World Applied Sciences Journal 39 (2): 69-83, 2021
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2021.69.83

A Review of Soilless Agriculture in Nepal

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Abstract: Soilless growing is expanding worldwide because it offers methods of growing food (including fish in aquaponics) at high densities in small spaces, features that are advantages in urban agriculture. Nepal is experiencing rapid urbanization with associated loss of agricultural land near cities. Distant import of vegetables and fish can be problematic due to natural disasters, political unrest and lockdowns due to disease. We evaluated the status of aquaponics and hydroponics in Nepal by attempting to locate as many existing operations as possible in the country. We discovered 50 aquaponics and 38 hydroponics units and through interviews of owners and other methods we documented system designs, the types of fish and plants grown and other characteristics. It appears, soilless growing, particularly family scale units, have potential to contribute to food production in cities in Nepal where flat topped roofs offer space for growing food.

Key words: Aquaponics · Aquaculture · Hydroponics · Nepal · Soilless Agriculture · Sustainable Agriculture · Urban Agriculture

INTRODUCTION

Nepal, like many other countries with growing populations, is concerned about food security, in part due to rapid urbanization with associated reduction in available agricultural land [1, 2] and seasonal water shortages [3]. In response, government incentives for roof top gardening in the Kathmandu Valley recently have been announced [4]. Similar plans associated with urbanization are occurring in other metropolitan areas of Nepal [5, 6].

Usually roof top or small space "kitchen" gardening is soil based, but hydroponics and aquaponics are the two soilless methods often practised, particularly in urban areas to grow food at high density. Aquaponics is a combination of recirculating aquaculture [7] and hydroponics [8], both which have been practiced historically [9-12]. However, the widespread integration of the two disciplines (aquaponics) is relatively new [13-16]. Interest in soilless growing, particularly aquaponics, has proliferated in the past 10-15 years [17, 18]. Universities and non-government organizations are taking an increased interest in soilless growing as demonstrated by the substantial rise recently in the number of technical reports and scientific journal publications [19-21]. Additionally, schools are now using aquaponics or hydroponics, especially in STEM (i.e., Science, Technology, Engineering and Mathematics) education programs [22].

Soilless growing could have benefits in urban Nepal to grow vegetables year around. The technologies have characteristics that address seasonal water shortages. For example, water reuse in these closed-loop systems is much more efficient than soil irrigation (aquaponics using about 10% as much water [23]). Furthermore, covered systems (even with inexpensive fabric) can allow growing during monsoon and systems on roof tops, inside buildings, or raised off the ground are less subject to flooding.

Our objective was to document and characterize the status of aquaponics and hydroponics in Nepal. The intent was to provide information for others with interest in soilless growing including families, schools, businesses, researchers and policy makers.

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This information contributes to the “baseline” data on the use of these methods being compiled for various parts of the world [11, 17, 24-28].

MATERIALS AND METHODS

To document the status of aquaponics and hydroponics in Nepal, we used key word searches of websites, Facebook pages, newspaper articles and “word of mouth” (i.e., asking those we interviewed if they know about other systems) to locate as many operations as possible. Attempts were made to contact all known operators and interviews were arranged in person or through telephone or email discussions with key informants/respondents (45 aquaponics and 11 hydroponics systems). In addition, when we were unable to interview operators, we gathered data on physical components of systems by viewing images on Facebook or websites (3 aquaponics, 26 hydroponics) or information from informants other than owners (2 aquaponics and 1 hydroponics).

To gather information, we used a standard set of questions in semi-directed interviews and we measured components of systems we could visit. Several companies engaged with construction of units provided detailed information about the design of systems they had built, but due to privacy concerns they were not at liberty to give us direct contacts. Most aquaponics operators contributed information directly, but many hydroponics operators declined to respond to our requests for visits or interviews. The combination of information from these sources and social media images allowed us to document physical characteristics, the types of fish and plants being grown, issues related to operation and opinions of operators about soilless growing in Nepal.

RESULTS

Soilless growing is new to Nepal. The first aquaponic system was built in 2010 and hydroponics began about 2016. New construction of both types of systems is increasing almost every year (Fig. 1). Nepal is still in the early stages of soilless growing, but 50 aquaponics and 38 hydroponics operations were discovered in 2020-2021. More systems probably existed than we found, nevertheless, the data was collected provides a basis for characterization of the soilless systems currently operating in the country.

Locations, Purposes and Construction Costs: Most of the soilless systems we found were in the Kathmandu Valley (66% for aquaponics and 71% for hydroponics), but we found at least one soilless system in each of 12 districts outside the Kathmandu Valley (Table 1).

Many owners we interviewed had multiple purposes for starting their systems. However, the primary purpose stated most frequently for aquaponics and hydroponics was family food (many of these are small “hobby” systems) and/or food for children’s homes or student hostels (Table 2). Sale of produce was the primary purpose for 19% of the aquaponic systems and 26% of hydroponic systems. Most systems were relatively small, but 2 aquaponic and 3 hydroponic systems were substantially larger than all others. Demonstration and sale of commercial systems were also listed frequently as a primary purpose for hydroponics; somewhat less so for aquaponics (Table 2). So far, only a few cafes were incorporating soilless systems and in Nepal use of hydroponics for STEM education started in 5 government schools in 2019 and 2020. We found only 2 systems that were built specifically for formal research in Nepal. Secondary purposes listed frequently were learning about the technology (informal research), demonstration for others and selling produce excess to family needs.

Funding for aquaponics systems came from individuals or businesses (71%), NGOs (24%) or government (4%). About 58% of the aquaponics systems were built by the owners, 24% were built by contractors (including those contractors built for themselves as demonstrations) and 18% were built by an NGO (usually with owners’ direct involvement). In contrast, 89% of the hydroponics systems were built by contractors and only 11% were built by owners. The funding for these was mostly individuals and companies (87%) but 4 systems (11%) were built by a combination of NGO and government funds (all in government schools) and in one case systems were built at a government facility for research.

Approximate construction costs varied depending on system size, inclusion of a greenhouse and whether owners built the systems themselves. We were able to get construction costs for 32 aquaponics and 10 hydroponics systems. About 38% (12 of 32) of the aquaponic units cost less than 300 USD, mainly for materials because these were home built and typically only had rain covers and not greenhouses. Nine aquaponics units (28%) cost 300-500 USD, one was 500-700 USD, six were 2000-5000 USD and four were more than 10, 000 USD. For hydroponics, single units each were in the <300, 300-500 and 500-700 USD ranges. Four hydroponics systems cost 2000-4000 USD and the other six were more than 10, 000 USD.

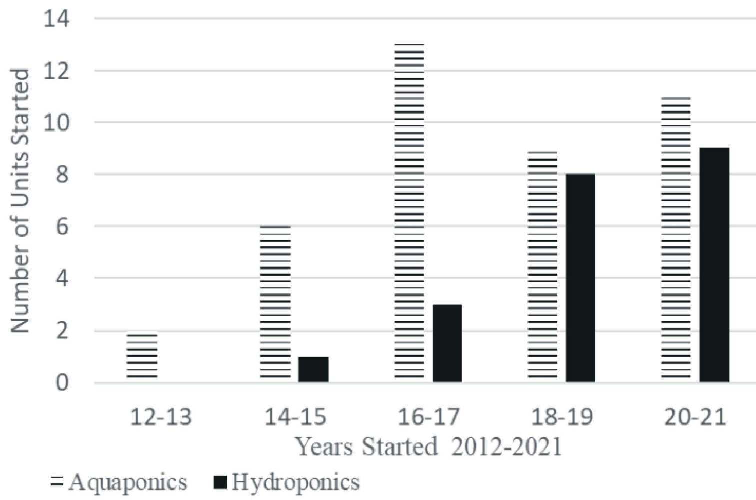

Fig. 1: Number of soilless units started in different years in Nepal

Table 1: Locations of soilless growing systems in the Kathmandu Valley and Districts outside the valley

Location	Aquaponics Systems	Hydroponics Systems
Kathmandu Valley	33	22
Kaski	6	
Jhapa	4	
Sunsari	1	3
Kavre	1	3
Surkhet	2	
Banke	1	
Chitwan	1	
Syangja	1	
Dang		1
Dhanusha		1
Nawalpur		1

Table 2: Primary purposes of soilless growing systems in Nepal

	Aquaponics		Hydroponics	
Purpose	Number	% of systems	Number	% of systems
Family food/hobby	20	0.42	9	0.29
Child Home/hostel food home/studenthostil food	10	0.21	0	
Produce sales	9	0.19	8	0.26
System sales/Training	4	0.08	7	0.23
STEM education	0		4	0.13
Research	2	0.04	1	0.03
Cafe	3	0.04	2	0.06
Total w/data	48		31	

Physical Descriptions of Systems: Of the 48 aquaponics systems for which we had specific site data, 20 (42%) were on roofs or balconies and 28 (58%) were on the ground. For hydroponics systems about half each of the 34 systems for which we had data were on the roof (47%) and the ground (50%); one was inside a café. Most of the aquaponics systems had covers (46% with plastic of fabric roofs and 43% were in some type of greenhouse). Nearly half (46%) the hydroponics systems were in greenhouses, but 38% lacked any type of cover.

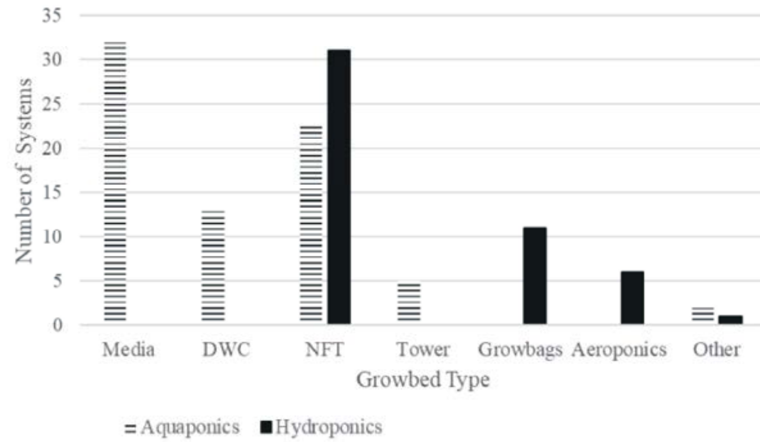

Fig. 2: Number of soilless growing systems using different types of plant grow beds in Nepal

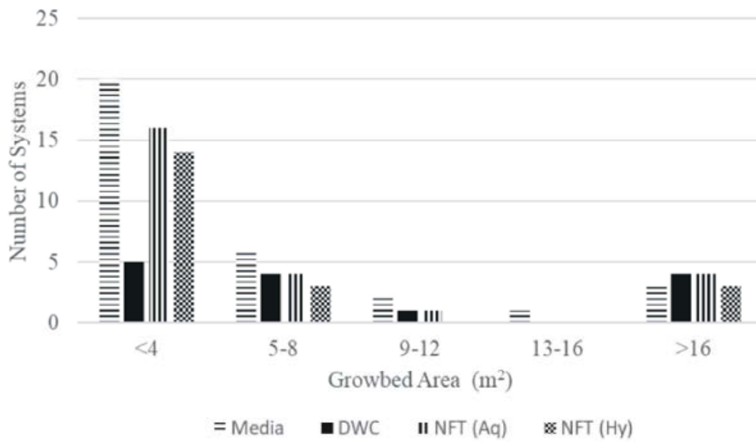

Fig. 3: Size of plant growing area in different types of grow beds in soilless systems Nepal

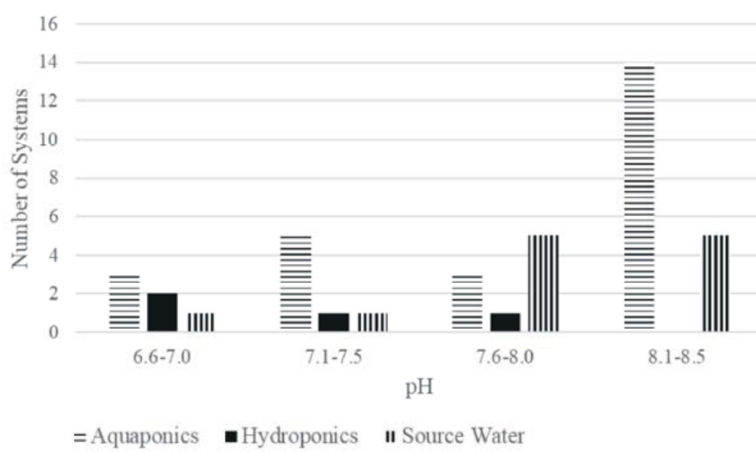

Fig. 4: Number of soilless systems and source water with various pH values

Types of Grow Beds: The results showed that soilless growers in Nepal using media, deep water culture (DWC) rafts, nutrient film tubes or galleys, vertical towers, grow bags (usually fabric bags on the ground or roof), aeroponics drums and a few other types of grow beds. Any of these grow beds could be used with either aquaponics or hydroponics, but media, DWC and vertical towers were used exclusively in aquaponics systems and growbags and aeroponic drums was used exclusively in hydroponics. Both types of soilless approaches used nutrient film tubes (Fig. 3).

About 40% of the aquaponics systems in Nepal contained more than one type of grow bed (17% had two, 19% used three and 2 operators (4%), used four types of grow beds). The most frequent combination was media and NFT. Of the systems that used only one type of bed, 61% (19) were media, 32% (10) were NFT and two were deep water culture. For hydroponics, most systems had only one type of grow bed (either NFT or aeroponics), but two systems had both NFT and aeroponics and five systems had NFT and growbags.

The primary material used for media was gravel, typically 3-4 cm or "chips" around 2 cm. DWC rafts were Styrofoam sheets approximately 2 cm thick. Media used in NFT systems was most often sponge material coco coir, or rock chips, although some operators used saw dust or in some cases nothing, just placing the seedling into a net pot or plastic cup (often modified as a homemade net pot).

Size of Grow Beds: The surface area of grow beds is a standard measure of the capacity of a system to produce plants and this can be calculated for all types of grow beds (e.g., diameter x length for PVC used in NFT systems). Most of the soilless systems in Nepal had plant growing areas under 4 m^2, including all three of the primary grow bed types (Fig 4). For hydroponics, there was a large gap in size, only three systems in the 5-8 m^2 range and others were much larger, two systems having more than 100 m^2 of grow bed area. The pattern was similar for aquaponics, although a few more systems were in the relatively medium size ranges (Fig. 4). Larger aquaponics systems tended to use all three types of grow beds and although there was only one system over 100 m^2, three had growing space between 40 $m^2$and 65 m^2.

Grow Bed Materials: Media beds were most frequently made with blue plastic drums (about half of all systems). For most of the remainder, IBC, cement and lined wood were about equally chosen. DWC systems were about half each constructed of cement or wood with liners. In aquaponics, all the NFT systems and vertical towers used PVC which was also most used in hydroponics. Nevertheless, about 39% of the hydroponics systems used commercial gullies instead. Plastic buckets were used for the few "Dutch bucket" systems (included in the "other category" in Fig. 3) and commercial fabric grow bags, usually placed on the floor (for roof tops) or ground, were the standard for hydroponics. All the aeroponics systems we saw used plastic drums made or modified specifically for this approach.

PVC pipes used for NFT systems in both aquaponics and hydroponics ranged from 2.5 inches (75 mm) to 6 inches (about 168 mm) but by far the most used sizes were 3 inch (about 89 mm) and 4 inch (114 mm) (comprising together more than 70%). The larger diameters (5-inch, 127 mm and 6-inch, 152 mm) were used as vertical towers in the few systems where these were observed.

Types and Sizes of Fish Tanks: Approximately half (23 of 47) the fish tanks used in aquaponics were plastic tanks (frequently 500 L), like those typically used for water storage in Nepal (Table 2). The smaller home systems often used 200 L blue drums or partial IBC tanks. Cement tanks usually were associated with larger systems (Table 3).

Types and Sizes of Hydroponic Nutrient Tanks: We were only able to gather these measurements on 24 hydroponics units. More than 80% of the units either had 200 L black plastic water tanks (41%) or were small units with plastic buckets or small plastic water tanks with 60L or less capacity. Three of the units we observed had either 250 L (1) or 500 L (2) black plastic water tanks. We were only able to measure nutrient containers at one of the larger commercial farms (2500 L), but several of these would likely have had larger nutrient solution containers.

Biological and Solids Filters: Aquaponics systems with media grow beds typically did not have any other filter, the media functioning as both a biological and physical filter. All the NFT and DWC systems, even if they had media beds also, typically had passive or swirl settling containers (usually plastic drums or water tanks) and/or solids filters (containing netting, fabric, or Kaldness or other types of plastic beads). These too usually were in plastic drums, water tanks, or some other waterproof plastic container. Several of the larger systems had cement settling tanks. Volumes of these clarifiers and solids filters varied a great deal. More than half the clarifiers for which we had data were less than 100 L (12 of 22) and only 3 were larger than 200 L. There was little understanding among those interviewed about how to determine the appropriate size of filters.

Table 3. Types and sizes of fish tanks used in aquaponics in Nepal

Volume (L)	Water Tank	Blue Drum	IBC	Cement	Wood	Other	Total
100-200		8				1	9
201-400	3					1	4
401-600	10		2	1			13
601-800	1						1
801-1000	3		3		1		7
1001-1500	1			1			2
1501-2000	5			3			8
2001-3000				1			1
>3000				2			2
Total	23	8	5	8	1	2	47

Table 4: Species of fish used in aquaponics in Nepal

Common Name	Scientific Name	Nepali Name	Systems w/species[a]
Common Carp	*Cyprinus carpio*	Aachhep Machha	64%
Nile Tilapia	*Oreochromis niloticus*	Tiple Machha	36%
Goldfish	*Carassius auratus*	Jarda Machha	18%
Grass Carp	*Ctenopharyngodon idellus*	Ghass Aachhep	14%
African Catfish	*Clarius gariepinus*		14%
Rainbow Trout	*Oncorhynchus mykiss*	Trout Machha	9%
Pangas Catfish	*Pangasius pangasius*		7%
Rohu Carp	*Labeo rohita*	Rahu Machha	5%
Bighead Carp	*Hypophthalmichtys nobilis*		5%
Guppy	*Poecilia reticulata*		5%
Snakehead	*Channa argus*	Hile Machha	2%

[a]We had data from 44 systems

The Fish Component: At least 11 different species of fish have been used in aquaponics systems in Nepal (Table 4). Common carp and Nile tilapia are the most used species, but goldfish, African catfish and bighead carp also were used in 6 to 8 systems each (Table 4). Of the 44 systems where we had data, 23 (52%) of the operators had used only a single species of fish, 11 had tried two species and 10 had tried three or four species. Typically, only one species was used at a time, but at least 5 people had tried polyculture, usually with two species of carp. Aquaponics operators usually got their fish either as fry from hatcheries or as larger fish from markets where fish live were held for sale as food.

Commercial fish food, usually purchased from the hatcheries or at aquarium stores, was used by 49% (21 of 43) of aquaponics operators. Eight operators (19%) were using corn-based commercial chicken feed (much more widely accessible and cheaper than commercial fish food). Other diets were homemade and included mustard cake and rice bran (3), "masaura" (dried vegetable balls) (3) and the remainder used various kitchen scrap including cooked rice and chicken livers). At least seven systems supplemented the regular diet with scrap lettuce and other leafy greens. Fish were fed twice a day in 62% of the systems and once daily in the others. Only 30% of the operators fed measured amounts of food daily, 48% fed a "handful" and the remainder fed as much as the fish would eat.

The Plant Component: Many species of plants have been tried in soilless agriculture in Nepal. For example, one company using hydroponics indicated they have grown 25 types of vegetables and other commercial operations indicated to us that they had tried dozens of types of plants in their aquaponics and hydroponics systems. We recorded at least 39 types of plants growing currently or in the recent past in aquaponics systems and 23 types in hydroponics (Table 5). Lettuce was the species most frequently grown in both types of systems. In nearly every system the green leaf variety, for which seeds are locally available, was the main variety, but particularly the commercial operations were trying different varieties as well. Tomato, bok choy and mustard leaf/greens also were relatively frequent in aquaponics and hydroponics (Table 5).

A comparison of which plants were grown in different types of grow beds shows that lettuce (and other leafy greens like bok choi and mustard leaf) was grown in all types of beds except hydroponic grow bags (Table 6).

Table 5: Types and frequency of plants grown in aquaponics and hydroponics systems in Nepal

Plant	Taxon	Nepali Name	Aquaponics[a]	Hydroponics[a]
Lettuce	*Lactuca sativa*	Salad	73%	67%
Tomato	*Solanum lycopersicum.*	Golveda	38%	33%
Bok Choi	*Brassica rapa*	Lataree ko Saag	27%	39%
Mustard Green/Leaf	*Brassica juncea*	Rayo saag	24%	36%
Strawberry	*Fragaria ananassa.*	Strawberry	36%	15%
Coriander	*Coriandrum sativum*	Dhaniya	22%	12%
Kale	*Brassica oleracea*	Kel saag	16%	12%
Cucumber	*Cucumis sativus*	Kakro	16%	9%
Mint	*Mentha* spp.	baabari	16%	6%
Watercress	*Nasturtium officinale*	Sim rayo	13%	0
Bean	Fabaceae	Simi	11%	3%
Chard	*Beta vulgaris*		11%	3%
Flower	Various types	Ful	9%	12%
Pepper	*Capsicum* spp.	Khursani	11%	3%
Onion	*Allium fistulosum*	Pyaj	9%	9%
Egg Plant	*Solanum melongena*	Vanta	9%	3%
Celery	*Apium graveolens*	Ajwaina	7%	3%
Sweet Basil	*Ocimum basilicum*	Mitho Tulsi	7%	15%
Bitter Gourd	*Momordica charantia*	Tite Karela	7%	3%
Cauliflower	*Brassica oleracea*	Cauli	7%	0
Kangkong	*Ipomoea aquatica*		7%	0
Spinach	*Spinaceae olreaceae*	Palak	2%	9%
Garlic	*Allium sativum*	Lasun	4%	6%
Garlic Chive	*Allium tuberosum*	Lasun Pitti	4%	3%
Parsley	*Petroselinum crispum.*	Ajamod	4%	3%
Thai Basil	*Ocimum basilicum*	Thai Tulsi	4%	0
Ginger	*Zingiber officinale*	Aduwa	4%	0
Pumpkin	*Cucurbita mixta*	Farsi	4%	0
Arugula	*Eruca sativa*		4%	0
Taro	*Colocasia esculenta*	Karkalo	4%	0
Rosemary	*Salvia rosmarinus*		2%	3%
Fennel	*Foeniculum vulgare*	Saunph	2%	0
Bottle Gourd	*Lagenaria siceraria*	Lauka	2%	0
Beet Root	*Beta vulgaris*	Shalgam	2%	0
N. Zealand Spinach	*Tetragonia tetragonioides*	Palungo	2%	0
Choy Sum	*Brassica chinensis*		2%	0
Dragon Fruit	*Selenicereus undatus*		2%	0
Corn	*Zea mays*	Makkai	2%	0
Okra	*Hibiscus esculentus*	Bhindi	2%	0

[a]Data for 45 aquaponics and 33 hydroponics systems, data are percentage of systems with a particular crop

Table 6: Plants grown in different types of grow beds[a] in aquaponics and hydroponics systems in Nepal

	Aquaponics			Hydroponics		
Plant	Media	DWC	NFT	NFT	Bag	Aero Drum
Lettuce	21(44)[b]	10 (21)	16 (34)	18 (82)		4 (18)
Tomato	13(81)	1 (6)	2 (12)	1 (8)	9 (69)	3 (23)
Mustard Leaf	7 (58)	1 (8)	4 (33)	9 (69)		4 (31)
Bok Choi	7 (47)	4 (27)	4 (27)	11 (85)		2 (15)
Strawberry	8 (47)	1 (6)	8 (47)	3 (60)	1 (20)	1 (20)
Coriander	6 (60)	1 (10)	3 (30)	3 (100)		
Cucumber	6 (86)		1 (14)	2 (67)		1 (33)
Kale	4 (57)	1 (14)	2 (28)	3 (75)		1 (25)
Mint	5 (71)		2 (29)	2 (100)		
Watercress	4 (57)	1 (14)	2 (28)			
Bean	5 (83)		1 (17)		1 (100)	
Flowers	3 (75)		1 (25)	3 (75)		1 (25)
Pepper	5 (100)			1 (100)		
Onion	3 (75)		1(25)	3 (100)		
Chard	5 (83)	1(17)		1 (100)		
Egg Plant	4 (100)			1 (100)		
Other[c]	32 (84)	1 (3)	5 (13)	7 (88)		1 (12)

[a]Total number of systems with data: media=28, DWC=11, aquaponics NFT=20, hydroponics NFT=28, bags=9, aeroponics drum=6

[b]% of the plant grown in each type of growbed, (e.g. 44% of the aquaponic lettuce was grown in media growbeds)

[c]All species grown in less than 4 aquaponics or hydroponics systems (Table 5)

These grow bags were used almost exclusively for tomatoes which also were grown in media (13 of 28) and aeroponic systems (4 of 6). DWC grow beds were used primarily for lettuce and bok choy (Table 6). Strawberries were grown primarily in media and NFT systems. Aquaponic media grow beds were used for the most varieties of plants. For example, of the 32 systems growing one of the less common species, most were in media grow beds (Table 6).

Nearly all aquaponics (37 of 39) and hydroponics (7 of 9) operators who shared their data with us, used seedlings they grew themselves to stock units instead of direct seeding. Almost everyone used seeds bought locally but about 30% of the soilless operators also brought in some seeds from outside Nepal. Several commercial operators exclusively used seeds they got from elsewhere citing low germination rates of locally purchased seeds, a theme we heard from many operators.

The Water Component: The frequency of nutrient solution replacement in hydroponics varied from weekly (in a small system) to every 20 days or sometimes longer in large systems (data for only 6 systems). Water lost to evaporation and evapotranspiration was replaced by operators of aquaponics systems every 2 weeks or less by 6 of 14 systems where we obtained these data, 2 operators typically replaced water monthly and 8 told us they replaced only when they though it was needed but did not keep track of intervals.

Several of the larger hydroponics systems had electronic monitoring of pH and some measures of water quality and a few of the aquaponics operators measured at least pH, but most of the soilless growers in Nepal do not have the capacity to monitor any aspects of water chemistry (testing kits or instruments are not readily available and are expensive to order).

Source water for replacement was from wells (18 systems), rivers or streams (8 systems) and delivered from unknown sources (6 systems). Two large hydroponics operations used reverse osmosis to purify their water. Obviously, water chemistry parameters can vary over time, but for pH for example, the five operators who had records indicated the values we measured were within the normal range for their systems. Water in more than half the aquaponics systems we checked had pH values higher than 8 (Fig. 5) and this is higher than the range typically recommended (e.g., ideal 6-7, but no higher than 8 [15]). Water characteristics in some of the larger hydroponics systems was controlled by computer-controlled chemical inputs and the pH in the few systems we could measure was lower than in aquaponics but were still typically higher than the recommended range for hydroponics (5.5-6.5, [29]) which is lower than for aquaponics.

The primary reason for the relative high pH water in soilless systems in Nepal appeared to be the pH of the source water (10 of 12 measures were higher than 7.5) (Fig 5). We were able to measure water hardness for source water in 8 cases and carbonate hardness and general hardness were 180 ppm or higher in all but one system, suggested high buffering capacity which resists change in pH which typically gradually declines in aquaponics due to nitrification.

Most (9 of 11) aquaponics systems where we measured water chemistry had ammonia, nitrite and nitrate concentrations within recommended limits. Interestingly, there was measurable ammonia (0.25-1.0 ppm), nitrite (up to 0.5) and nitrate (up to 40) in the source water for 6 of 8 systems we measured.

Other than adding the nutrients for hydroponics, very few soilless system operators added anything else. Typically, fish food does not contain iron and some plants show iron deficiency with yellowing. Also, it is often recommended that plants like tomatoes have potassium supplemented [30]. Nine operators added chelated iron when needed to their systems, but they mentioned it had to be imported. Compost or worm compost tea was being added to seven systems either as a supplement or as the main input in the interim while they waited to acquire fish. In attempts to reduce pH, four people said they added phosphoric acid.

For the 20 aquaponics systems and 4 hydroponics systems with data on insect pests, the same four types were most often mentioned in both types of systems. Three types of soft-bodied insects were prominent: aphids (*Aphididae*) in 14 cases, thrips (Thysanoptera) in six cases and whiteflies (Aleyrodidae) in 5 cases. Caterpillars of cabbage butterflies (*Pieris brassicae*) were mentioned by 9 growers. Two operators had a problem with snails and slugs and another had damage from an unidentified caterpillar.

The soft-bodied pests were controlled the same way they are elsewhere [31] with neem oil, typically as a foliar spray, in various mixtures with water and soap. Cabbage butterflies were less of a problem in greenhouses, but where they were a problem, the typical foliar sprays of oil, soap and water were not effective. Biological control approaches were reported in two cases: one with house sparrows (*Passer domesticus*) and the other with domestic quail (*Coturnix japonica*) where the birds ate the caterpillars but did not damage the plants.

Table 7: Comparison of characteristics of aquaponics systems in Nepal with other locations.

Factor	Nepal	Bangladesh[a]	Europe[b]	South Africa[c]	International[d]	International[e]
Sample	45		68	44	399	809
Starting Year[f]	Since 2010 100% Since 2015 77%	50% after 2011	Since 2010 75%	Since 2010 78% Since 2015 45%	Since 2010 85%	Since 2010 89%
Purpose	Own food/hobby 63% Commercial 27%	Mostly own food	Research 75% Education 41% Commercial 31%	Own food/hobby 71% Commercial 25%	Own food/hobby 100%	Own food/hobby 84% Education 57% Commercial 32%
Build	Owner[g] 76% contractor 24%	68% owner, 14% contractor, 18% NGO	owner 74% contractor 25%	owner 71% contractor 27%	owner 94% kit or contractor 6%	owner 83% kit or contractor 17%
Site	roof 42% inside 2% outside ground 56%	65% roof, 6% inside, 29% outside on ground	roof 8% inside 34% outside ground 58%		roof 1% inside 19% outside ground 83%	roof 3% inside 28% outside ground 69%
Cover	greenhouse 43%	23% greenhouse	greenhouse 45%	tunnel/greenhouse 85%	greenhouse 33%	greenhouse 46%
Type of grow beds	media 69% NFT 51% DWC 29% vertical 6%	Media most common, seldom DWC or NFT	DWC 30% media 25% NFT 15% vertical 4%	media 96% NFT 16% DWC 14%	most media	media 86% DWC 46% NFT 19% vertical 17%

[a][25] and MA Salam email 2021 June 2
[b][27]
[c][28]
[d][24] 95% of data from US, Canada and Australia
[e][11]
[f]Years calculated from 2021, accounting for earlier dates of cited studies
[g]Included help by NGOs

Table 8: Primary fish and plants grown in aquaponics in Nepal compared to other areas

				International	
Species[a]	Nepal	Europe[b]	S. Africa[c]	All Systems[d]	Non-Commercial[e]
Fish					
Tilapia	36%	27%	82%	55%	43%
Carp	69%				
Catfish	21%	10%	18%	20%	14%
Trout	9%	7%	30%	8%	8%
Ornamental	18%	8%	16%	48%	53%
Plants					
Lettuce	73%	47%	75%[g]	69%	75%[f]
Tomato	38%	32%	16%	64%	72%
Bok Choy	27%			30%	
Herbs[g]	49%	58%	46%	58%	74%
Pepper	11%	19%	32%	55%	57%
Cucumber	16%	15%	25%	40%	41%
Strawberry	36%	10%		35%	
Watercress	13%	10%		20%	
Basil	11%		50%	70%	65%
Chard	9%			36%	
Kale	16%			38%	31%

[a]Scientific names in tables 4 and 5
[b][27]
[c][28]
[d][11] (80% of responses from the US)
(Approximate percentages extracted from figure 5, p 8)
[e][24] (95% of responses for US and Canada)
[f]including leaf lettuce and chard
[g]Not clear what this category included in other reviews, but in Nepal it was mainly coriander and mint.

Plant disease was only mentioned in two cases, both where mildew (*Peronosporaceae*) became a problem during monsoon in greenhouses. Four operators indicated they had lost fish to disease, all cases where they had purchased live fish from markets. Three of the four involved catfish.

The most frequently mentioned problem for aquaponics was difficulty in getting fish (reported by 18 operators). This was exacerbated during the Covid lockdowns in 2020 and 2021 (as many mentioned) but it seemed to have been a problem prior as well. Access to fish in the Terai, where commercial fishponds are common, or locations near government fish hatcheries (e.g., Balaju in the Kathmandu Valley and Begnas Lake in Pokhara) was less of an issue, but availability was restricted to short periods seasonally from the hatcheries. Particularly, owners of small aquaponics systems frequently bought fish from the local markets intended for consumption and mortality was common of these larger, stressed fish.

Commercial fish food in bulk also was not readily available to most operators. Those operators who bought small amounts at a time from aquarium stores considered fish food expensive.

A problem with hydroponics was that chemicals were apparently readily available from only a few sources and several of the operators we interviewed said they considered them expensive. Also, some small operations expressed confusion about how often to add chemicals.

While much reduced recently, electrical outages still cause problems for soilless growers, sometimes causing fish loss in aquaponics. One associated problem mentioned by eight people was the concern that surges and variable current is causing electric water pumps to be damaged and need replacement much more often than expected.

Six operators mentioned excess heat in greenhouses during summer. These particularly affected NFT systems where the thin layer of water does not prove a temperature buffer. Clogging of NFT pipes or gullies was mentioned as a problem on four occasions.

Many operators we interviewed mentioned the need for more knowledge and we received unsolicited comments about desiring local training from 9 operators. Most operators had learned on their own from research on the internet, although 5 growers had taken some type of online training and several of the companies that build and sell systems provided some training and technical assistance. Several of the owners of largest soilless operations in Nepal had formal training and a few companies were offering training and technical assistance for their customers.

Very few of the owners of soilless growing systems were aware of each other in Nepal, but nearly everyone indicated an interest in informal networking to share information and experiences. As of 2021, we found several regional Facebook groups where soilless growers had posted information and this type of media may be a way to increase interest and facilitate encouragement.

Perceptions: Of the 33 aquaponics and 11 hydroponics operators we were able to directly ask or view their recent testimonial on Facebook, all but 3 (2 aquaponics, 1 hydroponics) were positive about their systems. Covid positively affected soilless growers by giving more time at home during lockdowns and at least 12 soilless operators had recently expanded their systems. In contrast, schools and several operators (total of 10 systems) were forced to temporarily shut down during lockdowns due to lack of access. Three operators told us they lost fish due to pump or power failures that could not be fixed due to lockdown. All but 3 of the systems (all aquaponics) we had information for had already or were in process of getting their systems operational again in spring 2021.

DISCUSSION

New technologies typically go through a process called "diffusion" [32] including the following stages: 1. "innovation" (initial research and development), 2. use by "early adopters" and 3, then progressively more people become engaged as the technology matures [33]. Currently, aquaponics (and to some degree family scale hydroponics) is in the innovation and early adopter stages in most of the world, but the potential of these technologies to contribute to food security is being widely reported (e.g., [34- 36]).

The infrastructure in Nepal's metropolitan areas in 2021 was adequate for success with soilless technologies in that reliability of grid electricity had much improved over the past few years. Disruptions due to Covid notwithstanding, needed supplies and equipment were becoming more widely available than previously and a few new commercial companies were offering systems and technical support particularly for family scale aquaponic and hydroponic systems. The recent trend of increasing interest in aquaponics in Nepal is similar elsewhere in the world (Table 7).

Based on our inventory of current soilless systems, there seemed to be a preference, particularly at the family scale, for aquaponics over hydroponics, suggesting an interest in having the fish component as a source of animal protein. Nevertheless, this may be partially a function of aquaponics starting in Nepal a few years before hydroponics and getting more publicity initially (newspaper articles, TV news, social media). Currently, three of the four largest soilless growing systems in Nepal are hydroponics systems.

Like in Nepal, the primary purposes for most aquaponics systems elsewhere were not for commercial production but frequently for families to enjoy growing some of their own food [11]. The survey of aquaponics systems in Europe was an exception in that most of the units there were for research and/or education, at least in part because of highly regulated food production there [27].

A challenge of soilless systems in comparisons with soil-based growing is the need to have some knowledge of technology (e.g., water circulation), water chemistry and, for aquaponics, both fish and plant systems. Readily available, affordable training in the Nepal context would help to encourage the advancement of soilless growing and improve the operation of existing systems. A similar situation occurs in South Africa [28] which is in a similar stage of development of soilless growing as Nepal.

Roofs were chosen for building aquaponics (and probably hydroponics) more frequently in Nepal and Bangladesh compared to South Africa, Europe and the North America (Table 7). Flat, accessible roofs were much more common in Nepal and Bangladesh than in the other locations and they provide a substantial potential for future food production [4, 32] and environmental benefits from plants [6, 33].

We were only aware of one aquaponics system and one demonstration hydroponics system inside buildings in Nepal, much less common than in other areas for which surveys were available (Table 7). Nevertheless, the proportion of aquaponics systems in greenhouses in Nepal was like other areas, except in Europe where this practice was much more common. The types of greenhouses used in various parts of the world, where surveys were available, varied from bamboo frames covered with sheet plastic, like most of those seen in our surveys in Nepal, to temperature and humidity-controlled systems like many in Europe and the United States.

Like in Nepal, media grow beds were the most frequently used types in aquaponics in most surveyed areas (Table 7), but deep-water culture beds were a little more frequent in Europe. The emphasis on research for potential commercial application vs smaller home systems elsewhere explains the difference, since DWC are used more often in commercial systems [17].

Water circulation was frequently intermittent in soilless systems in Nepal. This has the advantage of saving on electricity and pump wear. Maucieri *et al.* [34] reviewed studies of effects of flow on plant and fish production (e.g. [35, 36]) and they conclude it is more beneficial to pump water continuously for about 12 hours and then have pumps off for about 12 hours rather than pumping only partial hours.

Although tilapia was used frequently in aquaponics systems in Nepal, as they are elsewhere (Table 8), common carp was by far the species most often used in Nepal. This is because this species and other carps can withstand warm temperatures in summer and cold temperatures in winter. Without heating the water, which few aquaponics operators in Nepal do, tilapia is frequently not able to survive the lower winter temperatures in the mid-hills, although they survived in the Terai where winter temperatures are milder.

The diversity of plants grown in soilless systems in Nepal was like other areas. Lettuce and other leafy greens, tomato and herbs were particularly common (Table 8). Mustard green and coriander were more commonly grown in Nepal than elsewhere (Table 8). As indicated above, the diversity was higher in aquaponics than hydroponics in Nepal, probably because media beds were used for many species and this type of grow bed was not used in hydroponics in Nepal.

In hydroponics, characteristics of source water are especially important because chemicals are added to the water according to recipes based on the type of plants being grown. Since source water mixed with appropriate chemicals is added regularly, knowing which nutrients are already in the source water is crucial [42]. As indicated above, samples of source water we measured in the Kathmandu Valley indicated pH typically near or over 8, the lower readings of pH all being outside the Kathmandu Valley (Fig. 5). This contrasts with the findings of Pant [43] and Bhandari *et al*. [44] who found wells in the valley had water with an average pH of near 7.0. Most aquaponics operators were running their systems at pH near or over 8 because they indicated they could not keep it down, as they used acid to temporarily reduce it. Source water seemed to be part of the reason for relatively high pH, but another contributing factor was that most aquaponics operators had media grow beds with local gravel which apparently has high limestone content [45]. This probably raised the pH in these systems. There are several potential problems with pH values routinely over

8 in aquaponics. A higher proportion of ammonia nitrogen is progressively expressed as the toxic form NH_3 as pH increases above 7 [46] and at pH higher than 8, several plant nutrients become less available including nitrogen, phosphorus, iron and some of the trace elements (see Lennard and Goddek [16] for a discussion of pH in aquaponics). Nevertheless, Villaverde *et al*. [47] found that nitrification increases with an increase in pH and Maucieri *et al.* [48] who showed that pH of 8.5 in their research system, detected no problems with nutrients. Hydroponics users were able to add chemicals within the nutrient mix to lower their pH to recommended levels to try to maximize nutrient uptake of plants (5.5 to 6.5, [49]).

Typically, iron must be added to aquaponics systems, particularly those growing plants that require relatively high concentrations, because iron is typically not in fish food. Iron is relatively high in ground water in the Kathmandu Valley, but since aquaponics is an aerobic method, the iron is oxidized to a ferric form which is not bioavailable to plants [38].

Insect pests encountered by soilless operators in Nepal were not unique. In fact, the four main types are among the most common elsewhere in greenhouses [50]. As indicated above, soilless operators in Nepal used similar "organic" control approaches as are used elsewhere [15]. These "natural" approaches were used in aquaponics because of the sensitivity of micro-organisms and fish to chemical pesticides and hydroponics operators typically wanted to produce "organic" food.

Live fish for aquaponics are more regularly available in the Terai region of Nepal (where most fish farming occurs [51]) than in the mid-hills where it is often difficult to get healthy fry according to the operators we interviewed. Government production facilities in Pokhara and Kathmandu Valleys have fry, particularly carp fry, for sale for a limited time in spring. Otherwise, operators had to make their own arrangements to transport or pay for transport of fish from sources, usually from a great distance (e.g., from the Terai to the Kathmandu Valley), often without appropriate methods to insure maximum survival (e.g., [52]). Alternatively, live fish, usually carp, are sold at a few shops where are being sold for food. These fish are generally large and have been transported for at least several hours typically without supplement oxygen in the water. They are likely to be stressed from transport and from ammonia build up in the water where they reside until they are harvested. Therefore, according to our interviews, many of these fish die after aquaponics operators introduce them to their systems. Methods of transporting live fish from distant sources using oxygen infused containers needs to be improved to assist aquaponics operators in urban areas.

CONCLUSIONS

Many of the early adopters of aquaponics and hydroponics in Nepal have been operating their systems for less than 5 years, but this group is demonstrating that soilless growing can work in an urban Nepalese context, particularly at the family scale. Currently, most owners are building their own home system, but several companies are beginning to sell small units in Kathmandu indicating increasing popularity of soilless growing. There are currently only a few relatively large commercial soilless farms and as has been noted in other parts of the world, the key to their success will be the capacity to sell vegetables at premium retail prices. As indicated, research into various aspects of soilless methods has increased substantially of late and it seems likely that improvement in understanding of operations and design will improve efficiencies. The interest in sustainable, environmentally friendly, locally grown and healthy food systems is growing globally as publicity expands about the future need to feed more people with less fertile farmland, water shortages in many places and the uncertainties associated with climate change. Nepal still has a lot of arable land, despite a shortage of farming labour, but agriculture land near cities is disappearing rapidly. The interest of municipalities in promoting roof top gardening indicates a desire to promote family food production in the cities.

Constraints to expansion of soilless growing currently include initial cost compared to soil-based growing, training for new operators and availability of technical assistance when needed. Research to evaluate optimum approaches for Nepal (e.g., which combinations of fish and plants work best, cost and benefit analyses) also would be helpful. One area where soilless growing is expanding elsewhere in the world is in schools and the few schools who have systems in Nepal seemed to be incredibly positive on their benefits for teaching science.

Though soilless growing is just beginning in Nepal, it could potentially become an important contributor to food systems at least in urban areas. The enthusiasm of current operators and the potential of soilless growing to provide unique opportunities for production of healthy food and positive experiences for their owners suggest soilless growing will continue to increase in Nepal. Finally, considering many of the advantages of soilless growing, this could be beneficial in urban Nepal.

ACKNOWLEDGMENTS

We are grateful to all the aquaponics system owners in Nepal who shared information with us for this publication. Our advisors at Kathmandu University (Dr. Bibhuti Ranjan Jha and Dr. Smriti Gurung) and at the University of the Nations (Dr. Derek Chignell) directed our work with helpful suggestions throughout.

The study was supported by financial assistance from NORHED SUNREM Nepal Project.

Disclosure Statement: The authors declare that the research was done without potential conflict of interest.

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