International Journal of Agricultural Sustainability

Towards Conservation Agriculture in Central Syria: Developmental insights from innovation driven research

--Manuscript Draft--

Full Title:	Towards Conservation Agriculture in Central Syria: Developmental insights from innovation driven research
Manuscript Number:	TAGS-2016-0356
Article Type:	Original Article
Keywords:	Conservation Agriculture; crop-livestock interactions; Syria; soil health; agricultural innovation
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Order of Authors:	Baqir Lalani, BSc, MSc, PhD (viva pending)
	Bassil Aleter, BSc, MSc, MSc
	Shinan Kassam, BSc, MSc, PhD
	Amyn Bapoo, BA, MBA
	Amir Kassam, BSc, MSc, PhD,
Additional Information:	
Question	**Response**
Number of words	7690

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Word count: 7,690

Abstract

In this paper, we report on early outcomes from Conservation Agriculture (CA) benchmark sites located within the marginal rainfed environment of agro-ecological zone 4 (rainfall 200-250 mm) in pre-conflict Central Syria; and specifically those, which relate to beneficial soil health and water retention attributes relative to conventional (tillage based) land use management practices applied to the fodder barley-livestock system, the dominant system in the zone. In addition, we argue that in marginal environments where strong crop-livestock interactions exist, inclusive and equitable access to finance, functioning land rental markets, and efficacy in the provision of extension and advisory services through participatory approaches are key underpinnings for critical mass in the shift towards a more sustainable land use management paradigm. This is a somewhat different argument to that which suggests that competition for straw in feeding livestock, in lieu of utilization of some of it for ground cover, (generally) places a limit to the extent to which CA is applicable within drier marginal environments. In addition to supporting the notion that CA is an avenue for sustainable production intensification, we also argue that a shift in land use management paradigm towards CA is likely to additionally bode well for social and environmental resilience, particularly in those marginal environments where both pastoralism and agro-pastoralism production systems co-exist.

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Introduction

Conservation Agriculture (CA) has been promoted as a land use management practice which is better able to achieve a desired objective of sustainable production intensification (Food and Agricultural Organisation of the United Nations [FAO], 2015). CA systems comprises the implemention of three interlinked principles: (i) no or minimum mechanical soil disturbance (no-till seeding and weeding); (ii) maintenance of soil mulch cover with crop residues, stubbles and cover crops; and (iii) cropping system diversification through rotations and/or associations involving annuals and perennials including legume crops (FAO, 2015). Aground cover of 30% or more is recommended, because it reduces soil erosion and provides substrate to soil biota to build and sustain soil health and functions, as well as increase soil organic matter content which improves structure, infiltration and soil moisture retention capacity. The significance of the 30% minimum ground cover relates to the fact that there is up to 80% decrease in soil erosion at that level of cover.

Establishing a CA system from an existing conventional tillage-based production system therefore requires time for the transformation to occur in which the three core CA practices are promoted along with other good agricultural practices including those of integrated crop, soil, nutrient, water, pest and energy management. It is thus clear, that adopting CA or implementing CA practices will depend on a range of biophysical, economic, socio-cultural, management and developmental issues related to the prevailing agricultural environment. While CA has three principles, at the level of implementation, there cannot be 'one size fits all' approach when it comes to how CA can be introduced, practiced and evolved in a particular biophysical environment and socio-economic rural setting and how adoption can be scaled and organized to harness territorial level benefits for rural communities and society at large? CA principles apply to all land-based production systems, including sown fodder crop-livestock systems or sown pasture-livestock systems of various kinds. In some respects, they are relatively simpler systems to transform to CA systems because they lend themselves to no-till seeding using a diverse mixture of species. However, what is required in transforming such systems to CA systems is the need to manage livestock differently such that grazing management is based on a rotational system and that minimum ground cover is maintained to build soil health, control erosion and increase biomass production.

Research findings from marginal areas with Mediterranean environments in a number of countries indicate that grain and biomass yields and factor productivities have improved through adoption of CA, in addition to improvements in soil quality (Mrabet, Moussadek, Fadlaoui, & Van Ranst, 2012; Kassam et al., 2012, 2013; Bashour et al., 2016). Additionally, and of particular relevance to dryland areas, a number of other likely benefits have been reported. These include, even within dryer months of the year, improved rates of water infiltration, appreciable reduction in run-off losses and replenishment of groundwater (Kassam et al., 2012, 2013; Gonsalez-Sanchez, Veroz-Gonsalez, Blanco-Roldan, Marquez-Garcia, & Carbonell-Bojollo, 2014). The spread of CA cropland systems worldwide has been occurring at the rate of some 10 million hectare per year since 2009, with some 50% of the area located in the developing countries, including in the Mediterranean environments (Kassam et al., 2012, 2015). However, broad uptake of CA has been less than desired within the West and Central Asia region, particularly so within the dryland[1] Mediterranean environments. However, the situation has begun to change in recent years in countries such as Kazakhstan, Kyrgyzstan, Tajikistan Armenia, Iran, Turkey, Lebanon, Jordan, Iraq, Syria and Pakistan reporting CA adoption (Kassam et al., 2012, Kassam, Friedrich, Derpsch, & Kienzle, 2015; Sommer et al., 2014; Jat, Sahrawat, & Kassam2014; Aziz et al., 2016).

Within dryland environments, as in many other parts of the world, intensive tillage based agriculture and continuous mono-cropping continues to contribute to land degradation and low crop (including fodder and pasture) and total land productivity, thereby inhibiting the prospects for enhanced sustainable agricultural production within these regions (Rasmussen, Collins & Smiley, 1989; Masri & Ryan, 2006). Options for uncovering contextually relevant shifts in land use management paradigms with sound environmental, social and economic underpinnings have therefore been of key concern to institutions of agricultural research - both national and international. In Syria, the benefits of CA on soil moisture and yield have recently been uncovered (Wahbi, Miwak & Singh, 2014), but in a number of cases, these have been in piecemeal fashion in terms of testing the application of the three interlinked core components identified by FAO under their generally accepted definition of CA.

Two aspects are important in a persistent argument for not favouring the maintenance of minimum ground mulch cover through the utilization of crop stubbles and straw residues in marginal environments exhibiting strong crop-livestock interactions. The first relates to conventional wisdom which frowns on direct grazing, given concerns over the retention of animal droppings which have implications for weed growth.[2] While the concept of managed rotational grazing is now well recognized for its potential to retain stubble and crop residue, and if undertaken with efficacy, a certain amount of residue retention as ground cover, it is argued that animal droppings are likely to contain weed seeds, which would lead to competition with the main cereal crop. This argument is not as important when the crop concerned (i.e. barley) is for fodder as is the case in zone 4 in Syria

A second, and more influential argument, is a concern over competition for fodder biomass (including straw during the dry season) in feeding livestock - in lieu of retaining a portion for maintaining minimum ground cover. Contesting this argument, Sommer et al. (2014) have shown favourable impacts of no-till system with respect to the potential for biomass retention for ground cover, as well as on soil properties and moisture retention.

Other studies have further highlighted the beneficial aspects of straw biomass retention on the surface during the dry season when it is not needed for feeding livestock (Sommer, Ryan, Masri, Singh, & Diekmann, 2011). Pala, Harris, Ryan, Makboul., & Dozom (2000) have demonstrated fodder yield improvements from barley-vetch intercrops in dryland Syria with reduced tillage and barley straw used as surface ground cover. More recently, Piggin, Haddad, Khalil, Loss, & Pala (2015) have documented significantly higher grain and biomass yields and gross margins for a variety of crops, including barley under no-till system when compared to conventional tillage-based agriculture in Syria in zone 2. Implicitly included is an understanding that above ground crop biomass (stubble base with root tops, and cut straws and leaves) yields are also likely to increase under no-till system and relative to conventional tillage-based production system. Taken together, there is an argument that in the early phase of shifting from tillage-based production practices to the adoption of CA practices, a constraint for crop biomass in the use as soil cover is a limiting factor which is released over time with increase of biomass yield in the case of zone 4, and of grain and biomass in the case of zones 2 and 3, and with introduction of cover crops in the cropping system contributing additional biomass. Further, with no-till, plant base with root tops also contributes to ground cover and soil health.

The developmental question, therefore, is how to reduce this constraint and overcome it over time in zone 4 where the crop-livestock farming system is based on growing fodder crops of barley, vetch, fodder shrubs and natural rangeland vegetation.

We believe this to be the first applied research study carried out albeit preliminary within the marginal rainfed environment of agro-ecological zone 4 in Syria (Figure 1), which borders the vast rangelands within the republic, and with an aim to investigate the potential benefits of CA production system relative to conventional tillage-base production system.[3]

[FIGURE 1 NEAR HERE]

Our study aims to assess the validity of CA within this marginal environment with strong crop-livestock interactions, and through an analysis of a barley-vetch and ervilia-barley rotation intercropped with fodder shrubs (atriplex and salsola), under both CA system and conventional tillage system. In previous research conducted in Ghrerife, Syria (mean annual rainfall 267 mm i.e. zone 2), Jones and Arous (2000) have highlighted the benefits (under conventional tillage) of barley intercropped with atriplex in providing sources of additional feed as well as in reducing the likelihood of soil erosion from wind. This form of alley cropping was found particularly useful as a method to buffer total feed output against seasonal fluctuations brought about by variability in rainfall.

In addition to an assessment of productivity gains and economic impact, we also examine the early impact of each treatment on a number of soil parameters - including soil moisture. It must be mentioned at the outset that the purpose of this study was not to carry out an on-station type trial, but rather to engage in on-farm operational research which actively engages farmers within the surrounding areas through demonstration, consultation and dialogue. On-farm operational research reflects a two-way dialogue where farmers in the field are active partners in the investigation, and able to assess the impact of different options in the 'field' (Kassam et al., 2014). Mrabet et al. (2012) have also argued that without farmer engagement and appropriate commitment from farmers to test CA system practices, integration into production systems and rapid uptake of CA by farmers, including the required transformational changes for CA system development, is unlikely to occur. This sentiment is very much in line with recent attention paid to efficacy in innovation systems, away from a historical concentration on linear models for technology dissemination and into more participatory multi-stakeholder processes for agricultural innovation (Rajalahti, 2012; Sanyang, Pyburn, Mur & Audet-Belanger et al., 2014).

In keeping with this notion, we further argue that in addition to sustainable production intensification, the role of CA in supporting resilience (productivity, environmental, social, economic) within fragile production systems is equally relevant, but not (generally) promoted in dissemination and demonstration strategies by both developmental agencies and national centres of agricultural research. This is particularly true in terms of the ability for CA in production areas, where there are interactions between pastoral and agro-pastoral livelihood systems and the potential to reduce conflict in periods of sustained drought and fluctuations in production volumes of cereal and fodder crops.

Study Region

The district of Salamieh is situated in central Syria and covers approximately 5000 km^2 with an estimated population of 241,000[4]. A significant portion of cultivable land is rainfed (100,174 hectares) with only a small portion (9,225 hectares or 9%) under irrigation (MAAR 2007). The district is divided into four agro-ecological zones which span the entire republic. Instituted more than a half century ago, these zones have been (for reasons not entirely known) immutable to change, despite significant variation in annual and seasonal rainfall patterns and a general downward trend in rainfall; the latter resulting in sustained periods of drought and increasing instances of winter frost. Zone 2, located to the east, is relatively the wettest area with average annual rainfall of 300 mm. In contrast, zone 3 is slightly drier with a typical average of 250 to 300 mm of rainfall per year. Zone 4 is a marginal area receiving on average between 200 to 250 mm of rainfall and bordering zone 5 - the badia (desert) and steppe zone which on average receives less than 200 mm of rainfall annually.

Zones 2 and 3 are characterized by mixed crop-livestock production systems, with zone 4 exhibiting the heaviest crop-livestock interaction. An incentive to produce barley, the primary cereal crop grown within the district, varies by zone. Grain production is a primary economic incentive within the relatively wetter zones (2 and 3), while fodder is of primary interest and incentive in zone 4. Prior to 2004, government support in the form of input subsidies, together with a guaranteed buy back scheme (price and quantity), provided significant economic incentives in the production of grain barley, as well as a number of other key national strategic crops such as wheat, tobacco and certain food legumes in particular. Since that time, and after the removal of regulatory support, the production of grain and fodder barley has largely been driven by an economic need to support a fairly significant stock of small ruminants, specifically sheep; and particularly within zone 4 and the vast rangelands of zone 5 where a large portion of national small ruminant livestock holdings are located.

Conventional wisdom, supported by anecdotal evidence, suggests that over years of sustained drought, farmers (particularly mobile and semi-settled farmers) will often liquidate their livestock holdings, sometimes even abandon them in times of severe market depression, as they are unable to meet necessary feed requirements. Reducing the feed gap through sustainable improvements in fodder biomass production is therefore of significant importance to livelihoods and security in marginal zones; and particularly so when poverty is prevalent and linkages to markets either weak or not inclusive. While farmers in marginal areas may be concerned with good soil health, higher levels of soil organic matter and all of the beneficial environmental outcomes that accrue from shifting land use paradigms, these outcomes in Syria at least for now are largely situated within the ambit of some research scientists.

In general, it is now well accepted that the initial appeal for farmer to engage in the CA adoption and transformation process is in the form of reduced costs due to no-till seeding and weeding. Yet, predictability in providing a stand of fodder barley for direct grazing may be more of an incentive to farmers in marginal zones, where strong crop-livestock interactions exist, and where crop mix choices are limited by the extent of access to groundwater and exacerbated by regulatory restrictions on cropping. The implications of residing within 'static' agro-ecological cropping zones is that historic edicts on cropping patterns are fixed, and when desired deviating farmers can be punished under the extent of the law. Within zone 4, cropping is restricted to rain-fed production of fodder crops, and the planting of trees, especially olives, is prohibited by regulatory code. National statistics would suggest that regulations are being adhered to with respect to prohibitions on the planting of trees, yet anyone familiar with the landscape of central Syria is cognizant of what is stated in official statistics and what exists on the ground. While not as dense and lucrative as in other relative wetter zones with relatively well endowed access to groundwater resources, olive production provides a valuable source of revenue to supplement income streams from the production of dairy products and in support of investments in livestock holdings which are a form of capital assets and security.

The production of cereal-based fodder cropping, therefore, provide an anchoring financial input which supports the livelihood systems for both resident farmers as well as nomadic farmers who rent out land for grazing in order to support livestock holding. Supporting resilience and improving productivity of cereal and fodder based crops and shrubs through a shift away from tillage-based production systems is, therefore, a priority area of focus within the broader strategy of research "for"- "in"- "and" development. This is not simply an agenda for cost savings and productivity enhancement, but equally important for reversing agricultural land degradation, rehabilitating abandoned agricultural land, and for social and environmental stability; and particularly so since the armed uprisings within Syria and the region more generally in 2011.

Material and Methods

Trial plots initiated in October 2010 (Figure 2) were managed by Aga Khan Foundation[5], an international development organization, in collaboration with a private landowner. The plots were located in Al-Bawi village within zone 4, but on the edge of the rangelands within zone 5.

[FIGURE 2 NEAR HERE]

[FIGURE 3 NEAR HERE]

The on-farm trial (CA vs TA – Tillage Agriculture) which was unreplicated and aimed to assess the impact of different seeding options incorporating barley and ervilia vetch intercropped with atriplex and salsola on plots under CA and TA.[6] Plots P.11 (CA) and P.14 (TA) were seeded with barley (intercropped with artriplex and salsola) in 2010/2011 followed by a mixture (70% barley and 30% ervilia) in the subsequent season 2011/2012. Plots P.12 (CA) and P.13 (TA) were seeded with ervilia (intercropped with fodder shrubs atriplex and salsola) in the 2010/2011 season followed by barley in 2011/2012.

Undisturbed and disturbed soil samples were taken from both CA (P.11 and P.13) and TA (P.12 and P.14) plots at 0-20cm depth in February 2011. Five cores per plot were taken in a zig-zag pattern from each plot (See Figure 2) and analysed at the International Center for Agricultural Research in the Dry Areas (ICARDA) laboratory based in pre-conflict Aleppo (See Figure 1 schematic). Watermark sensors (Gypsum block) were placed on both plots (P.12 and P.13) for the 2011 to 2012 growing season. In order to convert pressure head data into moisture equivalents, the Van Genuchten equation (Van Genuchten, 1980) was used through employment of the Rosetta neural network calculation.

All plots sizes were 2.5 dunums (1 dunum=0.1 hectare). To estimate yield, five replicate samples of one metre by one metre square quadrants were harvested from each plot at the end of the crop growing period. After drying, the samples were weighed and recorded and the mean weight of the five replicates was used to calculate total biomass yield (above ground biomass, including grain yield). Applications of fertiliser and seeding rates were kept constant between the two treatments. Seeding rates were 10 kg/per dunum for barley and 15 kg/dunum for ervilia vetch. Plots received 5 kg of phosphorous and 5 kg of nitrogen fertiliser per dunum over each season. No herbicides were applied. Atriplex and salsola shrubs were also intercropped in all plots, but with little growth in the two years under study; and therefore it was not possible to record their biomass yields. For the CA plots, a minimum of 30% ground cover with crop residue (barley straw and leaf biomass) was maintained. All plots were sown with a no-till seeder developed by ICARDA at its research station in Aleppo but modified in order to suit the soil types and topography within the on-farm benchmark site.

Partial farm budgets were used to calculate the financial returns of the various treatments. These do not include labour or harvesting and transport costs and only relate to the treatments used i.e. cost of fertiliser, and tractor service for ploughing and seeding for conventional seeding and for no-till seeding. From the perspective of the discipline of economics, a lack of inclusion of these costs would raise hackles. Two reasons support our argument for excluding these costs. First is that the experimentation was being undertaken in a period of initial civil unrest and markets for all inputs had been significantly affected, and particularly for labour and material inputs (fuel, machinery, etc.). Secondly, as we were looking primarily at improvements in productivity and returns for farmer demonstration, together with beneficial environmental outcomes for research and public good interests, the collection of these data was not directly relevant for the immediate purpose at hand. Providing information to farmers on the saving of material inputs was in line with conventional wisdom that out of pocket savings in expenses is an initial motive for engaging in the process of CA adoption and establishment. Labour within these marginal areas is predominantly household based and farmers would have likely made quick calculations on the impact of a shift in land use management practices on their household labour utilization. For ease of comparison, input and commodity prices are based on 2011 prices prior to the civil unrest in Syria. Those wishing to undertake a comparative analysis of returns with Piggin et al. (2015) work conducted in zone 2 would find similarity in this respect. For the CA plots in our study, all of the crop biomass (residue) was retained as surface mulch and valued at going market rates for biomass (straw) in feeding livestock.

Discussion

Rainfall

Rainfall over the 2010/2011 and 2011/2012 cropping seasons was 154 mm and 197 mm respectively. This was higher than the mean annual rainfall between 2005 and 2011 (Figure 3), and while beneficial in terms of demonstration for the benchmark trials to farmers, this higher than average rate of rainfall should be factored into an analysis of early results obtained.

[FIGURE 3 NEAR HERE]

A monthly analysis of average rainfall, however, indicates that rainfall was erratic throughout the 2010/11 and 2011/12 seasons, with required rainfall at the sowing time being below historical averages but generally higher within the later stages of crop growth (Figure 4).

[FIGURE 4 NEAR HERE]

Soil Characteristics

Soil characteristics measured through soil sampling are presented in Table 1 and provide a baseline of textures which are largely sandy clay loam or loam with high proportions of clay and sand and low levels of organic matter and nitrogen. (See Table 1 (a) and (b)). Sommer et al. (2014) have documented similarly low levels of organic matter, nitrogen and plant-available phosphorous within soils in other areas of Syria.

[TABLE 1 A AND B NEAR HERE]

Soil Moisture and Hydraulic Conductivity

Figure 5 shows that soil moisture contents for CA (P.12) compared to TA (P.13) at peak rainfall periods during the growing season for 2011/2012 are higher under the CA plot. The higher soil moisture under CA, measurable immediately in the first two years during the period of transition, provides an indication of improved water infiltration and moisture retention capacity under CA conditions, albeit under transition, relative to TA conditions, with an implication for reductions in water runoff and soil erosion (Kassam et al., 2012, 2013; Sommer et al., 2014). Given relative assessment between CA and TA treatments at the same point in time in the growing season, the impact of higher rainfall within the agricultural season, relative to the recent ‘historical’ averages can be dismissed.

[FIGURE 5 NEAR HERE]

Figure 6 also highlights that the soil under CA has higher moisture rates at different water potential levels. Moreover, soil moisture content is significantly higher under CA relative to TA (P=<0.05) (See Table 1). Likewise, hydraulic conductivity in the topsoil (0-20cm) is also appreciably higher under CA (P=<0.05) (Figure 7 and Table 3). This is likely an indication of increased soil water retention capacity (Verhulst et al., 2010), a result which was also found by Sommer et al. (2014) in relative comparisons between no-till system and conventional tillage system.

[FIGURE 6 NEAR HERE]

[FIGURE 7 NEAR HERE]

[TABLE 3 NEAR HERE]

Yield, economic returns and market linkages

The results indicate that even during the first two years of transition into CA, there are already clear financial gains for CA and promising signs of improvement in total biomass produced (Tables 4 and 5).

[TABLE 4 NEAR HERE]

[TABLE 5 NEAR HERE]

In fact, fodder biomass yields under CA for plot P.13 (Table 5) in 2011/2012 are more than double those compared to TA (i.e. conventional tillage). Bashour et al. (2016) have also reported similar yield gains for CA under a barley/vetch mixture in Lebanon, a region with much higher average annual rainfall (550 mm). For semi-arid and dry Mediterranean environments, we estimate, on the basis of information from various sources for barley and wheat (Dicky and Havlin, 1985; USDA, 1992, Lyon and Christensen, 1992; McCarthy McCarthy, Pfost, & Currenece, 1993; Scott, Eberbach, Evans, & Wde, 2010; BC-MoA, 2015), that at least some 0.5 tonnes of crop biomass residue is needed in order to provide a 30% ground cover for one hectare of land. In the 2011/2012 season, under a barley/ervilia seeded mixture (Table 5), straw biomass production was greater than 0.5 tonnes required to cover 30% of the soil surface, i.e., roughly 2.7 t ha^{-1} (i.e., 270 kg/dunum). We find the optimum amount that can be put down is 200 kg/dunum, i.e., approximately 2 tonnes per hectare (i.e., roughly four times as much as is required for some 30% ground coverage). Moreover, during the first year under study, for the same crop mix we calculate the optimum amount that can be put down as ground cover to be enough to 63kg (i.e. 63 kg/dunum or 0.63 t ha^{-1}) This is because any higher amount put down as mulch under CA system makes a financial loss relative to conventional system given the opportunity cost of mulch. Likewise, for the crop mix presented in Table 4 it is only feasible to put down roughly 17 kg/dunum in the second year (i.e., 2011/2012) - any higher amount results in a financial loss relative to conventional system. This highlights the importance of crop mix to the profitability of CA relative to conventional system. Another argument is that straw biomass, applied as ground cover, should be considered as an economic investment for future benefits in the form of better soil health, increased productivity and resilience, and higher and more reliable profit. Yet, farmers, and particularly poor and marginal farmers, are likely to be more myopic and cost conscious as opposed to investment savvy.

How to bridge this short-term deficiency becomes a key question for innovation systems to address. Our analysis, however, excludes other costs such as labour which may provide additional gains for CA system relative to TA system (See Bashour et al., 2016). The results support the contention that even in very dry areas enough biomass can be generated (and increased over time) to allow for in-situ mulching of crop residues to meet minimum CA requirement, i.e. 30% surface coverage. Piggin et al. (2015) have suggested that trade-off for feeds and livestock may not be as pronounced given the increase in biomass that offsets input of mulch residue retained. We agree with the assessment of Piggin et al. (2015) but note that the time lag in reaching a sufficient level of increase in biomass may be a deterrent to broad uptake, even where there is already simultaneous utilization of straw for ground cover as well as for feeding livestock. This is because it is possible to start harnessing economic and environmental benefits during the early transitional years of the CA adoption process while still building up biomass output, soil mulch cover and soil health. Further, in-situ coverage (which would be enough to maintain a 30% ground cover) may certainly be possible in an above average or good rainfall year, especially in the initial stages of CA establishment However, progress can be made where the commitment for residue retention is managed through improved grazing such as rotational grazing agreed upon by all sides, including at the community level.

There are clear trade-offs which exist in marginal dryland areas at the start of the transformational process to establish a CA system, particularly within a setting where livestock is central to crop farmers' and pastoralist's livelihoods and where fodder biomass (straw) production is valued highly over grain production. Moreover, this is exacerbated in a region with frequent droughts and dry spells. Magnan, Larson and Taylor (2012) estimate that the shadow value of straw in a drought year is three fold the price of grain signifying its importance to crop-livestock farming communities where crop-livestock integration is based on pastoralists relying on access to fodder produced by settled farmers. The value of fodder during the growing season and of straw during the dry season, particularly in a drought year, may however further complicate the problem noted by Sommer et al. (2014) who found difficulties in farmers adopting CA in Syria due to competing uses of biomass for livestock. Bashour et al. (2016) further note the importance of conducting research to determine the 'optimum quantity of crop residues' that can be retained for ground cover without restricting the amount of biomass needed for livestock whilst also ensuring that enough residues are left on the soil surface to capture the full productivity, socio-economic and environmental benefits that can occur over time.

Notwithstanding this there are a number of options which exist within many dry environments which may enhance the variety of feed sources available and thereby limiting or minimizing the competition between crop biomass (including post-harvest waste) for livestock feeding and that required for building and maintaining ground cover under CA. In Syria, the prominence of olive trees and pruning waste provide one avenue as do other forms of compostable waste. Grass, leaf litter and other dead plant biomass may also be utilized as a source of groundcover, and is showing promise in parts of Sub-Saharan Africa (Thierfelder et al., 2015). Suggestions have also been made to incorporate a range of agro-industrial waste combinations into supplemental sources of livestock feed (e.g., molasses and olive-oil pomace) with potential beneficial outcomes for joint products produced – such as milk and yoghurt quantity and quality (Solh & van Ginkel, 2014). Supplementary feed sources may thus reduce the amount of feed needed from crop fodder biomass and residues.

From the standpoint of a collaborative research and developmental initiative, there are also likely to be significant gains made in assessing the efficacy of testing contractual agreements between farmers in marginal zones with farmers within irrigated zones. Given that barley is no longer protected under government subsidy support, at least at the time of this study or likely in a stable Syria in the future, there is a need to appeal to the incentives for barley production between zones. As previously mentioned, the incentive in irrigated areas is for grain production, with straw biomass a joint by-product typically sold into the market for supplementary livestock feeding. The potential for farmers in marginal zones to contract farmers in irrigated areas for the production of both grain suitable for their production environments (drought tolerant or locally adapted) and straw has yet to be tested and validated. It would appear that the incentives for both cohorts of farmers would be aligned under such an arrangement; and particularly so given that rainfall levels within marginal zones do not permit the regular production of grain; and therefore a continued reliance on nascent (local) grain markets. Why such contractual arrangements have not taken root organically is an equally important research question. One conjecture is that the markets for rural finance (credit, insurance, deposits) in Syria are still not mature enough to handle such arrangements; and therefore risk mitigating the potential for efficiency in contractual agreements across agro-ecological zones.

Land rental markets, rural finance and social stability

As has been mentioned repeatedly, the key incentive for production of barley within marginal zones in Syria is as green and dry fodder for livestock. Grain is only produced in years of adequate and timely rainfall. There is, however, a qualifier to this statement. The production of fodder and dry straw, as the primary economic objective, is not in the form of harvested product but rather an in situ product for on-site consumption by nomadic livestock. It is the ability to capitalize on land rental rates for direct grazing which is the key motivation for producing a stand of fodder barley and often a stand without any grain production. Why does this observance interest us in a study on the relevance and broad applicability for CA in marginal zones?

Firstly, in an environment where access to credit has typically been constrained, the provision of microfinance within rural communities has played a large role in relaxing working capital constraints such that greater areas of marginal land are brought into production. Reliable statistics in Syria are notoriously difficult to acquire, and in many cases have been pencil marked in order to ensure that they are consistent with regulatory rules and ordinances. It is difficult therefore to support this claim of correlation between microfinance availability and increased amount of marginal land under production. Easier to justify is the argument that standardized norms for disbursement of microfinance across zones, based on a set monetary value per unit of land, will inherently benefit farmers in marginal zones. Given that quantities and costs of material inputs such as fertilizer and specifically irrigation are much higher for farmers in irrigated areas, fixed rates per unit of land provide marginal farmers with both working capital and an excess of funds to be used in order to smooth out consumption over the growing season. The incentives to bring more land under production with simplified rules for microfinance are therefore clear. With land rental values for direct grazing increasing within periods of drought, the ability to pay back loans is bolstered. When more productive land use paradigms such as CA offer the potential for improved reliability in yields as well as savings in costs, the incentives for bringing more land into production are greater; as is the ability to repay loans at the end of the growing season. Microfinance, when coupled with improvements in land use management practices such as CA has the potential to improve both adoption rates (measured in terms of land under CA) as well as rural household livelihoods through an ability to smooth out consumption throughout the year; notwithstanding improvements in profitability from cropping in marginal zones. The inherent outcomes attainable from broad uptake of CA are therefore not restricted solely to savings in production costs and beneficial productivity and environmental outcomes (soil health among others) but also in terms of improving quality of life for rural households through improving security of income streams and a reduction in vulnerability from systemic shocks.

Secondly, the ability to capitalize on land rental rates for direct grazing is of immense importance in periods of drought, given the nature of pastoral livelihood systems within the region, and in Syria more specifically. Within an era of subsidized barley production and distribution, it was not uncommon for Bedouins to settle within the vast and often barren rangelands and to rely on a network of marketing agents who supplied subsidized barley, water and necessities of life to their communities. With the removal of state subsidy programmes, there has been increased movement of livestock flocks and in periods of drought frequent clashes and disputes between settled farmers and nomadic flock herders. Options under CA land use such as 'managed' rotational grazing and/or 'communal agreements' at the village/community level for balancing stocking rates with livestock carrying capacity are applicable as measures for mitigating conflicts (Kassam et al., 2012). Yet, these are very much dependent on land use rights and security in land use rights. While there have been significant challenges to the development of a land cadastral system and issuance of certificates of land ownership, land rental markets have strengthened and continue to strengthen with increased availability of credit (at least prior to the civil conflict in 2011). Improved productivity and reliability of production on marginal lands, through shifts in land use management paradigms, is therefore likely to bode well for reducing conflicts between settled farmers and pastoral herders. There is an element of fostering social stability and reduction of conflict within the set of outcomes desired from broad uptake of CA and this is sometimes missed given that a lot of research and attention related to broad uptake of CA has been within more stable environments.

Enhancing broad uptake of CA through lessons learned

One of the major limitations of this study was the inability to follow up on the baseline soil sampling given difficulties in access to the field in light of armed conflict and heightened lack of security. Similarly, caution should also be used in generalizing the yield and economic returns given lack of replicability in the benchmark site. Given that the initial objective of the field sites were for on-farm demonstration, these results provide indication of the validity of proof of concept and of applicability for CA to potentially thrive in the marginal dryland environments under which it was tested. Thus, we are unable to ascertain the full impact of the various treatments on soil biological, chemical, hydrological and physical properties, and on cropping system and land productivity and resilience, over time but buoyed by initial results which were encouraging. Although the need to replicate the trials should also be considered in future research, a number of published on-farm managed trials have been unreplicated yet yielded useful insights (see for instance, Grace, Oades, Keith, & Hancock, 1995). Moreover, other authors have noted that a trial design with no replication on a farmer's field simplifies the demonstration, thereby making it easier for farmers to understand and evaluate the technology (Snapps, 2002).

What is worth noting is that where ever CA has been practiced in dryland Mediterranean environments for more than 10 or 15 years, such as in Western Australia, South Africa and southern Europe, benefits include improved biomass and yield output as soil organic matter and health improved with time but also reduced use of purchased inputs of seeds, nutrients, pesticides, fuel, water and time, in addition to reduction in soil erosion and land degradation (Crabtree, 2010; Basch et al., 2012; Kassam et al., 2012, 2013; Rochecouste and Crabtree, 2014; Friedrich et al., 2014). Such benefits have often led to increase in livestock carrying capacity and stocking rates. In Western Australia with dryland Mediterranean environment, CA farmers are able to cultivate sustainably and profitably with 200 mm of rainfall (Crabtree, 2010; Rochecouste & Crabtree 2014). It would therefore seem probable that such benefits would be potentially available to farmers in Syria, making it attractive to establish CA crop-livestock systems in which crops and livestock can co-exist productively and sustainably through various forms of win-win integration involving viable arrangements at all levels of rural organizations.

Within the Middle East and North Africa region, agricultural advisory services have largely been within the domain of national systems of agricultural extension. In Syria, the inclusion of non-governmental and international organizations (both research and development) was very recent, expanded after the death of the last President Hafez Al Assad in 2000, and with initial support from his now President son Bashar Al Assad. A discussion on the background for why more pluralistic forms of knowledge dissemination were not permitted in Syria is a topic for another paper. The general point, and a more global one at that, is that perspectives on the role of agricultural innovation have shifted considerably, moving from linear transfer-of-technology models in the 1960s to, more recently, a focus on ***agricultural innovation systems*** (AIS). AIS argues that both development and adoption of contextually relevant technologies and innovations are more likely to be successful when there is a process of continuous learning, jointly undertaken by research organizations, farmers, marketing agents, donors, NGO's, financial service providers, policy makers, and relevant civil society actors.

Notwithstanding that Syria is currently embroiled in a full scale civil war, there is an unanswered question of whether nations within the region are ready to embrace participatory learning in order to uncover inclusive systems development approaches for: (i) identifying and sharing contextually relevant set of interlinked practices for research and development; (ii) uncovering avenues for strengthening capacities in effectively adapting and adopting paradigm changing agricultural technologies and best practices; and (iii) providing rural communities with opportunity for greater participation in regional and national policy dialogue.

The success in adoption of CA globally has been attained in favourable and unfavourable environments, including in dryland Mediterranean environments such as in Europe, Central Asia, South Africa and Australia (Kassam et al., 2012, 2013, 2014, 2015). Thus, we speak to the question of enabling investment, regulatory, policy as well as social and cultural environments which support knowledge, participatory learning and enhancing of national capacity to innovate.

While there is anecdotal evidence to suggest that no-till agriculture has been broadly accepted in Syria, one could easily argue that this has been fostered by shortages in fuel, within the post-revolution period, and which has influenced a move towards limiting machinery use for tillage in crop establishment and in weed management. In the period prior to the revolution (2008-2011), there are claims that over 30,000 hectares in Syria was under no-till systems

(Piggin et. al., 2011, 2015; Haddad et al., 2014; Loss et al., 2015; Yigezu et al., 2015). How much of this was influenced through incentives provided by donor funds (gratis use of machinery and equipment, complimentary seed distribution, etc) and disseminated through research and public extension organizations is not clear and not well documented. Whether this trend will reverse itself in a stable Syria remains, therefore, to be assessed and is a valid question for future research. What is clear is that without supporting systems for participatory knowledge generation and dissemination, together with an enabling investment and policy environment, the ability for broad uptake of CA approach, and the desired environmental, social and economic outcomes are likely to be limited.

Conclusion

CA was shown to maintain higher levels of soil moisture ($p=<0.05$) over the growing season, together with improved hydraulic conductivity when demonstrated within a dry and marginal agro-ecological zone in Central Syria. Although it is difficult to ascertain whether there are statistically significant differences in yield within this study (or visible trends in the medium to long term), there are clear economic advantages in the adoption of CA coming through in the first two seasons of adoption and system transformation. These include a reduction in fuel used for crop establishment and weeding, which has particular relevance for the region given recent fuel and input shortages, and within an era of ongoing armed civil conflict. There is also preliminary evidence to support the contention that CA can improve yield and biomass output and overall net returns (though crop mix is important) even in the driest agro-ecological zones. Preliminary results also suggest (at least in the short term) that residue retention may not immediately fulfil the requirements of 30% groundcover for CA and which may be more difficult to maintain in a drought year. This is due to the marginal nature of the environment and the strong crop-livestock interaction. However, there is evidence that it should be possible to establish and maintain minimum ground cover as greater crop and land potentials are mobilised during the early transitional phase of CA adoption and uptake process.

The role of soil mulch cover is to improve soil health and biology as well as provide physical surface protection against soil erosion, supress weeds and sustain food webs below and above the ground. Thus, soil mulch cover will always remain an important component of CA, however difficult it may be to maintain it against the pressures from and competition with livestock. The increase in yields vis a vis improvements in biophysical parameters in CA relative to TA does suggest, however, that the competition with livestock for biomass is likely to reduce over time and farmers' would be able to return increased levels of straw (as stubble and residue) as mulch given improved biomass yields. Our data supports previous research in the region on CA, or components of CA cited herein, and also provides indication that CA has a beneficial role to play in marginal cropping zones such as that under study.

These benefits are much broader than those ascribed to beneficial environmental outcomes and increased profitability through a reduction in production costs and higher yields. We argue that in marginal zones with interactions between pastoralists and settled farmers, and thereby strong crop-livestock interactions, CA approach to sustainable intensification has the potential to also foster beneficial outcomes in terms of improvements in social stability, in potentially smoothing out seasonal consumption needs (household and livestock) when supported through inclusive finance provision, and in reducing risks from systemic shocks. The key to broad uptake of CA in marginal environments is a supportive and enabling environment for participatory innovation, comprised of both research (invention) and avenues for dissemination of knowledge which influence shifts in land use management practices (adoption) at all levels, including community level within production systems and across components of crop production and livestock production. How ready Syria is for fostering inclusive and enabling environments for agricultural innovation, and towards the attainment of critical mass in the adoption of sustainable long term shifts towards environmentally, socially and economically sound land use management practices is a question for future research to answer within a stable environment. The applied research initiative reported herein suggests that there are significant reasons for hope and promise.

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Table 1(a). Soil characteristics based on baseline soil sampling for CA (P.11 and P.13) and TA (P.12 and P.14) in 2011

	PH (1:1)	Polsen *	N total*	Kextractable ppm*	CaCO3 (%)	OM** (%)
CA	8 (0.06)	4.7 (1.8)	1298.8 (158)	299 (63)	33.9 (1)	2.0 (0.3)
TA	8 (0.2)	4.4 (1.0)	1342.4 (72)	267 (54)	35.6 (2)	2.0 (0.1)

Notes: Based on Mean of five cores taken. Standard deviation in parenthesis *Ppm=measured in parts per million ** organic matter.

Table 1(b) Soil characteristics based on baseline soil sampling for CA (P.11 and P.13) and TA (P.12 and P.14) in 2011

	Clay (%)	Silt (%)	Sand (%)	BD (g/cm3)	Soil Water Content % (W/W)	C/N ratio
CA	29 (2)	39 (4)	31 (3)	1.3 (0.10)	24.7 (1.10)	15.0(0.8)
TA	25 (3)	38 (3)	36 (3)	1.3 (0.14)	24 (1.8)	15.1(0.6)

Notes: Based on Mean of five cores taken. Standard deviation in parenthesis

Table 2. Mean values for soil moisture CA (P.13) and TA (P.12)

Soil moisture (cm/cm) (CA)	95% confidence interval (CA)	Soil moisture (cm/cm) (TA)	95% confidence interval (TA)
0.28 (0.69) a	0.28-0.29	0.26 (0.59) b	0.25-0.26

Note: Means with different letters denote statistically significant difference at the 5% and 1% level (standard deviation in parenthesis).

Table 3. Mean values for soil moisture CA (P.13) and TA (P.12)

Soil hydraulic conductivity (cm/d) (CA)	95% confidence interval (CA)	Soil hydraulic conductivity (cm/d) (TA)	95% confidence interval (TA)
0.32 (0.65) a	0.31-0.34	0.13 (0.21) b	0.13-0.15

Note: Means with different letters denote statistically significant difference at the 5% and 1% level (standard deviation in parenthesis).

Table 4. Yields (kg/dunum) and partial budget (Syrian pounds/dunum) for CA (P.12) and TA (P.13) for 2010/2011 and 2011/2012 season

Budget item	CA		TA	
	2010/2011*	2011/2012**	2010/2011*	2011/2012**
Grain yield	25	98	28	104
Straw yield	38	230	69	204
Grain value	675	1960	756	2080
Straw value	266	2070	483	1836
Opportunity cost of mulch	266	2070		
Seed cost	270	200	270	200
Seeding cost	60	75	50	50
Fertiliser cost	90	165	90	165
Land preparation i.e. ploughing			40	70
Total production costs	686	2510	450	485
Total revenue	941	4030	1239	3916
Net revenue	255	1520	789	3431

*Note:**Ervilia intercropped with atriplex and salsola **barley intercropped with atriplex and salsola.

Table 5. Yields (kg/per dunum) and partial budget (Syrian pounds/per dunum) analysis of CA (P.11) and TA (P.14) for 2010/2011 and 2011/2012 season[7]

Budget item	CA		TA	
	2010/2011*	2011/2012**	2010/2011*	2011/2012**
Grain yield	17	87	13	59
Straw yield	91	276	46	130
Grain value	272	2349	208	1593
Straw value	273	3257	138	1534
Opportunity cost of mulch	273	3257		
Seed cost	160	282	160	282
Seeding cost	60	75	50	50
Fertiliser cost	90	105	90	105
Land preparation i.e. ploughing			40	70
Total production costs	583	3719	300	437
Total revenue	545	5606	346	3127
Net revenue	-38	1887	46	2690

Note: *seeded with barley intercrop with atriplex and salsola **seeded with a mixture of ervilia (70%) and barley (30%) and intercropped with atriplex and salsola.

[1] Within the CG system of international agricultural research, drylands are defined on the basis of an aridity index. Consistent with that employed by the United Nations Convention to Combat Desertification (UNCCD) as well as the United Nations Food and Agriculture Organization (FAO), drylands are defined as regions having an aridity index of 0.65 or less (http://www.eatlasdcl.cgiar.org/Docs/WorkingDefinitionOfDrylands.pdf). Estimates suggest that close to 2.1 billion people call drylands their home.

[2] Based on discussions with staff at ICARDA and author discussions in the field.

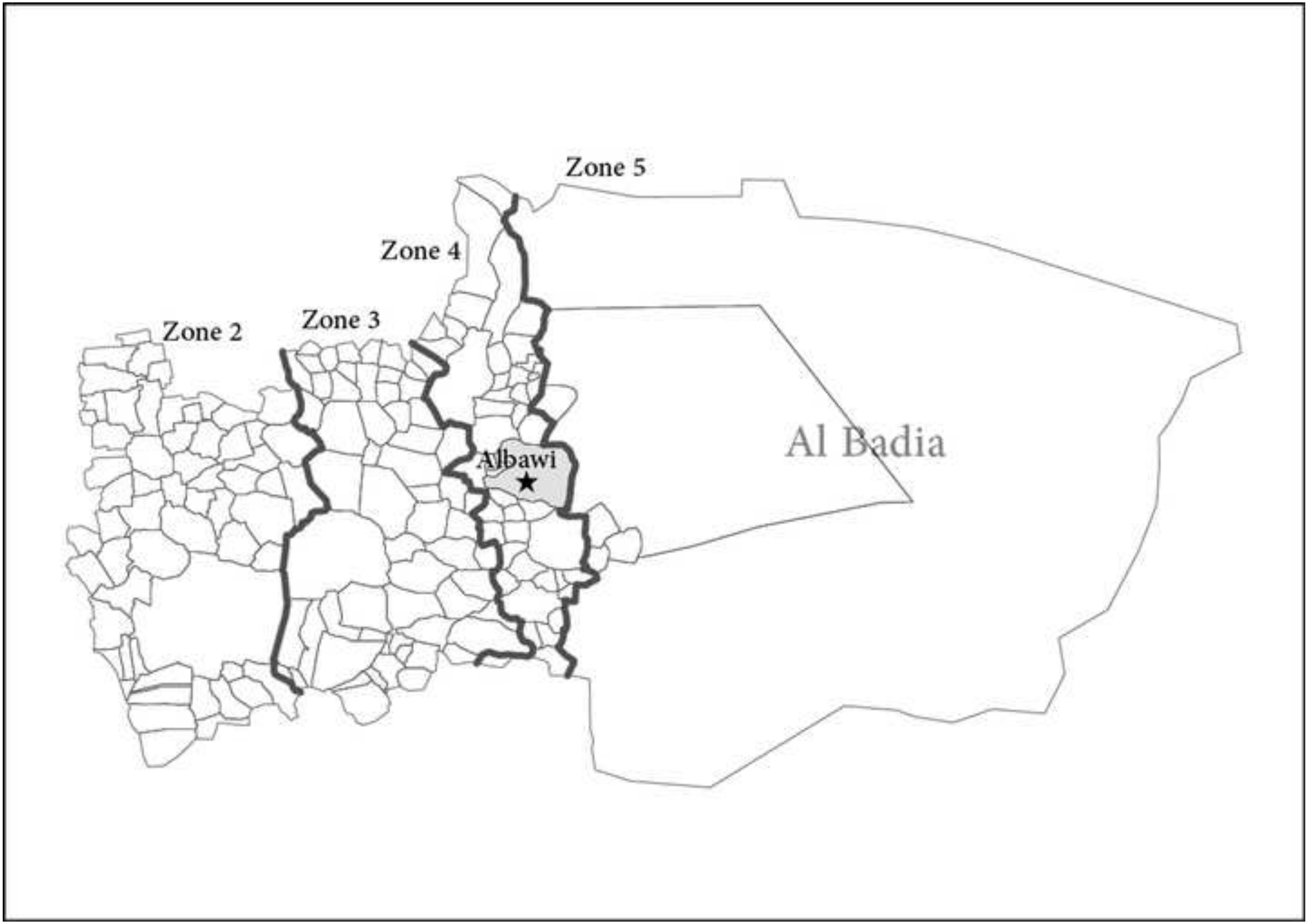
[3] For this manuscript conventional tillage and traditional agriculture will be used interchangeably to denote the treatment which utilizes ploughing.

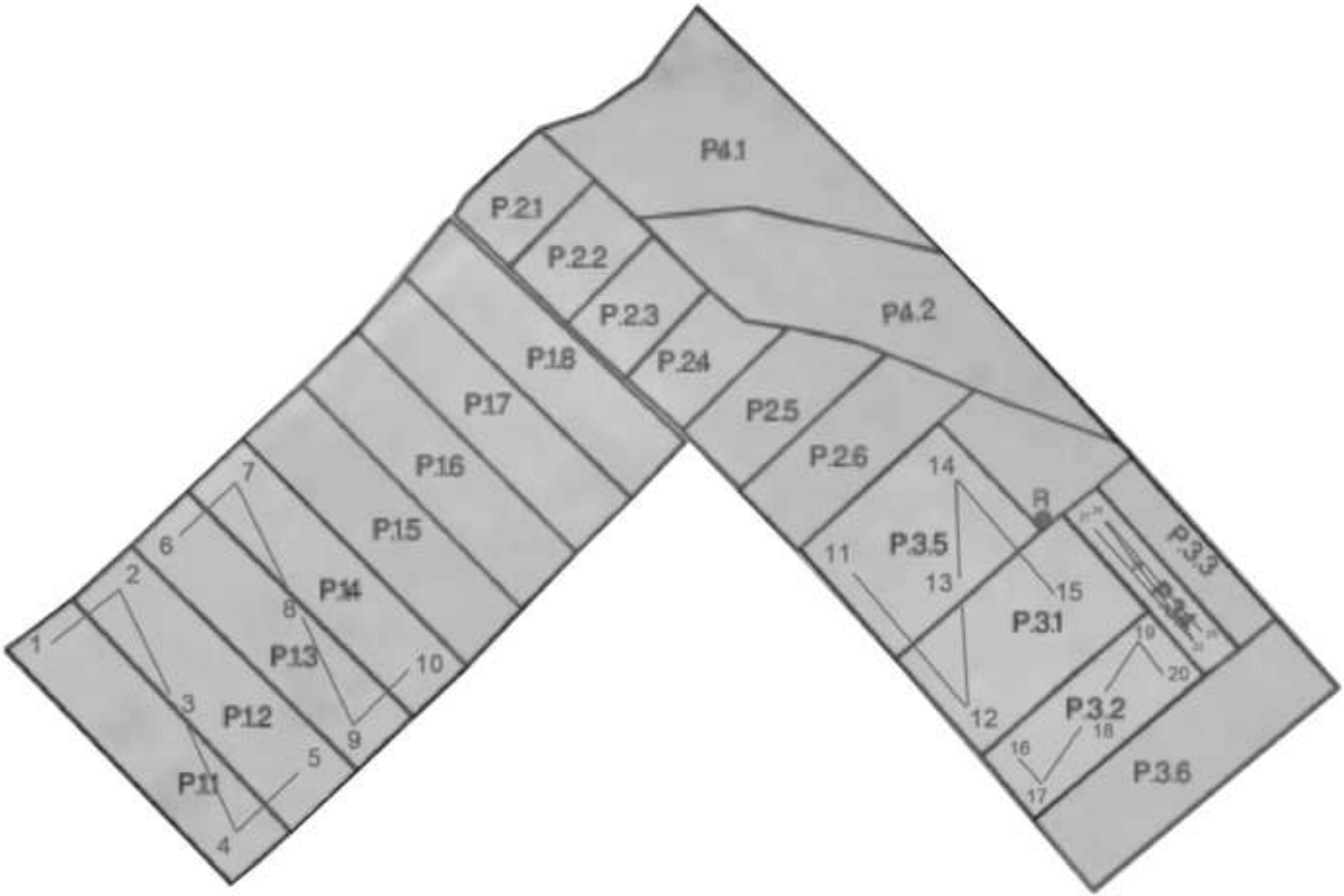
[4] Civil statistics in Syria are guarded with much sensitivity; and given that registration of individuals is by place of birth and not residency, it is sometimes difficult to obtain accurate statistics of residents within a specific geographical area. This population estimate is based on informal surveys undertaken by Aga Khan Foundation in Syria over the period of 2008 to 2011.

[5] http://www.akdn.org/our-agencies/aga-khan-foundation

[6] We denote TA as a short form of 'traditional' or conventional agricultural land use practices which utilize motorized tillage based practices.

[7] Water mark sensors were not placed in these plots


Zone 5
Zone 4
Zone 3
Zone 2
Albawi
Al Badia



P.4.1
P.4.2
P.2.1
P.2.2
P.2.3
P.2.4
P.2.5
P.2.6
P.1.1
P.1.2
P.1.3
P.1.4
P.1.5
P.1.6
P.1.7
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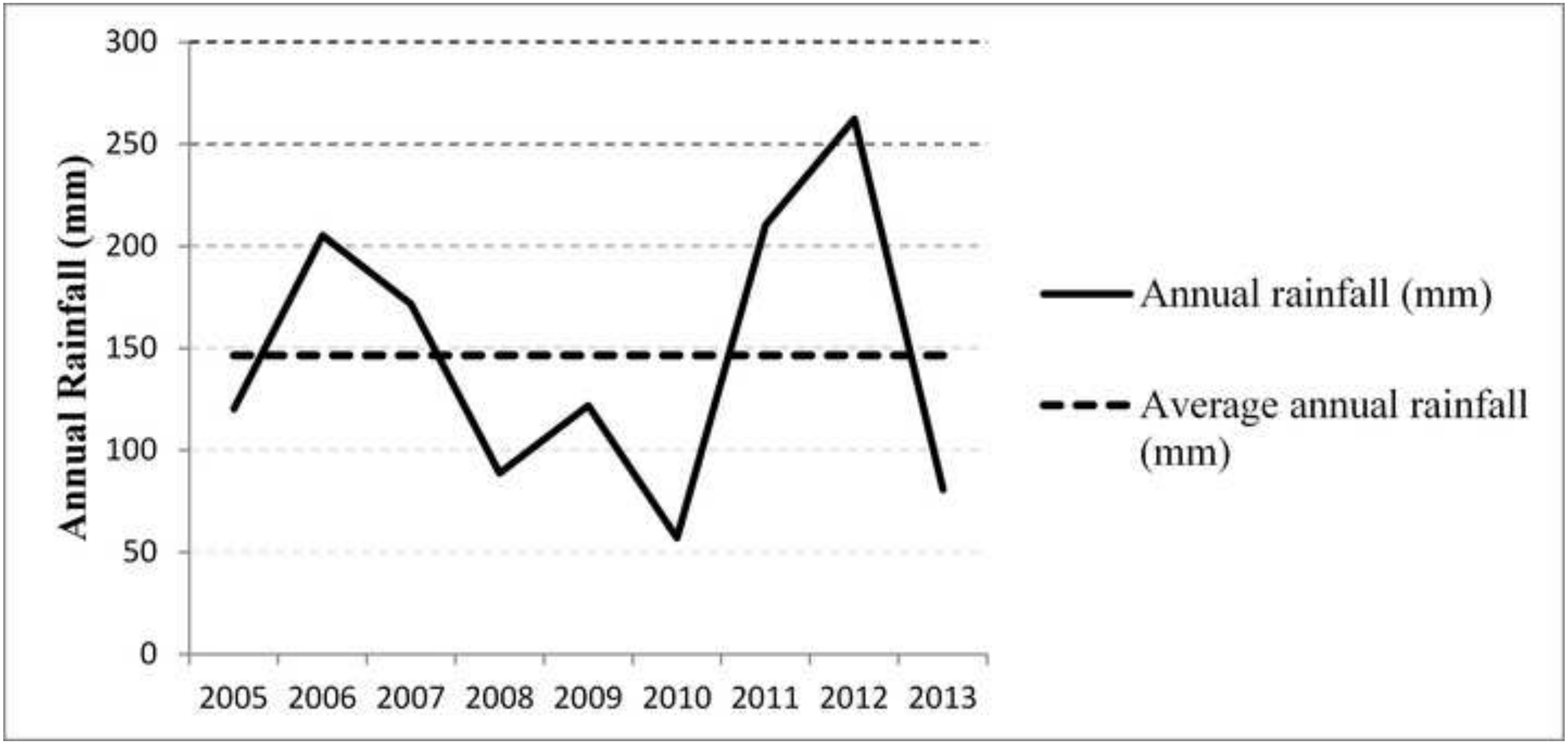
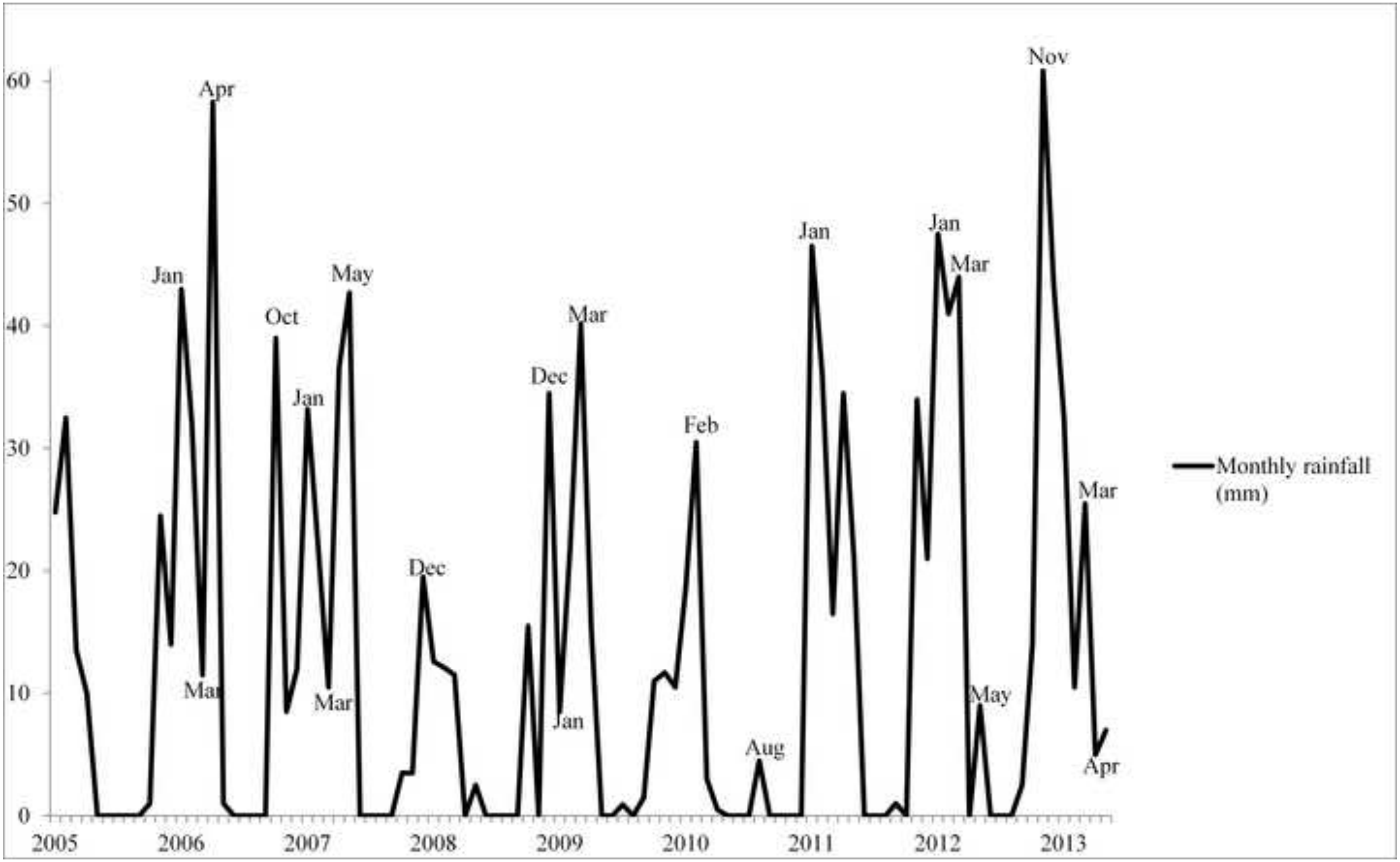
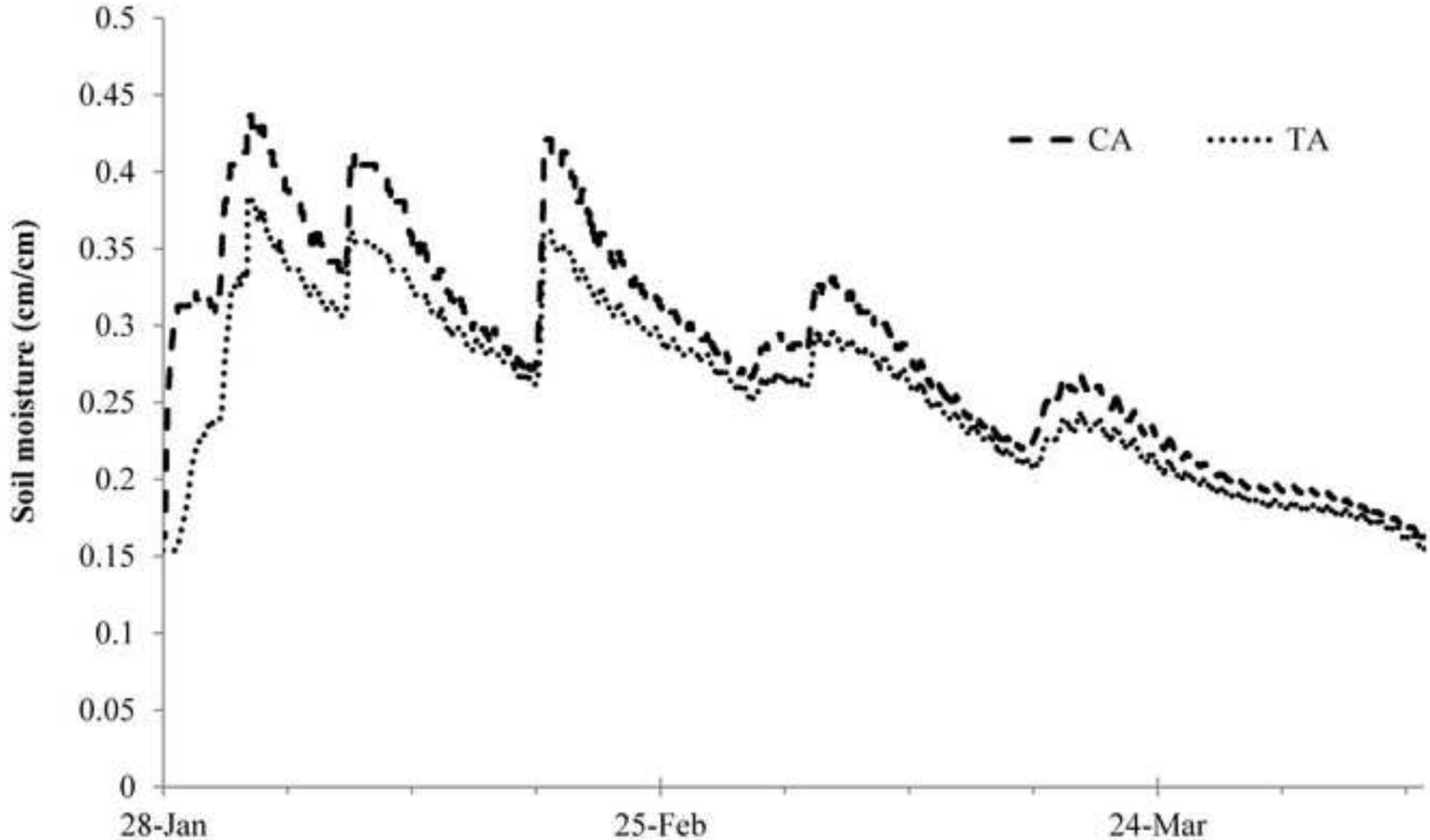

300
250
200
150
100
50
0
Annual Rainfall (mm)
2005 2006 2007 2008 2009 2010 2011 2012 2013
Annual rainfall (mm)
Average annual rainfall (mm)

Figure4



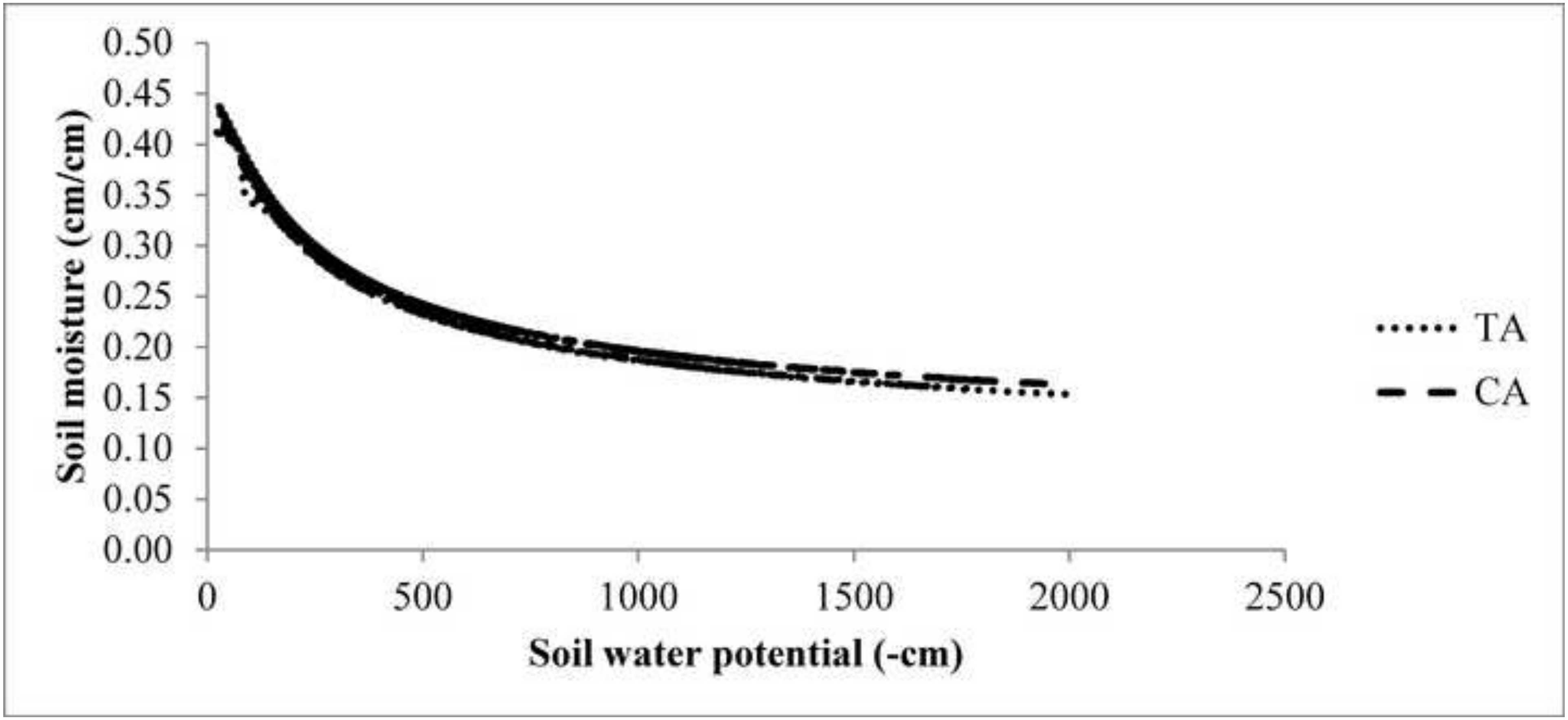
60
50
40
30
20
10
0
2005
2006
2007
2008
2009
2010
2011
2012
2013
Apr
Jan
Mar
Oct
Jan
May
Mar
Dec
Dec
Mar
Jan
Feb
Aug
Jan
Jan
Mar
May
Nov
Mar
Apr
Monthly rainfall (mm)

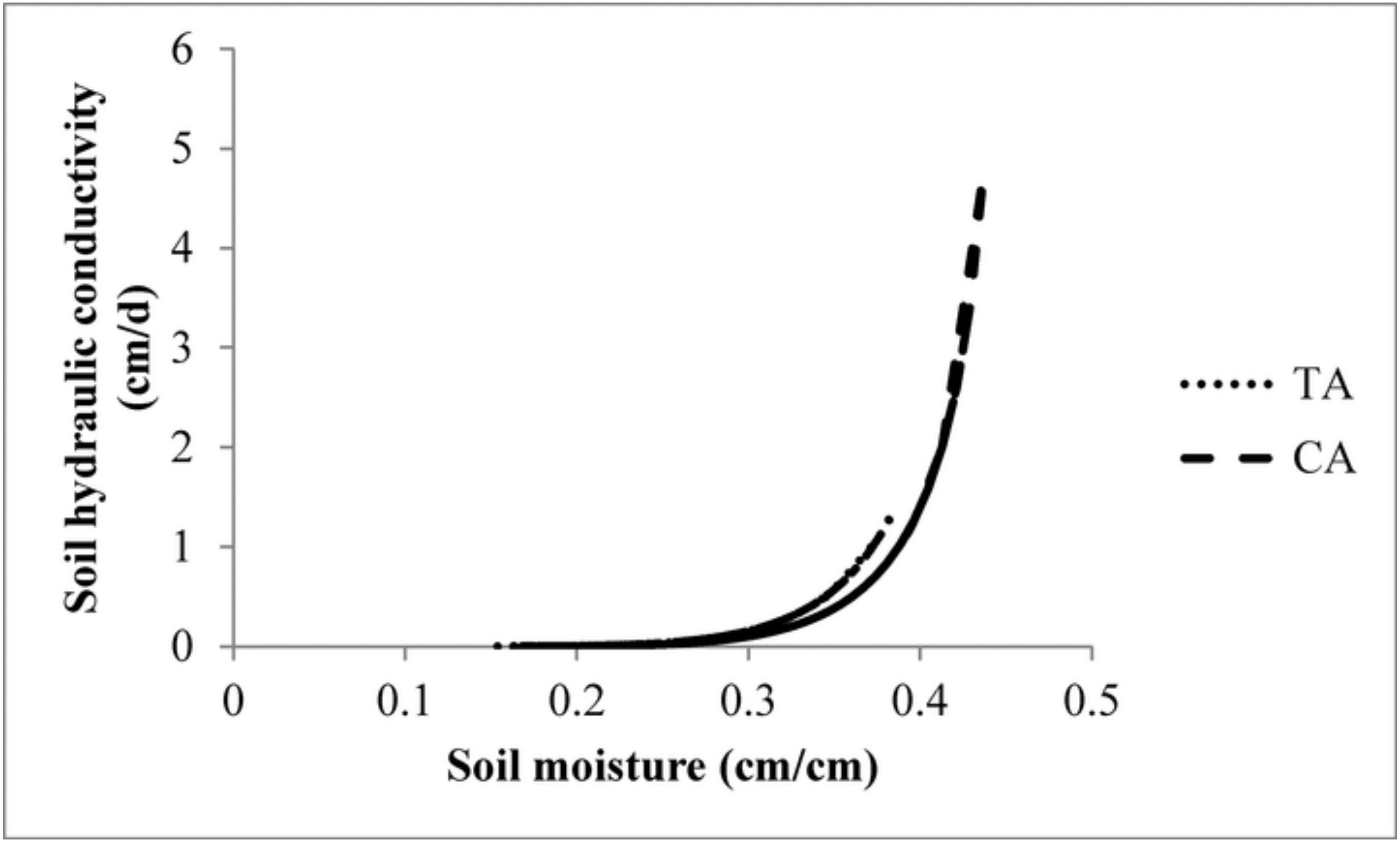
Figure5



Soil moisture (cm/cm)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
CA
TA
28-Jan
25-Feb
24-Mar

Figure6


0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Soil moisture (cm/cm)
0
500
1000
1500
2000
2500
Soil water potential (-cm)
TA
CA


Soil hydraulic conductivity (cm/d)
6
5
4
3
2
1
0
0
0.1
0.2
0.3
0.4
0.5
Soil moisture (cm/cm)
TA
CA