Application Of Permaculture Practices To Improve Sustainable Agriculture In The Maltese Islands

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Running title

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Abstract

Small island states, such as Malta face numerous, unique challenges in relation to agricultural sustainability, with solutions amenable to larger states being unfit given the particular characteristics of the island. These include the poor soil conditions, the limited water resources, the aging farmer population, farming being mainly part-time, and most farmers having no formal training. Currently farmers practice intensive agriculture to achieve higher crop productivity at lower production costs by relying heavily on agri-chemicals and over-extracting groundwater. This destroys the Maltese natural environment and urges for the development and implementation of sustainable agriculture practices, whereby traditional farming is supplemented with sustainable alternatives such that local agriculture remains productive in the long-term while safeguarding the local environment. Here we outline some of the critical issues that urgently need to be addressed and potential ways forward in relation to soil, water and biodiversity, implementing permaculture principles in small-scale, practical actions in order to improve the sustainability of local agricultural through a combination of scientific evidence, agricultural technology and traditional practices.

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Sustainable agriculture implementation in small island states

Sustainable development according to the Food and Agriculture Organisation of the United Nations (FAO) is set on three main pillars: economic growth, social inclusion and environmental protection [1]. The term sustainable agriculture thus implies the long-term maintenance of natural systems, whilst providing farmers with adequate income and society with food, through optimal crop production with minimal non-renewable inputs [2]. In tangible terms the three primary goals of sustainable agriculture translate into an effort to improve soil productivity through innovative agricultural methods, promote environmental stewardship by improving soil quality and reducing dependence on non-renewable resources, and provide profitable farm income in order to guarantee the food supply of both current and future generations [3]. The desired goal is organic farming, as it generates a yield whilst promoting ecosystem health through conservative soil management practices such as utilising on-site resources, improving the soil structure and fertility, limiting the use of agri-chemicals, reducing tilling, increasing biodiversity, improving soil-water retention, inter-cropping, cover cropping, mulching, and crop rotation [4].

However, small island states face a number of unique challenges when it comes to sustainability and many of the solutions proposed for larger land masses need to be heavily modified in order to suit the characteristics of the area.

The current state of the agricultural sector in Malta

The Maltese Islands have a total area of 316 km^2. Agricultural land in Malta takes up around 110 km^2, with 12,466 total holdings (in 2013). Holdings are characteristically small scale (being less than 1 hectare), covering a total of 11,689 hectares. This makes up 75.6% of the utilised agricultural area [5]. Of these, 45.3% (~5,300 ha) is used for fodder cultivation, mainly wheat [5] and 9.5% (~1,100 ha) are used for the traditional production of tomatoes [6].

Farming in Malta is predominantly a part-time activity, practised by an aging population, with the majority of farmers having only practical experience and no formal training. Agricultural production for most farmers is limited to two growing cycles (September to January and February to June). Farmers practising dry farming, which still might not rely entirely on rain, mostly grow fodder crops, onions, garlic, broad beans, vines, and olive trees. For most other kind of fruit and vegetable cultivations irrigation by drip or sprinklers is a necessity, even in Winter months.

At present the only drivers within the agricultural sector are increased crop productivity per area and reduced production costs. This is due to the fact that local produce must be competitive in price compared to foreign imports, especially considering that both distributors and retailers will be adding a mark up to the farmer’s initial price.

Given the poor quality of Maltese soils, in their effort to achieve high production, apart from a heavy dependence on irrigation in order to sustain their crops, farmers also depend on fertilisers to ensure optimal flowering and fruiting as well as the use of plant protection products to minimise losses in high density mono-cultures. This form of intensive agriculture, with its heavy dependence on agri-chemicals (synthetic fertilisers and toxic plant protection chemicals), over-extraction of groundwater in high quantities through boreholes (including a number of illegal ones) contaminated with agri-chemicals or high salinity, and impoverishment or complete destruction of the natural habitats surrounding agricultural land is a threat to the Maltese environment. Over decades of such practices, this has had severe impacts on the natural environment, resulting in soil degradation and impairment of natural biodiversity cycles, to such an extent that it has been identified as “the principle anthropogenic pressure in countryside areas” [7].

Though the situation is much more complex as will be expounded below, this clearly illustrates how unsustainable the current system is and these practices are having a toll on both the agricultural sector as well as the natural environment, where many compounding factors offer bleak prospects for the agricultural sector. Thus, an urgent need for implementation of sustainable agriculture practices has become evident, particularly in the context of upcoming EU directives.

It is imperative that traditional farming techniques be supplemented and improved with more sustainable agricultural technologies so as to create farming practices that are more adequately poised to safeguard the local ecosystems and biodiversity, especially when considering that on such a small island farmland constitutes a substantial proportion of the rural environment, thus playing a major role in maintaining a healthy and diverse natural environment. As a result, agricultural land does not only contribute towards food production but also participates in sustaining ecological services (such as air quality regulation and crop pollination) [8].

That being said, the option of organic farming in Malta faces several disadvantages since parcel size is small and fragmented, leading to a high chance of pesticide contamination from adjacent fields that are still treated with forbidden agri-chemicals. This is particularly so since due to its small land area Malta has obtained a derogation of the 100m buffer zone from conventional fields. A measure to counteract this issue is having tree rows as barriers, which can to some extent reduce the contamination coming from traditionally cultivated fields [9]. However, vegetation buffers as well as rubble walls, which assist in creating such barriers from conventionally farmed fields are fragmented, mostly due to neglect.

The nature of agricultural issues in Malta

The issues encountered in the sector can be categorised into those related to soil, water and biodiversity. These issues are closely interrelated and interdependent and do not only concern agriculture but the Maltese natural environment as a whole, considering the extensive rural land proportion occupied by agricultural land. This means that damage to fields permeates easily and extensively into the surrounding natural environment and greatly impacts biodiversity in the vicinity of agricultural land. This implies that ecological services are also severely impacted, permeating the life of the general population and requiring remediation for the country's environmental sustainability.

Soil

Maltese soils are of three main types: carbonate raw soil, xerorendzina and terra rossa. These generally lack organic carbon (usually 1-5%), whilst tending to be saline due to their proximity to the sea and high evaporation rates. Furthermore, they tend to be mostly shallow (20-60 cm deep). All these factors taken together make Maltese soils less suitable for agriculture [7,10-13].

Owing to prolonged intensive land use, Maltese soils suffer from degradation by erosion, loss of organic matter, structural deterioration, and contamination from excess nitrates, agri-chemicals, and salinity [6]. Most farmers apply relatively high amounts of fertiliser (averaging 530 kg/ha on vegetable crops), despite recommended application amounts of 445 kg/ha. These excessive applications are partly due to the farmers' limited literacy and partly due to hard-headedness where more is better, paying little to no attention to references for optimum use [14]. The same is also true for the application of plant protection products.

In fact local nitrate levels (collected in 2011) exceeded the EU limit of 50mg/l in 11 out of 15 groundwater bodies [15]. This trend has only worsened in more recent years, where for example the average tonnage of phosphorus and nitrogen used from 2007 to 2016 has increased by almost 91 and 15 tonnes respectively. This heavy use of fertilisers, negatively impacting the environment, has no correlation with agricultural training, as farmers add phosphorus and nitrogen indiscriminately, irrespective of crop nutrient needs, with the only goal of maximising production to increase their revenue. This reflects the traditional character of Maltese farmers, resisting science and lacking modernisation [16].

Water

Maltese agriculture also has a significant challenge and limitation due to the scarcity of fresh water. Due to limited rainfall (averaging 500mm annually), spring and summer cropping is almost entirely dependent on irrigation [17]. Water resources (both in terms of quantity and quality) in Malta are also under severe stress owing to socio-economic development, over-abstraction for agricultural irrigation and from diffuse pollution [6]. Groundwater is generally over-exploited in terms of quantity, while its quality is deteriorating due to saline intrusion and nitrate pollution [18,19]. Agriculture remains the largest sector, responsible for nearly half (46.7%) of all freshwater consumption between 2005 and 2013, followed by household demand (36.2%) [20].

Biodiversity

This negative situation is compounded by the fact that most arable land has become severely fragmented and neglected due to bad government planning, bird trapping practices of burning land using gasoline, illegal dumping of construction and bulky waste and no maintenance of rubble walls and wild trees. Fragmentation and neglect have reduced biodiversity, as indigenous flora and fauna species suffer from the loss of their ecosystem, thus allowing pest species to thrive. The use of pesticides greatly impacts a number of important pollinators including the Maltese endemic sub-species of honey bees *Apis mellifera ruttneri*, which is also key for local honey production, with Spring, Summer and Autumn honeys all having different organoleptic properties and health benefits. Another group of species that are particularly hit by this situation are bats, which are essential to maintaining pest insect species under control but are poisoned by bioaccumulation of pesticides [21]. As a result of all this, crop production is stunted.

Implementation of EU directives to local government policy for sustainable agriculture in Malta

The EU has drawn up the Common Agricultural Policy which came into force at the start of 2023 and the Green Deal which sets a number of environmental, climate, and biodiversity protection commitments for 2030. However, the crux of the matter is how these are going to be implemented by local legislators for the betterment and sustainable growth of the agricultural sector in Malta. Local government policy attempts to address: soil conservation and regeneration, reduction in water consumption, use of renewable energy, promotion of indigenous plant species integration, increase of tree cover, creation of microclimates, increased carbon capture and increases crop, fruit and honey production. It all boils down to how adequate these policies are for the local context and how willing the farmers are to embrace them.

The relevant Government policy is covered in the The National Agricultural Policy (NAP) for the Maltese Islands 2018-2028. The NAP includes sustainability in its strategic policy objectives in that it aims to protect crucial resources and attempts to move the sector forward through numerous changes supported by local research [9]. It outlines 6 strategic policy objectives, divided into 4 operational objectives, translated into 70 tangible measures. Four of the six strategic policies are relevant to sustainable agriculture i.e. 3) Sustaining water and key resources, 4) Competitiveness and diversification, 5) Adaptation to and mitigation of geo-climatic conditions, and 6) Research and development. The operational objectives are divided into 20 economic, 8 social, 26 resources and 16 governance measures of which 5 economic, 1 social, 13 resources and 2 governance measures could be supportive of local sustainable agriculture (details in Table 1).

Research is essential for such implementation to be successful, however as pointed out even in the NAP,

Table 1.Measures from the NAP which could support sustainable agriculture in Malta.

0	Measure	Application	Description
Economic	4	Education and training	Farm Support Services; Knowledge dissemination; Alternative crop production
	5		Demonstration sites; Circular economy
	6		Farm waste as a resource; By-product creation; Farm Waste Management Plan
	17		Pilot research projects for dissemination
	19		Pilot projects in small holdings; Recreational farming
Social	25		Curricula development, Hands-on training; Applied teaching on farms
Resources	34	Research and experimental implementation	Research and experiment on soil conservation techniques
	35		Experiment with multi-purpose trees
	37		Maximise the use of experimental research centres; Focus on sustainable cultivation practices
	39		Increase organic production
	42	Water conservation	Water-crop assessment and conservation methods
	43		National research programme on optimising water use
	44		Deficit irrigation strategies
	45		Rainwater run-off collection
	46		Smart irrigation systems
	47	Plant protection	Enforce on plant protection products
	48		Service provision on pesticide management and fertiliser application
	49		Data gathering on integrated pest management
	50	Way forward	Develop a Soil Action Plan
Governance	58		Tackle data gaps in agricultural sector; Create an information database
	59		Research and data collection platform

agricultural R&D in Malta is lacking for a number of reasons. Primarily, the farmers (and other stakeholders involved) do not understand or appreciate the benefits of research. Another reason is that EU grants are not really concerned with small island issues and require projects to be multi-faceted, multi-level and ideally international in scope, making them daunting for researchers interested in addressing Maltese issues. To promote agricultural R&D, the Maltese government must dedicate an adequate and consistent amount of local (non-EU) funding over several years to specifically address local agricultural issues, commit towards tangibly reducing bureaucratic procedures and identify a functional alternative to public procurement procedures which when involving low literacy farmers, particularly focused on bartering services, is close to impossible to follow and as a result many prospective researchers give up. With such local funds available, higher educational institutions would be more likely to dedicate their scarce human resources and focus their research programmes to meet the critical needs of the Maltese agricultural sector. Finally, without adequate showcase fields, it is difficult to determine the expected rate of adoption of a new practice because farmers want to see the success in practice before deciding and are very distrusting of new technologies and changing practices.

Table 2. The 12 principles of permaculture and their implementation

	On-field implementation
Observe and interact	Design solutions that fit the natural microclimate of the field
Catch and store energy	Collect and store all natural resources available in the field for future application
Obtain a yield	Many types of yields beyond crop yield are to be considered in a sustainable system
Apply self-regulation and accept feedback	Understand the impact of agricultural actions on the environment and learn from mistakes
Use and value renewable resources and services	Reduce non-renewable resources and implement strategies to replace them with renewable ones
Produce no waste	Find ways to reuse and recycle on-site resources, and minimise any waste generated
Design from pattern to detail	Consider how the field design will work as a complete and efficient system following natural patterns and then look at specific plants
Integrate rather than segregate	Plant crops and other plants in such a way as to benefit each other such as through pollination or pest control
Use small and slow systems	Use techniques that are gentle and low-impact making them easier to maintain and more sustainable long-term
Use and value diversity	Plant diverse crops and plants to reduce vulnerability, and creates a resilient and productive field
Use edge and value marginal	Use the boundaries between planted plots and paths to increase the productivity and diversity of the field
Creatively use and respond to change	Be flexible and adaptable by observing the field condition and intervening appropriately

Generic implementation of permaculture principles

Permaculture is an acronym for the words ‘permanent’ and ‘agriculture’, and can be described as a design system used for sustainable agriculture which mimics the patterns and relationships which take place within an ecosystem in its natural state, having its own natural cycles [22], with the ultimate goal of balancing ecological sustainability and economical prosperity. Holmgren [23] embodied the idea of permaculture in 12 principles (Table 2).

In order to be sustainable, farming practices should be designed in such a way as to take into consideration the safeguard of the surrounding and interacting natural environment and biodiversity, since farming constitutes the major land use in rural areas and plays a crucial role in environmental sustainability. Towards this goal, permaculture offers a flexible framework whereby to tackle the local agricultural issues using sound scientific principles mixed with traditional practices.

Among the more basic and essential on-field practices applying the permaculture principles are: 1) reducing the use of plant protection products (herbicides and pesticides) and tilling machinery, 2) enhance the richness of flowering plants, and 3) changes in the crop species and cultivation system [24]. A meta-analysis showed that small-scale practices (such as including wildflower strips) enhanced pollinator richness, and that their effectiveness varied with 1) the magnitude of increase in flowering plant cover resulting from the practices, 2) farmland type, and 3) landscape context [25]. The best possibility to improve the situation for pollinating insects in the modern agricultural landscape is to enrich the remaining field margins by sowing various flowering plants, create new zones with permanent vegetation, and allow wild plant species mixtures as strips every so many rows within crop fields [26]. A priority should be to conserve and reinforce the vegetation features at field margins and their constituent wild plants such as nettles, wild umbelliferae, borage, wild clovers, etc., as well as herbaceous plants, especially the more specialist long-corolla perennials that tend to have more nectar than annuals [27]. In addition to pollen and nectar for adults and food plants for larvae, wild plants at field margins provide shelter and nesting sites for many pollinators [26].

Having a permanent ecosystem in a commercial set-up is not entirely possible and is more amenable to small plots for family production. However, setting up a system in which a certain percentage of total land, particularly field borders, is dedicated to such a permanent ecosystem with seasonal succession is easily doable, since this land area is not generally used for growing crops and in so doing provides a buffer zone protecting crops from both pests and environmental elements.

From the perspective of crop yield and sustainable profit, research shows that the resilience of the ecosystem increases with a larger functional biodiversity. When growing mixtures of different crops, the system becomes more resilient to fungal diseases and pests, yields are stabilised and the sustainability of the system as a whole increases. Therefore biodiversity increases productivity and stability of ecosystems [28]. The implementing a various permaculture practices have been shown to be effective through a number of research studies which have shown an increase in crop productivity. For example in one study, an increase in insect (69 flower visitor species) and plant biodiversity improved crop yield, with the number of honeybees and other flower visitors visiting sunflowers being invesely proportional to their travelling distance and decreasing to 61 and 24% respectively, and species richness dropping to 57% of their maximum by the time a distance of 1000m was reached [29]. Another two studies support this find, with an increase in yield of several crops by 19–37%, when using honeybees as crop pollinators [30,31]. In a study on blueberry production, a mix of 15 perennial wildflower species (that provided season-long bloom, increased plant density and floral area), increased pollinator insect abundance in the fields adjacent to wildflower plantings, resulting in significant increases in percentage fruit set, fruit weight, and mature seeds per fruit in fields adjacent to wildflower plantings, leading to higher crop yields and with the associated revenue exceeding the cost of wildflower establishment and maintenance [32]. In studies cultivating wheat and soybeans, this yield advantage has been estimated at 5.4% and 11%, respectively [33-35]. In short, yield and profit could be maximized with 20-30% of land uncultivated within 750 m of field edges [36]. When combined together, such permaculture practices allow farmers to increase production and reduce losses, save money supplementing the soil and mitigating pests, all of which increase the farmer's profit margin, even if production per area is not increased significantly.

Current application of permaculture in Malta

Presently, permaculture in Malta is already being applied at a handful of small sites namely in Baħrija (North), Għajn Tuffieħa (North), Siġġiewi (South West) and Marsaskala (South East). In terms of published local data, only 2 limited analytical studies have been performed in Malta comparing permaculture and conventional agriculture. The first study qualitatively analysed the use of sustainable techniques in local agriculture [37] and the second study quantitatively compared topsoil organic carbon content [38]. This latter study found that the conventional field had an average organic carbon of 4.7% due to the use of manure while the permaculture field had an average organic carbon content of 4.2% due to the use of compost [38].

A local pilot study called PerMaVia is currently underway to help bridge the gap between research in permaculture concepts and sustainable agricultural practices and their application to the local scenario, encouraging the regeneration of both farmland and the Maltese countryside. The aim of this research project is to test the viability of implementing permaculture practices to Maltese agriculture with the available local natural resources. The collection of quantitative data for crop yield and various environmental parameters, as well as biodiversity qualitative data will be used to determine whether using permaculture practices instead of the traditional intensive single crop farming could improve environmental conditions in the Maltese context without jeopardising crop output, for a more sustainable agricultural sector. The research design involves the implementation of practices related to renewable energy production and use, soil cover and tilling, reduced water consumption, wild plant diversity and control as well as insect and bat presence. Crops will be planted in 10m x 10m plots surrounded by a 1m border of wild plants. The ground cover selected is mulch or 60% shade netting and the wild plants are controlled by an electric grass cutter. The staple crops selected are potatoes, onions and broad beans, although other crops will also be investigated. The data collection methods include photovoltaic inverted data logging, laboratory soil chemistry (including metals) analysis and on-site NPK readings as well as irrigation water electrical conductivity using an RS-TRREC-N01-1 Dr. Soil recorder (Shandong Renke Control Technology Co. Ltd.), soil temperature and moisture content data logging at depths of 5, 15, 25 cm using Drill & Drop bluetooth sensors (Sentek Technologies), wild plant diversity will be qualitatively identified, pollinator and pest insect diversity and numbers will be measured from pan traps, while bat presence will be measured by analysing the calls recorded with a Song Meter SM4BAT FS Bat Detector with SMM-U2 Microphone (Wildlife Acoustics Inc.). This data collection will provide the much needed baseline data for a typical agricultural land parcel in Malta on which to build future research. An improved understanding of how permaculture applies to local agriculture will open avenues for farmers to innovate their practices and offer new business opportunities.

Application of innovative solutions to address Malta's agricultural issues

Agricultural technology is always developing but in most cases the application to the Maltese context is difficult because these solutions are either very expensive or more suitable for extensive land areas, with high soil quality. What is required is a set of optimised practices built on local or regional knowledge, combined with modular, sustainable technologies that can be scaled up when required by the farmer. Moreover, since most Maltese farmers are non-technical people, the solutions have to be easily implementable and low maintenance.

Soil

The primary goal should be soil conservation to prevent further loss of this limited resource, followed by a substantial effort to restore degraded soil and improve soil health in the long-term. Damage to the topsoil layers can be reduced by limiting the area of soil that is travelled by heavy vehicles and by reducing the surface contact pressure of vehicles [6]. Considering the need for automation and machinery to speed up certain processes and make production profitable, the application of robotic technology to replace certain heavy machinery tasks would be advantageous. Moreover, local farmers can derive significant benefit from soil monitoring using on-site sensors and data systems as well as off-site soil testing for nutrient status instead of blindly adding chemicals to their fields. Useful monitoring tests for local farmers would therefore include those for nitrate/nitrite, ammonium, phosphorus, and chloride. [6] as well as foliar analysis for residues of plant protection products prior to harvest. Moreover, adequate and viable soil cover options are required in an effort to effectively to reduce weeding, tilling, herbicide use, reduce watering, reduce weed seed deposition, and potentially assist in summer soil sterilisation by solarisation. There is potential for mulching with olive mill waste or some form of compost rather than straw or wood chips due to the dry, hot weather most of the year. Also, whilst netting or weedmats are extremely effective, single use plastic coverings, even if biodegradable should be avoided. In conjugation with this, effective composting strategies not requiring high moisture levels such as the Johnson-Su bioreactor need to be further explored and optimised.

Water

Given the critical shortage of this resource on the island, the agricultural sector should strive to preserve and safeguard the available water resource both in terms of quantity and quality by: 1) decreasing water consumption (e.g. by using low-flow localised drip irrigation instead of sprinklers or furrow irrigation), 2) using alternative sources of water (e.g. recycled waste water where available or on-site reverse osmosis of brackish water), and 3) reducing the negative environmental impact associated with the infiltration of agri-chemical loaded run-off water contaminating groundwater resources (which are also used for human consumption) [6]. Any irrigation water retained on the soil surface (particularly on clay soils) is susceptible to evaporation, reducing the volume of water effectively infiltrating the soil. The water content of the soil can be maintained by: 1) increasing the organic content of the soil (generally with manure before the start of the production cycle), 2) protecting the topsoil water content and structure during the growing seasons with mulch (despite wood chips, straw and compost not being ideal for Malta's context) or ground cover and 3) reducing surface evaporation and soil drying in summer by either maintaining a drought-resistant cover crop (if possible) or using ground cover [6].

A few years ago, the Water Services Corporation (WSC) in Malta started producing what is known as "New Water", which is a high-quality product of treated sewage water, well-beyond second class water, which is made available specifically for crop irrigation. This has the potential to cater for 35% of the total demand within the agricultural sector [39] and could also open the option of growing cover and fodder crops that require irrigation (e.g. corn) in summer. However due to infrastructural issues only a small proportion of local farmers have access to it and the abuse of this resource for non-agricultural use is highly likely.

By using recycled waste water or desalinised brackish water (by reverse osmosis using renewable energy) for irrigation, the environmental impacts of using groundwater can be gradually reversed and aquifers replenished. Furthermore, significantly reducing if not entirely eliminating the use of plant protection products will have a positive impact on groundwater quality [40]. Sensors that measure soil moisture can be used to collect data from different soil depths, and variable irrigation can then be scheduled in different zones within a field. Sensors placed at multiple depths can also help reduce irrigation requirements owing to the increased confidence in the knowledge that water stored in the deeper soil can be used by the plant, even if the surface and topmost layer are much drier [6]. Wireless technology could be added to transmit sensor data at pre-determined times to a control centre, which would remotely control irrigation equipment and deliver water according to the need across the field [41]. Such advanced irrigation technology including the use of robotics to deliver the water will contribute to the future sustainability of irrigation-dependent agriculture in Malta [6].

The overarching long-term goal should be to significantly replenish groundwater reserves. In order to do this there should be improved infrastructure implementing innovative ways and technology to increase rainwater capture [42] and a push to rely on more than one water source, including the use of New Water where available. The prospect is that by reducing the use and waste of agricultural water through real-time monitoring of crop needs, any negative impact on productivity will be avoided and revenue improved, whilst preventing further contamination of natural water resources in order to meet environmental sustainability.

Biodiversity

The importance of this resource is generally greatly underestimated by conventional farmers and most wild plants are considered to be weeds while wild insects are indiscriminately dealt with as pests. However, wild plants offer many benefits such as increase pollination, offer sacrificial protection leading pest insects to forage on them preferentially to the adjacent crop species and can act as a reservoir for pest predators. This increases the amount of crop producing fruit or reduces the amount of crop lost due to insect damage. Increase biodiversity can be achieved by dedicating patches within the field to wild plants. As a result, wild flower species, particularly perennial species, if properly managed, will likely provide these benefits for many years, with the added benefit of also attracting pollinators, providing habitat for natural enemies and enhancing biological control of pests in fields adjacent to those planted [24]. However, despite the disposition to include patches of wild plants with crops, it is essential to control the seeding of wild plants in order to avoid them from out-competing crops for resources and increasing the weeding effort required.

Wild pollinators are often more susceptible to pesticides than are domestic honeybees, and wild pollinators may be eliminated completely from a crop environment [26]. Increasing the abundance of honey bees may complement but not replace the pollination services provided by diverse assemblages of wild insects, and wild insects pollinate some crops more efficiently than honey bees [43]. The co-cultivation of wild plants has been shown to allow pollinator insects to persist within sunflower fields, maximising the benefits of the remaining patches of natural habitat to productivity of this large-scale crop because wild plant diversity increased flower visitor diversity, which also reduced the measured negative effects of isolation from natural habitat [29]. This is because flower visitors are known to be affected by distance to natural habitat and by floral diversity [44-45]. Abundant floral resources required by honey bee colonies may also act to increase abundance and species diversity of wild bee communities [46]. This is also true for other pollinators. Beyond their impacts on wild bee communities and managed honey bee colonies, semi-natural habitats situated among agricultural lands are of key importance for supporting other wildlife species and promoting biodiversity [47,48].

Due of differences in species functional traits, greater pollinator richness can lead to foraging complementarity or synergy, improving the quantity and quality of pollination [49] and therefore increasing both the proportion of flowers setting fruits (or seeds) and product quality (e.g. fruit size and shape) [24]. Indeed, richness and visitation rate (a proxy for abundance) of wild pollinators are strongly correlated across agricultural fields globally [43]. Therefore, practices that enhance habitats to promote species richness are also expected to improve the aggregate abundance of pollinators, and vice versa. The importance of small-scale practices is likely greater for insects with short flight ranges foraging from a fixed nest, such as small- to medium-sized bees, which usually forage within an area of a few hundred meters and comprise the greatest fraction of bee species [50,51].

A key aspect to consider in sustainable agriculture when not relying on pesticides is predator insect utilisation. The use of pesticides, tilling and automotive harvesting disturb natural enemy communities in crop fields [52]. As a result, crop fields are often poorly colonised by natural enemies of pest species owing to the lack of plant and prey food as well as other resources such as favourable microclimates and oviposition sites [53]. Sustainable agriculture thus requires the application of approaches that increase natural enemy effectiveness in controlling pest populations (i.e. top–down effects) [52]. Pest control can only be sustainable and effectively implemented through a mix of crop rotation, intercropping, conservation tillage, reducing plant density, avoiding transfer of contaminated soils, hygiene measures, mulching, cover crops, companion crop planting, use of natural pesticides, biological control, together with the protection of pest predators and their host plants. It follows that enhancing wild insect species richness and abundance improves crop yield [24].

The main query is always which areas to dedicate to wild plants and the obvious first choice based on their underutilisation are field borders or edges. Such areas can be very productive, offering multiple benefits to the field microenvironment and should be cared for. That being said, other areas can be dedicated to such wild plant patches and this fall in with planting in zones (i.e. leaving a row of wild plants every few rows of crops) as part of companion planting given the mutual benefits and overall diversification. Further to this is crop diversification, which affords greater diversification of the market, protection against pests and disease, as well as potential survival of certain varieties in case of extreme weather events.

In order to implement this in Malta, the initial exercise needs to be the identification of indigenous wild flower varieties that have both the best adaptability to Malta's soils and agricultural microenvironment as well as high pollinator visitation, which in practical terms would include the use of plants such as boar thistle, rosemary, thyme, fennel, dandelion, chamomile. Non-indigenous flower that can have a commercial value and hardy flowering trees which can provide a secondary benefit such as the olive, carob, pomegranate, almond and prickly pear can also be viable candidates around field borders. For example, olive trees are ideal because they provide land protection, soil conservation and crop protection from sea spray and wind [54]. Moreover, Malta has 3 local oil-producing varieties: il-Bidni, il-Malti, il-Bajda, which should be safeguarded. In Malta prickly pears are often used as wind breakers and as a hedge to separate fields from one another, thus reducing pesticide spray contamination from adjacent fields. Carob trees forms an important component of the Maltese ecology, being well adapted to calcareous soils, and can provide numerous benefits, both environmentally and economically [55]. Almond and pomegranate trees are also resistant trees that can grow in calcareous soils and can survive long dry seasons [56].

A similar exercise needs to be carried out in order to identify wild pollinators and predators, so as to gauge the success of the effort or include flower species that can attract missing pollinators and predators. While such ecological intensification is not a necessity for farmers to make their operations sustainable, the extra effort provides a healthier and more self-regenerating micro-environment that can withstand and recover from more extreme climatic events.

Conclusion

The farmer population in Malta is increasingly aging and the younger generation are more agronomists (technical specialists) or agricultural entrepreneurs (businessmen) with fewer hours on site directly working the land. This means that if heavy machinery is to be avoided, one of the few viable options is the application of robotics for tilling, watering, weeding, planting and in some cases even harvesting. The use of AI for monitoring the soil and plant parameters and taking decisions based on real-time information, is already becoming a focal point of agricultural research. The upcoming Maltese farmers will need to implement sustainable agricultural intensification in order to increase production on the same land area while reducing environmental impacts and maintaining ecosystem functioning [57].

Irrespective of how positive the data collected about permaculture is, there will always be resistance to change. The major resistance to the implementation of successful measures are the farmers themselves, who have been passing on their practices for generations and will not so easily change them based on either empirical data or national guidelines. Proposing new practices which require minimal investment costs encourages a higher rate of adoption as well as promoting their profitability. It is important to provide showcase sites where farmers can visit and experience first hand the successful implementation of these measures. Furthermore, at such sites farmers should find experts available to discuss with the farmers as well as to visit the farmers to help them set up these measures in their own fields.

Finally, while farmers need to understand their involvement in maintaining the rural landscape and be open to adopt innovative techniques and technologies to aid sustainability, consumers also play a crucial role. Consumer education would ensure more sustainable choices and thus create a demand as well as a push towards more sustainable crop production. There is also a need for infrastructure whereby consumers can connect with farmers directly, enabling farmers to get better prices for their products while consumers feel connected to the producers of their food.

Conflict of Interest

The author is the Principal Investigator of project Permavia mentioned in the paper and this research is being carried out on land privately owned by the author.

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