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1 Introduction

Climate change is challenging agricultural production worldwide (IPCC 2019). Vegetable production is no exception, and many climatic trends or extreme events (e.g. heat waves, droughts, excessive rains, change of seasonal patterns) threaten both productivity and quality (Gruda, Bisbis, and Tanny 2019; Mehdi Benyoussef Bisbis, Gruda, and Blanke 2018; Kumari, Verma, and Shweta 2018; Ayyogari, Sidhya, and Pandit 2014; Scheelbeek et al. 2018). This calls for support for the adaptive capacity of farmers, defined as the ability to cope with climate change, including climate variability and extremes, in order to reduce potential damage, take advantage of emerging opportunities, and/or cope with the consequences (IPCC 2001). Various literature reviews have been carried out based on studies on physiology, genetics or agronomy, focused on the behaviour of vegetables in constraining climatic conditions, and the impacts of climatic factors on yield and quality. Potential adaptation strategies and research priorities are drawn from these reviews (Mehdi B. Bisbis, Gruda, and Blanke 2019; Gruda, Bisbis, and Tanny 2019; Kapur 2013; Singh 2013; Koundinya et al. 2017). Many studies relying on laboratory or field experimentation have analytically explored management options to adapt a given vegetable crop (e.g. tomato, melon, lettuce) to specific climatic parameters or stresses (Arbel, Barak, and Shklyar 2003; Badr et al. 2010; Altunlu and Gul 2012; Kumar et al. 2006; Albacete et al. 2014; Hamedi, Soltani, and Alabboud 2022; Maraseni, Mushtaq, and Reardon-Smith 2012; de Cantuário et al. 2021). Other studies have used models to simulate the capacity of various strategies to support adaptation to climate change (Deligios et al. 2021; Di Bene et al. 2022). Experimental, modelling or single-factor approaches to specific vegetables are key academic contributions to adaptation. However, literature reviews highlight the necessity to combine different adaptation strategies at the farm level (Mehdi B. Bisbis, Gruda, and Blanke 2019; Gruda, Bisbis, and Tanny 2019; Kapur 2013; Singh 2013; Koundinya et al. 2017). In line with the Farming Systems Research field, we assume that supporting the (re)design of vegetable farms to adapt to climate change requires systemic and comprehensive approaches that take on board farmers' perceptions, objectives and specific socio-technical context (Darnhofer, Gibbon, and Dedieu 2012).

Some studies that draw on semi-structured interviews with vegetable farmers have described a wide range of farming strategies to adapt to climate change, and have investigated how socio-economic and structural factors impact farmers' adaptive capacities. They have been carried out in countries of the South where climate change has been on the research agenda for much longer (Arimi 2021; Asadu, Ozioko, and Dimelu 2018; Chepkoech et al. 2020; Tekuni Nakuja 2012; Gunathilaka and Samarakoon 2022; Irham et al. 2022). To our knowledge, no similar study has been undertaken in industrialized countries with temperate climates, such as Europe. Our exploratory study is a contribution to fill this knowledge gap. Our research objectives were to answer the following questions: (i) How do vegetable farmers perceive climate change and its impacts on farms? (ii) What adaptation strategies have they already developed to adapt to climate change? (iii) What are their adaptation perspectives for the future? And (iv) to what extent can adaptation strategies and perspectives be related to farmers' profiles?

Our analysis is based on semi-structured interviews in the Paris city-region, France, with 17 organic farmers belonging to the regional organic farmers' association[1], which has recently noticed growing concern about climate change in its network. Further research perspectives to support vegetable farmers' adaptation to climate change are discussed at the end of this paper.

2 Cases and methods

2.1 Context of organic vegetable production in the Paris city-region

In studies focusing on the transition of food systems and adaptation to climate change, the city-region, which includes urban, peri-urban and rural areas around a city, is increasingly presented as a relevant scale of planning and governance (Vaarst et al. 2018; Specht, Bohn, and Simón-Rojo 2022). We focus here on the Paris city-region, understood as the administrative regional entity called "Ile-de-France" where an "agricultural pact" has been promoted by the regional government to support more diversified, local production systems able to meet the challenges of climate change (Conseil régional IDF 2018). Nearly half (47%) of the Parisian region is dedicated to agriculture, which accounts for 562,220 hectares of Utilised Agricultural area (UAA), with a largely predominant share of arable crops (DRIAAF Ile-de-France 2019) and only 4,500 ha of vegetable crops (DRIAAF Ile-de-France 2019). Driven by a growing consumer demand and by environmental and societal health concerns (Terre de Liens 2011; Conseil régional IDF 2018), the organic UAA increased by 234% from 2010 to 2019 (GAB IdF 2020), reaching around 4% of the regional UAA (DRIAAF Ile-de-France 2019). Within the regional organic sector, vegetables play a central role although they account for only 5.1% of organic UAA. In 2019, around 25% of vegetable acreages were organic (GAB IdF 2020; DRIAAF Ile-de-France 2019) and 34% of organic farms produce vegetables as their main production (GAB IdF 2020). Market gardens, defined as field or sheltered diversified fresh vegetable production systems, are one of the main types of organic vegetable farms. They account for 95% of the 150 organic farms with vegetable as main production, covering 535 ha in 2020. This can be explained by a growing dynamic of new farming entrants who have set up organic small-scale market gardens over the last 10 years (GAB IdF 2020). While the development of local organic vegetable production is meeting societal expectations, the organic farmers' association of the Parisian Region (Groupement des Agriculteurs Bio d'Ile-de-France[2]) has recently noticed a growing concern about climate change in its vegetable farmers' network. This is why this association funded and co-supervised this study to deepen the understanding of how farmers perceive and adapt to climate change, and what their perspectives are, with a view to support them more effectively in the future.

2.2 Carrying out semi-structured interviews on a selection of farms

[1] https://www.bioiledefrance.fr/ [assessed 28 February 2022]
[2] https://www.bioiledefrance.fr/ [assessed 28 February 2022]

As our study aimed at exploring perceptions and adaptation strategies from a qualitative point of view, we selected farms through "theoretical sampling" (Eisenhardt 1989; Siggelkow 2007), to cover a wide diversity of contrasting farms rather than ensuring statistical representativeness.

Our farm selection relied on 7 criteria inspired by the scientific and grey literature (Morel and Léger 2016; Navarrete 2009; Pépin, Morel, and van der Werf 2021; Drouet, Réseau AMAP Ile-de-France, and Les Champs des Possibles 2020; Chambre d'agriculture de Région Ile-de-France 2019), to characterize farm structure and farmers' profiles (**Table 1**): UAA of organic vegetable production; total farm UAA; production other than vegetables; gender; age of farm; age of farmers; marketing channels.

Based on these criteria, we preselected a first set of 27 different types of farm within the network of the regional organic farmers' association. Only 17 farmers agreed to take part in the survey.

In line with our exploratory objectives, we carried out semi-structured interviews with vegetable growers, which took place on their farm (in the case of 16 farms) and by phone (one farm). The main topics to discuss were organized in an interview framework (Olivier de Sardan 2008; Beaud and Weber 2010) with 4 main pillars: (i) context and history of the farm, farming practices and markets; (ii) perceptions of climate change and its impacts on the farm; (iii) adaptation strategies implemented; (iv) perspectives, needs and priorities to adapt to climate change in the future. Questions were asked as spontaneously as possible in response to farmers' answers, to ensure an informal communication mode creating quality interaction between farmers and researchers (Olivier de Sardan 2008; Beaud and Weber 2010). Interviews were conducted in line with the European General Data Protection Regulation. Farmers were provided with a document explaining the context and objectives of the study, informing them about data management and their rights regarding their personal data. After growers had provided their written consent, interviews lasted from 1 to 3 hours and were recorded. The written transcription of these recordings was the material of our analysis.

2.3 Analysis of collected material

We carried out a qualitative analysis of the interview material with the NVivo software (released in March 2020), using thematic coding and matrix tools (Miles and Huberman 1984; Elo and Kyngäs 2008). Thematic codes were generated on the basis of an iterative cross-analysis of interview content from the multiple cases (Eisenhardt 1989; Yin 2009). To analyse the relative importance of one given topic across cases, we counted the number of farms with the associated code. We explored the correlations between adaptation strategies using a Multiple Correspondence Analysis (MCA) with the following R-packages (R version 4.0.2): FactoMineR (Lê, Josse, and Husson 2008; Husson et al. 2013) and Factoextra (Kassambara and Mundt 2017). To investigate links between farmers' profiles and adaptation strategies, farm characteristics described in **Table 1** were integrated in the MCA as supplementary variables. For this analysis, we did not consider the variables "Marketing channel" and "Gender" as their modalities were not well balanced across cases. To characterize the UAA of vegetable production, we identified two modalities to differentiate between farming structures (level of mechanization and specialization) based on the grey literature (see 2.2): <5 ha (10 farms) and >= 5 ha (7 farms). In our analysis, we examined the first two dimensions (pillars 1 to 2) of the MCA, explaining 33.1% of total variance (**S1**). We considered only the supplementary variables and adaptation strategies that were the most closely linked to the pillars using the dimdesc function of the FactoMineR package with a significance threshold of 10% (**Figure 1**).

Table 1: description of the 17 organic vegetable farms studied

Farm	UAA of organic vegetable production (ha)	Total UAA (ha)*	Other productions**	Gender	Farm creation (yr)	Age of farmer (yr)	Marketing channel***
1	1	[0.5-5[	No	M	[0-5[	[40-50[	Direct
2	10	>=100ha	Field crops	M	>=15	[50-60[	Direct; Short
3	0,5	[0.5-5[	Fruit trees	M	[0-5[	[50-60[	Direct
4	2	>=100ha	Field crops (including conventional); Fruit trees	F	[10-15[	[30-40[	Direct
5	8	[20-100[	No	M	[0-5[	[40-50[	Direct; Short
6	2	[0.5-5[	Fruit trees - Medicinal and aromatic plants	M	[5-10[	[30-40[	Direct
7	4	[0.5-5[	Fruit trees	M	[5-10[	[30-40[	Direct; Short
8	2,2	[0.5-5[	Poultry; Fruit trees	M	[0-5[	[40-50[	Direct
9	12	[20-100[	Conventional field crops	F	>=15	[40-50[	Direct
10	5	[5-20[	Poultry	M	[5-10[	[30-40[	Direct
11	4,5	>=100ha	Conventional field crops	M	>=15	[50-60[	Direct
12	2,5	[0.5-5[	No	M	[5-10[	[30-40[	Direct
13	2	[0.5-5[	Fruit trees	M	>=15	[50-60[	Direct
14	10	>=100ha	Field crops	M	[10-15[	[30-40[	Direct; Short
15	10	[5-20[	No	M	>=15	[40-50[	Short; Long
16	7,5	[20-100[	Field crops	M	>=15	[50-60[	Direct
17	3	[0.5-5[	Fruit trees	M	[10-15[	[40-50[	Direct

*Including all conventional and organic production on the farm. **If not specified, other productions are organic. ***Direct: community-supported agriculture, on-farm selling, open air markets; Short: retail selling in local stores, local supermarkets, institutional catering, cooperatives, restaurants; Long: wholesalers, central purchasing bodies. For total UAA, age of farms and farmers, we indicate wide categories to keep farms anonymous.

3 Results and interpretation

Farmers' quotes are in quotation marks, followed by "F" and the farm code in brackets.

3.1 Farmers' perception of the evolution of extreme climatic events and seasonal patterns

Farmers' perceive climate change in terms of changes relating to extreme events and seasonal patterns (**Table 2**). Extreme events are characterized by their absence of regularity: droughts, heats waves, excessive rains and extreme winds can happen in the same year. Some farmers say that it is therefore more relevant to describe what they experience as "climate deregulation" (F9) with "accidents" (F4) rather than "climate change". More intense, frequent and longer droughts and heat waves are the main preoccupation of vegetable growers. Excessive rains are also perceived to happen more frequently, last longer and to cause floods. More extreme wind events, e.g. above 100km/h (F1) happen more often and can damage tunnels.

Seasonal patterns refer to climatic factors characterizing seasons (average temperatures, occurrence of frost, rain distribution), which farmers perceive as changing but which are not considered as extreme events. In this regard, the phenomenon that most farmers mention relates to frost patterns. They have found that the frequency and intensity of frost are decreasing in winter, whereas late frost in spring can still occur. This is detrimental to crops, especially as spring temperatures (in February and March) can be higher, allowing farmers to start planting and sowing earlier. Farmers have also noted more rainfall in winter, although this rain does not directly benefit vegetables but does contribute to refilling water reserves. They have also recorded less rain in summer and autumn. Four farmers mentioned that winters and autumns are getting warmer.

3.2 Farmers' perception of impacts of climate change on the farm

Climate change is perceived by farmers as having direct impacts on vegetables and therefore also on farm management and economics (**Table 3**). Most impacts mentioned are negative but some positive impacts were also highlighted.

3.2.1 Negative impacts on vegetables

The most frequently mentioned impact is the increased pressure of arthropods on vegetables, due to higher temperatures, dryer conditions, and less frost in winter to regulate pest population. The increase of Flea beetle (gender *Phyllotreta*] is the main issue, mentioned by 13 farms, as its population is developing faster and earlier, causing substantial damage to Brassicacae vegetables. More pressure from aphids (e.g. *Aphidius colemani)* and *Tetranychus urticae* is also observed. High temperatures allow new pests to emerge, such as *Tuta absoluta* on tomatoes, which historically used to be present in southern France.

High temperatures over a long period cause metabolic disorders on vegetables, for example, plants going to seed in spring due to higher temperatures, flower abortion, poor fecundation due to lower activity of natural pollinators with higher temperatures. Heat waves also stop the growing of plants. After such events, plants may need a week to recover. All these factors can result in yield losses. Extremely high temperatures, even if they are occasional, can burn and damage vegetables, which can decrease production quality. As mentioned above, late frost after warm temperatures in spring impacts vegetables detrimentally (see 3.1.2). So far, none of the farmers in our ample have stopped growing a crop due to climatic constraints. However, some farmers say that they may do so in the future, e.g. no longer growing cabbages (2 farmers) due to increased flea beetle pressure, or lettuces in summer, given their large need for water and poor resistance to high temperatures (2 farmers).

Table 2: Farmers' perception of climate change (ordered and coloured by number of farmers mentioning them)

	Description	Nb of farms	Farmers' typical statements
Extreme events	**Droughts** are getting more frequent and/or longer especially in summer.	16	We sometimes have up to 5 months without rain (F16). // We've had summer droughts for 4 consecutive summers (F5). // We have to irrigate more (F14, F12).
	Heat waves are more frequent and/or longer.	9	Now we have heat waves almost every year and they're longer (F12). // Recently, we had heat waves for three consecutive years. This did not happen in the past (F10).
	Excessive rains have been observed (especially in spring), causing floods.	7	In 2016, we got so much rain in late May and June that crops were damaged and soils asphyxiated (F11).
	Droughts and heat waves occur simultaneously, which is very challenging.	5	For 2 consecutive years, we had droughts with perceived temperatures of 45°C, it's crazy (F1).
	Extreme winds and storms occur more often and are stronger.	5	We get much more wind than before, now wind has gone crazy (F16).
Seasonal patterns	There is **less frost** in winter (which is favourable to diseases and pests) but still **unpredictable late frost** in spring.	10	With less frost in winter, pests are getting worse, they come earlier in seasons (F10). // Now we don't know what spring will look like (F15).
	Rain patterns are changing. In particular, there is more rain in winter (when few crops are growing) and less in summer.	8	In winter, we have a lot of rain which is not useful because we can't water plants with it (F5). // Rains doesn't fall anymore in the same periods as before (F13).
	Spring temperatures are more variable within the year (e.g very early warm temperatures in spring followed by frost) and between years.	5	We used to have stable springs, we knew, with some rare exceptions, what spring was supposed to look like. But since 2006-2007, we don't know what to do in spring; it can be very warm or not, or very warm at the beginning and then frost comes (F15). // It's very freaky when warm temperatures occur when the period with frost risk is not over (F3).
	Autumns and winters are getting warmer (less very low temperatures, less snow, higher average temperatures).	4	There's no more winter (F1, F5). // Frost happen later in autumn so we can leave crops longer in the soil (F10). // Warmer autumns now allow us to get nice harvests of cabbages, turnips and radishes (F2).

3.2.2 Negative impacts on farm management

The main impact of climate change on farm management that was mentioned relates to labour. Climate change leads to more labour requirements, for example for watering during droughts, tillage of dry soils, setting up physical protection against pests, shade paints and cloths. Climatic constraints also prevent some technical actions. For instance, it is impossible to sow in muddy soil in a wet spring, and difficult to spread manure or destroy cover crops in winter, which used to be done in frost periods to reduce damage on the soil. High temperatures and droughts can also make labour conditions harder: “plants don’t like to work in heat waves, and nor do farmers” (F7). The fact that climate has become more uncertain, more variable between and within years, and less predictable, makes planning and commercialization more difficult. This is a real challenge as planning is already complex for diversified vegetable systems marketing through short supply chains. Avoiding extreme events can lead to shortened harvest periods, causing problems which are particularly challenging for selling products with a short shelf life: “if we get a heat wave, I can take the decision to harvest all my lettuces in one go before they get affected too much, but I then have 72 hours to get rid of 1300 lettuces” (F12).

3.2.3 Negative impacts on farm economics

Negative impacts on vegetables (pest pressure, metabolic disorders, burns, frost) can decrease both the quantity and the quality of harvests, and therefore reduce sales. The necessity to harvest and sell many vegetables in a single week to adapt to heat waves (for example lettuces as previously mentioned), while other farmers are doing the same thing, can also reduce selling prices. Increases in labour needs and investments in equipment (e.g. for irrigation, pest management) contribute to higher production costs. Altogether, these factors reduce farm profitability.

3.2.4 Positive impacts on vegetables, management and economics

Warmer temperatures can allow farmers to grow outside crops which used to be grown in tunnels, especially melons and tomatoes. Warmer temperatures also allow them to extend the growing period and increase productivity in autumn, e.g. for cabbages, turnips, radishes, beans. Dry conditions in summer can make weed management easier, if access to water is guaranteed for crops, while inhibiting weed growth. Dry summers can also enhance the taste of vegetables while increasing sugar content and dry matter. One farmer also mentioned that less frost in winter makes it easier to let root vegetables, especially carrots, be stored in the ground, resulting in fewer losses in the storage phase. These positive impacts on vegetable production and management could contribute to improving profitability. Most impacts mentioned by farmers are however negative and no farmer argued that positive impacts were enough to offset negative ones.

Table 3: Impacts of climate change on farming activities (ordered and coloured by number of farmers mentioning them)

Impact on		Description of impacts	Nb of farms	Typical farmers' quotes
Vegetables	-	Increased **pressure of arthropods** on vegetables.	15	Because of less frost in winter, insects arrive earlier and stay longer (F12). // Some insects love high temperatures (F2).
Management	-	Climate change leads to **more labour** requirements, precludes certain technical procedures or makes **labour conditions harder**.	13	In summer, when it gets too dry, I will have to hire a worker only for watering (F15). // With too much rain, I can't work (F2). // Working during heat waves is exhausting (F4). // Without true winter frost periods I can't go into the field to spread horse manure or to destroy green manure without damaging the soil (F5). // During heat waves and droughts, we're constantly watering and moving irrigation lines" (F14).
Vegetables	-	High temperatures over a long period cause **metabolic disorders** in vegetables, which results in losses of production.	10	During heat waves, vegetables simply stop growing (F17). // During heat waves, tomato harvests are reduced by two thirds (F9).
Vegetables	-	Extreme high temperatures (even for a short period) can **burn and damage vegetables**.	9	The tomatoes and sweet peppers have got sun burn (F10). // Lettuces don't like it when it's too hot, at the end of summer their quality is poor (F6).
Management	-	The climate has become **more uncertain and less predictable**. There is more variability between and within years, which makes planning and marketing more difficult.	7	We've had extreme events, the climate is more and more chaotic, there are no more norms or seasonal regularities. How can one adapt sowing planning to that? (F5). // Last year at that time of the year I had too many radishes compared to what I could sell and this year I haven't harvested any yet (F11) .
Vegetables	-	Late frost (after warm temperatures) **damages spring vegetables**.	5	Once French beans have got frost, it's over (F11).
Vegetables	+	Warmer temperatures allow farmers to grow **tunnel crops outside**.	5	Now we can grow melons outside (F14).
Vegetables	+	Warmer temperatures allow farmers to **lengthen the growing period and increase productivity in autumn.**	3	Later frost in autumn allow us to grow squashes outside till late October (F2). // We're now able to extend the harvest period of leafy vegetables to one month in winter, which is a real advantage (F9).
Management	+	Less rain in summer makes **weed management easier**.	2	Dry conditions in summer limit the growth of weeds, which is an advantage, if you can irrigate your crops of course (F10).
Vegetables	+	Less rain in summer makes some **vegetables tastier**.	2	With less water, we get some vegetables with more taste and dry matter (F13). // Melons and squashes get sweeter, they're very good (F7).
Vegetables	+	Less frost allows farmers to **store root vegetables in the ground** more easily in winter.	1	I used to harvest carrots in December. Now, as we get less extreme frost, I leave them to be stored in the ground with a wintering vail. It reduces storage losses by 60-70% (F2).

(+) positive impact; (-) negative impact. Most of impacts on vegetables and management have **economic consequences** described in the body of the text.

3.3 Farming strategies already implemented to adapt to climate change

3.3.1 Description of strategies

Adaptation strategies that farmers are already implementing are presented in **Table 5.**

Beyond farming practices, economic and marketing strategies are mentioned. Community Supported Agriculture (CSA) box schemes are perceived as a means to support farmers, for various reasons. First, customers have a contract (often yearly) with farmers, and in many cases they pay vegetable boxes in advance, which helps farmers to secure income despite climatic extremes. Secondly, CSA is based on a solidarity principle and customers are committed in accepting harvest variations. Third, CSA allows farmers to have direct interactions with customers, which enables them to explain the climatic challenges they face (pedagogy and transparency) and makes their potential harvest variations more acceptable.

Farms that are economically stable and robust are more equipped to deal with losses and variability linked to climatic variability, as well as covering increased production costs. For farmers, securing farm profitability also facilitates on-farm trials and the exploration of adaptation alternatives that can entail an economic risk. Adapting to climate change could also require better identification of the available resources (e.g. water) in the future, and the development of business models in line with these resources: “now the question is not to say, ok, I want to produce that much and so I need to irrigate and invest as much as needed, but rather to say, at a given period I have the capacity to access 7m^3 of water per hour and use it 10 hours a day, what can I grow with that?” (F3).

3.3.2 Climate change as a new parameter to integrate in farmers’ multidimensional decision making

This paper presents the strategies that farmers say allow them to adapt to climate change. However, they insist on the fact that most of the time, their decision to adopt a given strategy is linked to multiple considerations and objectives, and not only a reaction to climate change. For example, although planting trees and hedges is presented as an adaptation, farmers argue that this decision aims also to diversify production with fruits that match consumers’ demand (10), enhance biodiversity (8), create a pleasant landscape, and improve labour conditions (4). Similarly, diversifying production or being involved in a CSA box-scheme aims above all at fulfilling commercial or labour or social objectives. Cover crops also aim at improving the chemical, physical and biological characteristics of the soil’s fertility. Climate change has therefore to be considered as a new parameter to integrate, in addition to other numerous dimensions of farmers’ decisions.

3.3.3 Some farmers relativize the negative impacts of climate change or see opportunities

Some farmers (9) mention that it has always been necessary to adapt to climatic conditions and that vegetable growers have always integrated uncertainty and made their practices evolve. In this regard, they express doubts that adapting to climate change may be more challenging in the future. Others (9) argue that climate change can also bring opportunities (see positive impacts in 3.2). The positive effects are linked to warmer climatic trends to which farmers can adapt. The farmers who are perceiving advantages in those trends mention that they are nevertheless worried about extreme climate-related events. Although they react to climatic variations and extreme events, 8 farmers consider that climate change has not led to a deep and systematic redesign of their practices so far. This can be explained by the fact they still feel uncertain or that they do not yet have enough hindsight about the contrasting impacts of climate change. Some of them also deem that until now the negative impacts can be addressed mainly by incremental change or tactical adaptation during the season.

Table 4: Strategies implemented to adapt to climate change (ordered and coloured by number of farmers mentioning them)

Coding in MCA	Description	Nb of farms
Div_AD	**Diversify production** (fruit, new vegetables favoured by warmer climate) to spread risks and uncertainties.	13
Trees_AD*	**Plant trees and shrubs** (in hedges or agroforesty systems) to break winds and create microclimates, limit evaporation, buffer temperature variations, create shade.	13
Irrigation_AD*	**Implement more efficient irrigation systems** to adapt or mitigate the effects of heat waves and droughts: (i) employ precision irrigation equipment such as drip irrigation or soaker hoses; (ii) catch water in tanks to avoid pumping up groundwater; collect water from the roofs of buildings and tunnels.	11
Varieties_AD*	Use **varieties** which are more adapted to new climatic conditions (more resistant to droughts, high temperatures or going less to seed in warm spring). Some farmers (8) choose to reproduce their own seeds (only for some vegetables) on farm, based on heritage varieties, to adapt them to local conditions.	11
Cover_crops_AD	Grow **cover crops** to protect soils from erosion linked to extreme climatic conditions (strong rains, wind). Only 2 farmers mention that cover crops help to keep water in the soil and can be a way of mitigating drought.	11
Physical_protection_AD*	Use **physical protection** (nets and veils against pests), especially against flea beetles.	10
Always*	Consider that climate has always changed, and vegetable farmers have always adapted.	9
Positive*	Enjoy opportunities of climate change, e.g. extend growing period or grow tunnel crops outside.	9
Equipment_AD	Use **equipment** to control or mitigate climatic conditions, e.g. use shade paints on tunnels or shade cloths. Also choose adapted types of tunnels (4), e.g. double tunnels to ease air circulation, bigger tunnels with more temperature inertia, tunnels with lateral ventilation or with light-diffusing plastic (to buffer peak temperatures). Some farmers argue that climatic conditions, irrigation and shading are easier to manage in tunnels (3) and that adaptation to climate change will rely on an increased acreage of tunnels.	8
Planning_AD*	**Adapt crop planning** while delaying or advancing some crops. Doing so implies the need to find marketing outlets for products that come earlier or later in the season.	8
No_modif	Have not deeply modified their practices yet.	8
CSA_AD*	Mention that **CSA box schemes** can support farmers facing climate change.	6
Mulching_AD	Use organic (5) or plastic (5) **mulching** to keep water in the soil and reduce soil temperatures. Mulching cannot be used with crops that are sown (e.g. carrots). However, using straw can attract rodents or slugs, be a source of weeds, and increase labour. Plastic is perceived as a source of negative environmental impacts (energy consumption, presence of plastic particles in ecosystems).	6
Eco_AD	Consider that **securing farm income** and economic management is key to facing climatic extreme events.	4

The second column refers to the variables code used in the MCA (Figure 1). The 14 variables which are assigned the * symbol in the table are the most characteristic of the first two dimensions of MCA (with a significance threshold of 10%, see Figure 1).

3.4 Strategic perspectives for the future

Farmers mainly mention the need to acquire theoretical and practical knowledge to develop farming practices enabling them to better adapt to climate change, as indicated in **Table 5**. They have voiced expectations in terms of training that could be developed by agricultural extension services (9), as well as exchanges of practices between farmers (7), and experimentation (7). Farmers (5) also express the need for collective organization for two purposes: (i) to produce and share farm seeds of vegetable varieties that are adapted to climate change (4), and (ii) to mutualize some purchases, especially shade paints for tunnels (2). Some of them (4) argue that public authorities could support more adaptation to climate change, for example through subsidies and/or obligations to plant hedges and trees that create beneficial microclimates or that store carbon in the soil to enhance water retention.

3.5 Strategies and perspectives according to farmer profile: interpretation of MCA

The dimdesc function of the FactomineR package allowed us to highlight 14 adaptation strategies and 3 supplementary variables that were the most closely linked to the 2 MCA axes (**Figure 1**). We based the interpretation of MCA on interview content, grey literature, and expertise on the local context.

3.5.1 Two stereotypical farmer profiles

From the MCA results, we can distinguish two farmer profiles. On the left side of the graph we find the farms characterized by:

- larger acreage of vegetables (>=5 ha);
- older farmers (40-50 or 50-60 yr);
- older farm creation (>=15 yr).

On the right side of the graph, farms can be described by:

- smaller acreage of vegetables (<5ha);
- younger farmers (30-40 yr);
- recent farm creation (0-5 yr).

These two stereotypes, “larger and older farms” *vs* “smaller and younger farms”, are consistent with the situation of vegetable production in the Parisian region described in the grey literature (Drouet, Réseau AMAP Ile-de-France, and Les Champs des Possibles 2020; Chambre d’agriculture de Région Ile-de-France 2019) and the perception of the experts of the regional organic farmers’ association. This situation stereotypically consists in the coexistence between (i) longstanding vegetable farms generally occupying larger acreage with a higher level of mechanization and (ii) recently created vegetable farms, generally less mechanized, set-up by a generation of new entrants with no agricultural background, choosing organic farming as a meaningful life change and developing their activity on small acreages to reduce investment and overcome the difficulty to access to land (Morel and Léger 2016). Our MCA interpretation therefore focuses on linking adaptation strategies to these two stereotypic profiles which make sense in the local context.

Table 5: Strategic perspectives for adapting to climate change (ordered and coloured by number of farmers mentioning them)

Coding in MCA	Description	Nb of farms
Varieties_PERS*	Find or develop **vegetable cultivars** that are more adapted to climate change. Cultivars that are already used in more constraining climatic environments, for example southern France, could be a starting point, but they must be suitable for local conditions and practices. Five farmers believe that seed companies could play a central role in this adaptation. Only 1 farmer points out that on-farm selection could support adaptation, and wants to be trained on the subject.	8
Farming_PERS	Acquire or develop knowledge and experience to implement **alternative farming practices** such as intercropping (1), growing green manures (3), mulching (1), no-tillage or reduced tillage practices (3) that can help to optimize resource use and retain water in the soil.	7
Soil_PERS	Gain expertise on soil functioning (nutrients and water cycle, soil ecology) and use tools to monitor soil conditions (water and organic matter content, biological activity) to allow a more **holistic approach to soil** that combines various alternative practices and organic amendment.	7
Agroforestry_PERS*	Better characterize benefits and constraints of **agroforestry** and get knowledge on how to design agroforestry systems adapted to vegetable farms in their local context.	6
Physio_PERS*	Develop theorical and practical knowledge on **vegetable physiology** (biological cycles and biophysical requirements at each stage) as a prerequisite to better adapt practices to climate change.	5
Pests_PERS*	Acquire theoretical information on the identification and functioning (biological cycles) of pests and the impact of climatic parameters on them, as well as practical know-how to set-up farming practices to **regulate pest pressures**, e.g. plant decoction, biological control, attracting natural enemies.	5
Planning_PERS*	Acquire knowledge and experience on **adapting crop planning** to climate change: which vegetables to grow in which period of the year? Which vegetables to plant earlier or later? How to combine different sowing/planting periods to ensure climatic resilience?	4
Water_management_PERS	Acquire knowledge on **water resource management** in order to optimize or promote more efficient irrigation methods and practices, to catch and store water more efficiently in winter.	4

The second column refers to variables codes used in the MCA (Figure 1). The 14 variables which are assigned the * symbol in the table are the most characteristic of the 2 first dimensions of MCA (with a significance threshold of 10%, see Figure 1.

3.5.2 *Implemented strategies and relativization of climate change according to farmer profiles*

On larger and older farms, growers tend more to relativize climate change, arguing that they have always been adapting to climatic conditions and that climate change could provide new cropping opportunities ([Always] and [Positive], MCA codes in brackets)**.** Older farmers feel more confident about the fact they will be able to keep their farm going without drastic change, until they retire. On the other hand, younger growers feel more concerned about climate change and fear that it will be a central element to consider in their whole farming carrier. As one of them commented, "I'm a climate change farmer" (F6). Moreover, older farmers have had time to set up an economically robust system and acquire experience. They may feel more confident about their ability to adapt, whereas younger farmers are generally still improving farm organization and profitability and feel more vulnerable.

The only strategy implemented which is related more to older and larger farms is the use of efficient irrigation systems and facilities to catch and store water ([Irrigation_AD]). These farmers see the optimization of water resources above all as way to reduce production costs and increase profitability on larger and more extensive farms that consume more water than small farms. Additionally, as larger and older farms are generally economically more robust, it is easier to invest in water catchment and storing facilities.

The adaptation strategies which tend to be mentioned more on young and small farms are: using physical protection against pests ([Physical_protection_AD]), planting trees and hedges ([Trees_AD]), selling in CSA schemes ([CSA_AD]), and using adapted crop varieties ([Varieties_AD]). Physical protection and planting trees are easier and less expensive to develop on smaller acreages. The strong ecological aspirations of younger farmers make them generally more favourable to integrating trees and agroforestry which can seem unrealistic at a larger scale for older farmers. CSA is a really popular option for younger and smaller farmers as (i) the number of vegetable boxes to produce weekly matches their production capacity, (ii) the CSA philosophy of strong links and commitment between farmers and consumers echo young farmers' social aspirations, (iii) CSA schemes are a means to secure incomes, which can be a real support for setting up a farm. As explained in 3.2.1, most farmers who mention crop varieties refer to multiplication of their own seeds to adapt them to local conditions and climatic constraints. It is not surprising that this strategy is linked to smaller farms, as it is a time-consuming activity which is often deemed too constraining to implement with large production quantities on a large scale. For small growers, on-farm multiplication is also a strategy to limit costs and seek more autonomy.

3.5.3 *Perspectives according to farmer profile*

Interestingly, all strategic perspectives appearing in the MCA (**Figure 1),** relating to agroforestry ([Agroforestry_PERS]), pest management ([Pest_PERS])**,** crop planning ([Planning_PERS]), and water management ([Water_management_PERS]), are linked to younger and smaller farmers, who feel more concerned about their future.

As mentioned above, older farmers with larger farms tend to be sceptical about the possibility of integrating trees on their vegetable farm on a large scale. As they feel more confident in their ability to react to climate change in the remaining time of their career, planting trees, with benefits expected in the medium to long term, is not their priority. Some young growers have already planted trees in hedges and sometimes tested some agroforestry practices ([Trees_AD]). However, the wider development and full integration of agroforestry in farm design still raise many questions (see 3.4).

Young farmers have less experience in organic pest management than do older farmers. This explains why developing pest management strategies is a priority for younger farmers.

Dealing with crop planning complexity in diversified short-supply chain-oriented vegetable systems is a key challenge (Navarrete 2009; Bon et al. 2010; Aubry, Bressoud, and Petit 2011) requiring experience that older farmers have developed. This difficulty is compounded by the fact that younger farmers tend to sell through more different marketing channels (with small volumes of production through each channel) than do older growers who have often stabilized their sales over time with a more limited number of channels (with larger volumes). As climate change uncertainties will increase this complexity (**Table 2**, **Table 3**), this dimension is considered as a strategic priority for younger farmers.

Interviews show that, based on their experience, older farmers tend to have more knowledge about optimizing water use. Their main limitation or concern relates to investment costs and associated labour costs (see 3.2). Younger farmers on the other hand, have expressed the need to acquire knowledge on this aspect, which seems all the more necessary as water availability is perceived as a key to mitigate the negative impacts of climate change.

3.5.4 Adaptation strategies and perspectives not linked to farmer profiles:

The MCA results (**Figure 1)** include three types of strategy which cannot easily be related to farmer profiles: [Planning_AD], [Varieties_PERS] and [Physio_PERS]. Other strategies do not appear in MCA as they are not strongly linked to any pillar (with a level of significance of 10%): [Div_AD], [Cover_crops_AD], [Equipment_AD], [No_modif], [Mulching_AD], [Eco_AD], [Farming_PERS], [Soil_PERS].

None of these variables can be considered to be specifically linked to a farmer profile. This means that adapting crop planning, diversifying production, growing cover crops, mulching, using equipment to mitigate or control climatic conditions, and securing income are strategies which are already implemented both by younger and smaller farmers as well as by older farmers with larger farms. This is not surprising as all these aspects are broadly promoted by national and regional organic agricultural extension and training structures. The fact of not having deeply modified farming practices yet to adapt to climate change ([No_modif]) can be found on both younger and older farms. For older farmers, this can be explained by their confidence in being able to react based on incremental change, as they have always done, till the end of their career. Some younger farmers mention that they do not yet have a clear picture of future changes, and still prefer to get more hindsight both on climatic variation and on potential strategies to implement (need of knowledge).

As far as strategic perspectives are concerned, both younger and older farmers are interested in using or adapting new plant varieties, better considering plant physiology, developing alternative farming practices, and adopting a more holistic approach to soil management. This shows that despite the fact that some farmers relativize climate change impacts (at least that is what they say), and that some priorities are the focus mainly of younger farmers (see section above), all types of profile show the need for further research, development, knowledge exchange and/or training to support adaptation to climate change.

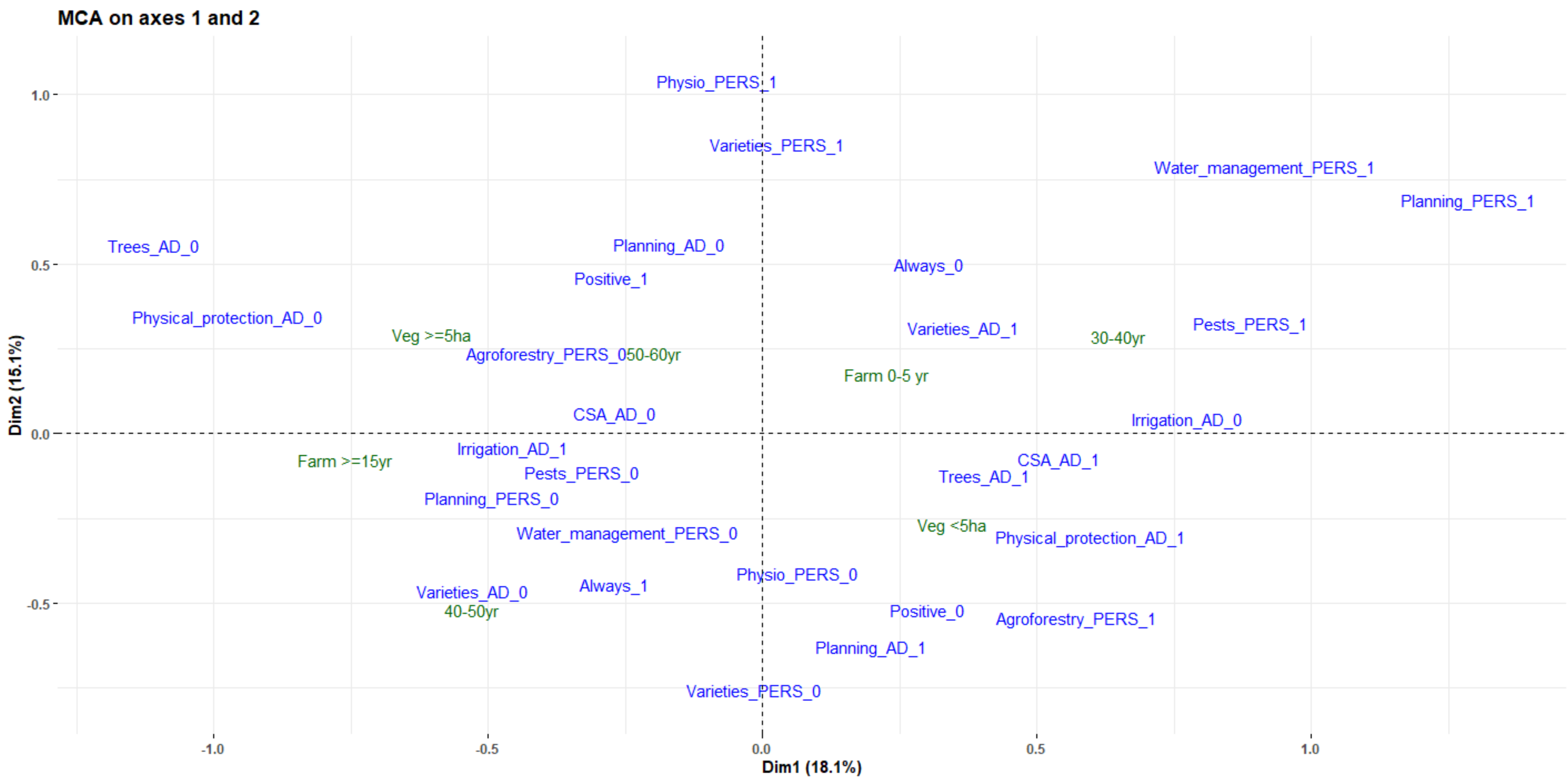

Figure 1. Results of the MCA analysis on the two first pillars for the variables that were most characteristic of the 2 dimensions. The most characteristic variables of the 2 dimensions were found using the dimdesc function of the FactoMineR package with a significance threshold of 10%. The 14 categorical variables related to adaptation strategies that were kept are in blue (N means "No", Y means "Yes") and are presented in Table 5. The 3 supplementary explanatory variables that were kept are in green are: (1) Age of farmers: [30-40yr [, [40-50yr [, [50-60yr]; (2) Utilised agricultural area of diversified organic vegetable production: Veg <5 ha; Veg >=5ha; (3) Age of farm creation: [0-5yr [; [5-15yr [; >=15yr.

4 Discussion

4.1 Methodological limits

The main limit of this exploratory study is the small sample of farmers (17) due to our choice of carrying out long comprehensive qualitative interviews. However, this sample allowed us to reach a "theorical saturation" (Eisenhardt 1989) on most topics of our analysis (**Table 2, Table 3, Table 5**), which means that no new topic appeared when we kept integrating new cases. Compared to other studies on the same topic involving more but shorter interviews with vegetable farmers (Arimi 2021; Asadu, Ozioko, and Dimelu 2018; Chepkoech et al. 2020; Tekuni Nakuja 2012; Irham et al. 2022), longer comprehensive interviews allowed us to (i) distinguish adaptation strategies already implemented and in future perspectives, (ii) detail direct impacts of climate change on vegetables and indirect impacts on farm management and economics, (iii) explore more precisely the arguments of farmers relativizing climate change and highlighting potential opportunities (see 4.2).

To enhance or discuss the genericity of our results, it would be interesting to carry out similar interviews on vegetable farms in other contexts. As this work was funded and co-supervised by the regional organic farmers' association (Groupement des Agriculteurs Bio d'Ile-de-France[3]), we involved only organic farmers. We think that it would be relevant to carry out similar interviews with conventional farmers to explore whether and to what extent their perceptions of climate change and adaptation strategies differ or not (see 4.3).

4.2 A study corroborating and enriching existing literature

Our study shows that in the context of an industrialized country with a temperate climate, farmers' perceptions of climate change (**Table 2**) in terms of seasonal patterns and extreme events are in line with the existing literature in countries of the global South (Tekuni Nakuja 2012; Gunathilaka and Samarakoon 2022; Arimi 2021). The higher frequency and length of droughts was the aspect of climate change that farmers noticed the most. This is consistent with the literature presenting droughts as a major challenge for vegetable production (Abewoy 2018; Keatinge et al. 2014; Mehdi B. Bisbis, Gruda, and Blanke 2019).

Although the general literature on climate change in agriculture usually presents increased variability as a key challenge of climate change (Alemayehu and Bewket 2017; Karki, Burton, and Mackey 2020; Reidsma et al. 2010; Obwocha et al. 2022), few studies based on interviews with vegetable farmers have clearly highlighted this issue (Arimi 2021; Asadu, Ozioko, and Dimelu 2018; Tekuni Nakuja 2012; Irham et al. 2022). Our study has shown that vegetable farmers are specifically concerned with intra- and inter-annual variability of rain patterns, temperatures, and frost occurrence, which result in uncertainties and difficulties in planning crops and selling produce.

Most negative impacts of climate change raised in our study (**Table 3**) also corroborate the findings reported in the existing literature (Arimi 2021; Irham et al. 2022; Ayyogari, Sidhya, and Pandit 2014; Gora et al. 2019; Mehdi B. Bisbis, Gruda, and Blanke 2019; Abewoy 2018). The negative impact that was signalled the most in our investigations was the increased pressure of arthropods, which confirms that in vegetable farming, pest pressure is a major challenge resulting from climate change (Mehdi Benyoussef Bisbis, Gruda, and Blanke 2018; Keatinge et al. 2014; Abewoy 2018). Although general studies on agriculture mention that climate change may stimulate weed growth (Korres et al. 2016), our work corroborates that of authors focused more on vegetable production, and who do not mention specific issues related to weed management (Mehdi B. Bisbis, Gruda, and Blanke 2019; Gruda, Bisbis, and Tanny 2019). Some farmers of our study even mentioned that dry conditions in summer could help managing weeds if irrigation water is available.

[3] https://www.bioiledefrance.fr/ [assessed 28 February 2022]

Some positive impacts of climate change on vegetables underlined by our study have previously been described in the scientific literature, such as the possibility of extending the growing period, allowing tunnel crops to be grown outside, and improved taste (Mehdi Benyoussef Bisbis, Gruda, and Blanke 2018). As far as product quality is concerned, farmers mentioned only higher levels of sugar and dry matter in some conditions. None of the farmers mentioned the content of other macro- or micro-nutrients (Dong et al. 2018), or the fact that an increase of atmospheric CO_2 could benefit yields by stimulating photosynthesis (Korres et al. 2016).

Studies have shown that climate change can raise labour and production costs (Arimi 2021; Tekuni Nakuja 2012) but few details are given. Our work shows that increased labour can be linked to watering during droughts, tillage of dry soils, and setting up physical protection against pests or equipment to provide shade. Whereas studies in countries of the global South have shown access to investment capacity (e.g. access to bank loans) to be a central concern for smallholders to adapt to climate change, this aspect is not mentioned by French farmers. A few of them did nevertheless mention that the impacts of climate change on income and costs should be considered in the design of long-term viable business models.

Our study has shown that organic vegetable farmers combine or intend to combine a wide range of strategies that are both low-tech (e.g. cover crops, mulching, agroforestry, diversification, modifications of crop planning) and high-tech (e.g. equipment to control or mitigate climatic conditions in tunnels, efficient irrigation systems) **(Table 5**) to adapt to climate change. In that sense, our work in a temperate European climate is consistent with results from studies carried out in countries of the global South (Mehdi Benyoussef Bisbis, Gruda, and Blanke 2018; Singh 2013; Arimi 2021; Mehdi B. Bisbis, Gruda, and Blanke 2019; Asadu, Ozioko, and Dimelu 2018; Gunathilaka and Samarakoon 2022; Irham et al. 2022; Koundinya et al. 2017). However, some strategies presented in the literature were not mentioned in our interviews, such as increased use of pesticides, using adapted varieties that could be developed through biotechnology, or employing climate warning information or prediction systems (Singh 2013; Arimi 2021; Irham et al. 2022). Not relying on pesticides or biotechnology are in line with the philosophy defended by the organic farmers interviewed.

In our study, farmers mentioned that CSA box-schemes can help to buffer climatic variability or extreme events. Farmers have also suggested that the success of adapting crop planning or diversifying crops depends on the possibility of finding adequate market outlets. Most organic growers of our sample are involved in direct selling, which can be both a constraint, as they then need to guarantee a certain diversity and quantity of vegetables throughout the year (Aubry, Bressoud, and Petit 2011; Morel, San Cristobal, and Léger 2018), and an advantage as farmers can communicate directly with consumers. Such market opportunities and constraints have rarely been mentioned in the literature, although some authors note that most vegetables have a poor shelf life, which reduces storage possibilities to mitigate variability (Arimi 2021). We think that it would be promising to further explore the role that post-harvest management, storage and marketing strategies could play in adapting vegetable production to climate change.

Looking forward, our study corroborates vegetable farmers' need for better access to information through training, exchange of practices with other farmers, and extension services (Arimi 2021; Asadu, Ozioko, and Dimelu 2018; Irham et al. 2022). This is in line with the fact that farmers foresee adaptation to climate change as a holistic, knowledge-intensive approach combining many strategies (**Table 5**) rather than the adoption of segmented ready-to-use innovations.

4.3 Accounting for the diversity of vegetable farms in climate change adaptation

We have shown that younger organic farmers with less experience and smaller farms feel more concerned about climate change and develop more adaptation strategies than do older ones with more experience and larger farms. This is in line with the literature showing a negative correlation between vegetable farmers' age and their adaptation (Tekuni Nakuja 2012; Gunathilaka and Samarakoon 2022), as the younger generations are usually more aware and educated about climate change challenges (Rahut and Ali 2017). However, our work differs from papers showing that adaptation to climate change is enhanced by farmers' experience (Gunathilaka and Samarakoon 2022; Irham et al. 2022) and access to financial and material capital or higher income (Gunathilaka and Samarakoon 2022; Chepkoech et al. 2020). We show, on the contrary, that farmers with more capital, income, and experience (and larger farms) tend less systematically to implement adaptation strategies. They may feel more confident in their capacity and ability to react to extreme events. By contrast, vegetable growers with less experience and income may feel more insecure and more eager to implement preventive adaptation strategies and to explore further options.

A study by Ihram et al. (2022) showed that organic vegetable growers have more precise perceptions of climate change and implement a wider range of adaptation strategies than do conventional ones. Our work highlights variability among organic farmers. Organic farming is often promoted as a response to climate change, e.g. with more use of organic manure, crop diversification, and so on (Irham et al. 2022). We suggest that it is necessary to account for and further explore the diversity of organic farming systems (Pépin, Morel, and van der Werf 2021) by considering adaptation to climate change.

5 CONCLUSION: Adaptation beyond the farm scale in a city-region context

Our work based on 17 interviews with organic vegetable growers in the Paris city-region globally corroborates existing studies in countries of the South showing that vegetable farmers: (i) perceive climate change in both climatic patterns and extreme events, (ii) link climate change mainly to negative impacts on vegetables, farm management (especially labour organization) and profitability, despite some positive impacts, (iii) implement a wide range of adaptation strategies and express the need to acquire knowledge to better adapt. This study also shows that organic farmers with contrasting profiles adapt differently to climate change. During the interviews, growers mentioned that their perception was based essentially on feelings and observation in the field. Others relativize climate change and choose not to make any significant changes to their practices without more certainty on climate change. Most of them told us that they were very interested in scientific approaches based on measurements and statistics to deepen their understanding of climatic phenomena and their impact. Providing empirical evidence on climate change and its impacts on vegetables seems to be crucial to contribute to building a shared consensus in support of further collective action and research on adaptation (Denhartigh 2014).

Farmers mostly mention adaptation strategies at the farm level. The only factors beyond the farm scale that are mentioned as facilitators of adaptation are public subsidies to support tree plantation, and collective exchange of practices between farmers. However, scientific studies highlight the necessity to foster and plan adaptation to climate change at municipal or regional level (Vizinho et al. 2021; Alam et al. 2020). We think that the preliminary understanding of farmers' challenges and adaptation perspectives allowed by our study could be a solid basis to develop relevant adaptation plans at the city-region level. Based on our results, some options could be suggested, such as insurance mechanisms to secure farmers' income, or ambitious watershed management plans to guarantee farmers' access to water. Vegetable growers mention the evolution of crop planning, change in varieties, and the integration of new crops or (fruit) trees as key adaptation strategies. This suggests that involving food chain actors to design coupled innovations (Meynard et al. 2017) in post-harvest management, storage, processing and marketing could play a key role in supporting farmers while matching a changing and more variable supply with local demand.

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Supplementary material

S.1 Variance explained by the different dimensions considered in the MCA (we kept only the first two pillars explaining 33.2% of total variance).