

Discussion

Scientific investigations on HMT, especially of sheep manure origin, are needed

Few scientific investigations seem to have been undertaken on dry manure-based tea, especially with regard to homemade preparations and those using organic matter of sheep manure origin. Some published studies have focused on compost tea produced with manure (Scheuerell and Mahaffee, 2002; Azeez et al., 2014; Ibijola et al., 2014), but these reports mainly concerned cattle or chicken manure. Scheuerell and Mahaffee (2000) found that composted chicken manure tea had a suppressive effect on powdery mildew. Evans et al. (2013) described positive effects of manure compost tea (1:3 manure:water w/v ratio, 48 h fermentation) in suppressing pathogenic *Botrytis cinerea* fungi. The tea preparations described differed however as they were produced with composted manure. In our case, the manure used was aged and hence degraded, but was not subjected to active composting. The HMT described in this study could at most be referred to as ‘passive compost’ which involves stacking the compost material with little agitation and management (Misra et al., 2003).



Fig. 3. Typical homemade dry manure tea (HMT) production methods: (a) plastic barrel (Merguellil plain, Tunisia); temporary pit; with (b) no bags (Saiss plain, Morocco); (c) and (g) bags (Zagora and Saiss plain, Morocco); (d) physical barrier (Merguellil plain, Tunisia); (e)–(f) permanent basin with physical barrier (Merguellil plain, Tunisia); and (h) in the irrigated cropping area (Merguellil plain, Tunisia). Photo credit: authors, except for (c) Z. Kadiri.

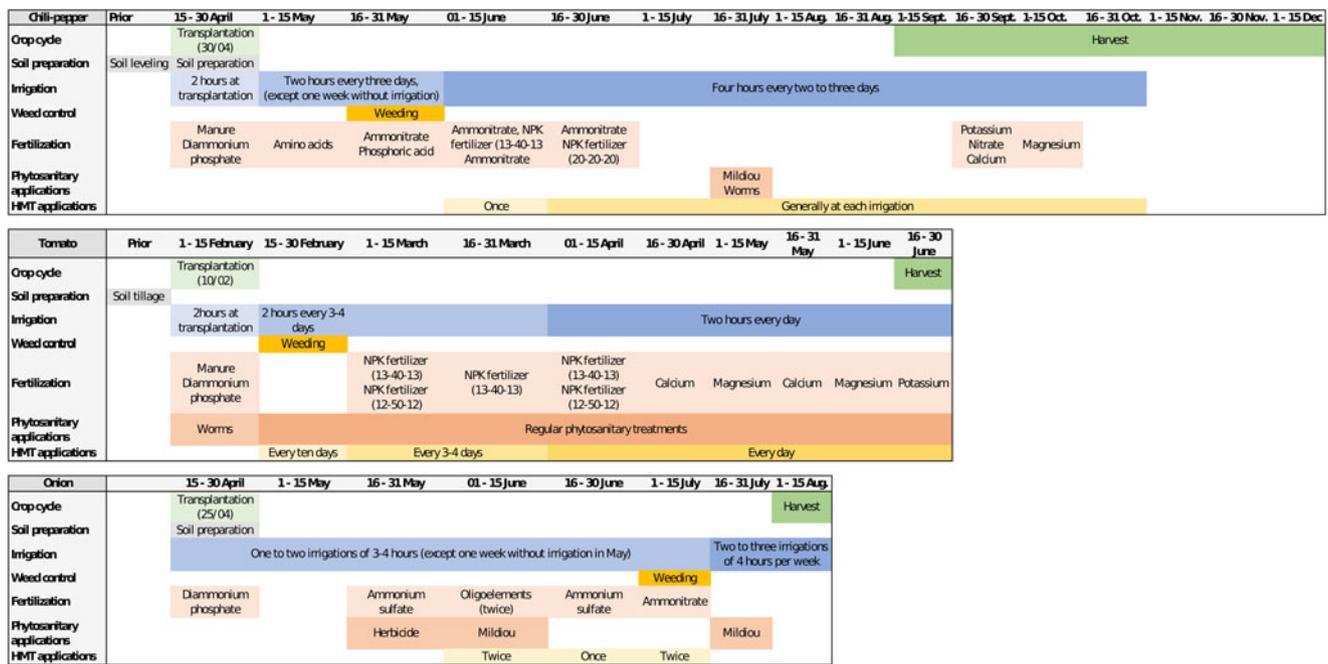


Fig. 4. Examples of crop technical management routes showing, in particular, HMT application dates for three representative horticultural crops (chili pepper and tomato on the Merguellil plain, Tunisia, onion on the Saiss plain, Morocco) at the case study sites. Applied active substances include abamectin, acetamiprid, bromuconazole, chlorantraniliprole, deltamethrin, emamectin benzoate, fosetyl-al, methomyl, propamocarb, spirotetramat, trifloxystrobin.

Production methods impacting the tea composition included choices regarding the origin and type of material, composting time, compost/water ratio, fermentation time, added nutrients, temperature, pH as well as the fermentation process (Scheuerell and Mahaffee, 2002). Some authors analyzed the impact of the tea preparation method on the final tea composition. For example, Pant *et al.* (2012) found that the compost composition impacted the nutrient extraction efficiency, microbial activity, phytohormones and total nutrient content of the tea. All of these variables probably influence the physico-chemical and microbial composition of HMT. Islam *et al.* (2016) found that the compost/water ratio and extraction time were the main extraction variables that influenced the tea chemical composition, while the storage time also influenced the microbial populations. Suggested optimal production parameters were a 1:2.5 compost-to-water ratio and an extraction time of 2–3 days. Interestingly, these values corresponded to the main production mode of the farmers interviewed in this study, especially pioneer farmers who tested this innovation and adjusted their production process after years of field experience. Although not precisely documented, HMT found in North Africa should be efficient, because they are used in the field by farmers; applied extraction ratios and times are within the range of those producing positive effects (Islam *et al.*, 2016).

Yet sheep manure-based tea—in particular those prepared with home-made recipes—requires further investigation. The main properties may be similar to those of compost tea preparations, but the production technique and origin of organic matter are important variables that influence the final tea composition, and hence properties. The high variability in production and application modes noted in our study could be a source of positive and negative feedback. At our case study sites, some farmers abandoned this practice, explaining that they had observed no effects. Inadequate dosages, poor production control and the difficulty of detecting these effects due to a multitude of other factors

could explain why some recipes and application modes worked, while others did not.

HMT is an interesting field of investigation for agronomists, particularly with respect to assessing impacts on crops. The effects of HMT on yield components require further investigation. Notably, the existence of two application modes suggests that farmers use HMT for different objectives. Infrequent applications imply that farmers apply this product for its biostimulant properties, while frequent applications suggest that they use it as a fertilizer. Finally, foliar HMT applications for crop protection would be an interesting new avenue to investigate, as pest infestations and disease outbreaks are major economic and environmental constraints affecting irrigated cropping areas in North Africa. This could increase farmers' investment costs. Optimal extraction protocols could also be designed. It is essential that farmers be involved at all stages in the experimental process to determine proper application doses, schedules and modes for different crops.

Organic matter availability as a driver of HMT production

Compost tea usage seems popular in certain regions of the world, due to the high availability of compost, practitioners' interest and enhanced awareness on its potential. In other regions worldwide, especially in semiarid areas, organic residue composting is seldom practiced. One reason for the absence of composting could be that the already limited available residual biomass is immediately recycled in the farming system (crop residues and weeds for livestock feeding, household waste for chickens, etc.), and natural vegetation is already under high grazing pressure. Compost production is also knowledge and labor intensive. At our case study sites, compost production was rare, so compost tea preparations were not used. However, an alternative local form of tea was produced using the most available organic matter, i.e., dry manure. Indeed, livestock rearing, especially sheep, can be

common in semiarid areas, so sheep manure would thus be the main alternative source of organic material for tea production. In our case, the widespread nature or not of HMT production seemed to be directly linked to the availability of a local source of dry manure. For example, in the Upper-Cheliff plain in Algeria, dried manure is imported from afar, so HMT and organic fertilization are uncommon.

HMT as an innovation for more sustainable irrigation systems

The use of manure and compost tea may be a long-standing practice. However, in this case, HMT could also be considered as an innovation, i.e., a technical, economic and social process leading to change (Alter, 2000). Based on their experience with commercial liquid organic fertilizers, farmers sought to produce their own organic fertilizers using existing local material. HMT is a technical innovation in the sense that filtration techniques have been tested, production protocols have been designed, and positive effects, especially on crops, have been observed. It is also an economic innovation as farmers reported that HMT had beneficial effects. Finally, it is a social innovation as farmers often pointed out that they began using it on the basis of discussions and observations with neighbors. Irrigated areas are no exception with regard to innovations, with multiple success stories of innovation adoption, e.g., drip irrigation, solar pumping systems or new fertigation techniques. These adaptations and adoptions are probably fostered by the fact that irrigated areas are dynamic, under multiple constraints (Jamin *et al.*, 2011) and have a highly diverse range of production and cropping systems. Yet these cited innovations have not always led to more sustainable farming. Concerning drip irrigation, increases in water-use efficiency at the plot scale is often counterbalanced by rebound or unaccounted effects (Kuper *et al.*, 2017; Venot *et al.*, 2017) and subsequent increases in irrigated areas.

Irrigated areas—of vital socio-economic importance—are often based on substantial input use (water, chemicals), which in turn leads to environmental problems. Hence, there is growing interest in low-cost agroecological practices (Akakpo *et al.*, 2021; Ameur *et al.*, 2020), farming systems (Baccar *et al.*, 2016), alternative environment-friendly and ethically responsible value chains (Banasik *et al.*, 2017), etc., that could be observed or set up to encourage the agroecological transition of these vital areas. In particular, farming practices with an agroecological potential, such as enhanced crop diversity, livestock-crop integration, use of non-chemical fertilizers, etc. (Wezel *et al.*, 2014), have long been recognized as economically, environmentally and socially interesting. However, numerous authors have also stressed that it is essential that these practices be tailored to local conditions, adopted by the stakeholders and economically viable (Guzmán *et al.*, 2013; Wezel *et al.*, 2020). Tracking, characterizing and encouraging local environment-friendly innovations is hence important. This is the case with regard to HMT, which could increase resource use sustainability by promoting the circularity of this use, or decrease synthetic fertilizer use. Note, however, that HMT is used in conjunction with conventional fertilizers, and does not impede pesticide applications. One reason is that these market-oriented crops have high production risks induced by important and rapid fluctuations of market prices. Farmers therefore apply large quantities of inputs to stabilize production, with the risk of degrading their environment. The potential added-value of organic management of cropping systems is still not recognized by markets or consumers, thereby impeding its development. In irrigated cropping

areas in North Africa, potential agroecological innovations such as HMT are still invisible, due to (1) the prevailing long-term interest in technological/conventional practices that have the image of being 'better'; (2) the long overlooked environmental and health externalities linked to intensive practices; and (3) the idea that agroecological innovations are 'linked to the poor'. Agroecological innovations implemented by farmers are even more invisible because they are often only disseminated locally, nor are they publicized or set up on a large scale. Overall, HMT is a typical example of an invisible innovative agroecological practice that nevertheless would be interesting to develop.

Conclusion

The use of homemade manure-based tea is widespread in horticultural cropping systems in North African irrigated areas. Yet the production and application techniques had not been previously described, alongside the potential impacts on the plant–soil continuum. The aim of this study was to address these shortcomings to foster scientific study of this potentially agroecological practice. The various techniques used, from the origin of the organic matter to its application, have hence been described here. Most farmers stated that the use of this practice had positive effects. The fact that the techniques are highly heterogeneous—as is common for DIY farmer innovations—offers opportunities for refining this practice. Combining this endogenous knowledge and a more rigorous scientific analysis of its properties and impacts through on-farm and participatory collaborations may help to meet this objective. It could also foster dissemination of this agroecological, technical, economic and social innovation. Moreover, in the long run, it could help build more sustainable irrigated farming and food systems in North Africa.

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