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Assessing alternative crops production under Nano-irrigation in Morocco (Case of Quinoa and Blue panicum crops under Moistube)

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Abstract

Moistube technology, widely known as nano-irrigation, is starting to gain popularity lately in Morocco compared to other buried irrigation systems made up of porous tubes. However, the technology remains unknown with installation difficulties for professionals, and only a few demonstration trials, and rarely scientific trials are conducted to demonstrate the potential to further minimize water consumption compared to drip irrigation. In this study, we compared the nano-irrigation (Moistube) and drip systems in terms of water-saving and their effect on the growth of two alternative crops tolerant to salt and water stress, “Quinoa with a single growth cycle " and " the Blue Panicum with several growth cycles". A factorial design was carried out for each of the two crops. Two different irrigation systems were installed for each crop, the standard drip system and the Moistube irrigation system (n = 12). For quinoa, there was no significant difference between the applied irrigation water amounts and shoot dry biomass under nano irrigation and drip irrigation while registering improvement in grain yield under nano irrigation system. For the blue panicum, the water savings, until harvest, were 26%, 29%, and 19% higher under the nano-irrigation than with the drip irrigation system for the 3rd, 4th, and 5th growth cycles respectively. However, the dry matter biomass was not significantly different between the nano irrigation and drip irrigation treatments. Insofar as the variations in water requirements on the scale of a growth cycle, the number of days between refills of the nano-irrigation tank increased over time to stabilize at an average of 6 days in summer and 10 days in winter. These results suggest that the nano-irrigation system could be efficient in terms of water-saving for crops with multiple growth cycles such as blue panicum. This leads us to assume that further water saving could be achieved particularly for tree crops with large lateral row spacings. The findings also suggest an earlier production under nano irrigation compared to drip irrigation. At last, we recommend the installation of the nano system during rainy periods when the soil is wet, and the soil suction forces are low which would increase the duration of irrigation of a filled reservoir and would allow important water savings during the crop growth cycle.

Keywords: Moistube, buried irrigation system, irrigation water saving, dry matter biomass, soil suction forces.

Évaluation de la production de des cultures alternatives sous Nano-irrigation au Maroc (Cas des cultures de Quinoa et Panic bleu sous Moistube)

Résumé

La technologie Moistube, largement connue sous le nom de nano-irrigation, commence à gagner en popularité ces derniers temps au Maroc par rapport à d'autres systèmes d'irrigation enterrés constitués de tubes poreux. Cependant, cette technologie reste encore méconnue avec des difficultés d'installation par les professionnels, et seuls quelques essais de démonstration, et rarement des essais scientifiques sont menés pour démontrer le potentiel de minimiser davantage la consommation d'eau par rapport à l'irrigation goutte à goutte. Dans cette étude, nous avons comparé les systèmes de nano-irrigation (Moistube) et de goutte-à-goutte en termes d'économie d'eau et leur effet sur la croissance de deux cultures alternatives tolérantes au stress salin et hydrique, le « Quinoa à cycle de croissance unique » et « le Blue Panicum avec plusieurs cycles de croissance". Un plan factoriel a été réalisé pour chacune des deux cultures. Deux systèmes d'irrigation différents ont été installés pour chaque culture, le système de goutte à goutte ordinaire et le système d'irrigation Moistube (n = 12). Pour le quinoa, il n'y avait aucune différence significative entre les quantités d'eau d'irrigation appliquées et la biomasse sèche de la partie aérienne sous nano irrigation et irrigation goutte à goutte et une nette amélioration du rendement en grains sous système de nano irrigation. Pour le bleu de panicum, les économies d'eau, jusqu'à la récolte, étaient de 26%, 29% et 19% plus élevées sous la nano-irrigation qu'avec le système d'irrigation goutte à goutte pour les 3eme, 4eme et 5eme cycles de croissance respectivement. Cependant, la biomasse de la matière sèche n'était pas significativement différente entre les traitements de nano irrigation et d'irrigation goutte à goutte. En considérant les variations des besoins en eau à l'échelle d'un cycle de croissance, le nombre de jours entre remplissages du réservoir de nano-irrigation a augmenté au cours du temps pour se stabiliser à une moyenne de 6 jours en été et 10 jours en hiver. Ces résultats montrent que le système de nano-irrigation pourrait être efficace et efficient en termes d'économie d'eau pour les cultures à cycles de croissance multiples comme le bleu de panicum. Ceci nous amène à supposer qu'une plus grande économie d'eau pourrait être réalisée en particulier pour les cultures arboricoles avec de grands espacements entre lignes. Les résultats suggèrent également une production plus précoce sous nano irrigation par rapport à l'irrigation goutte à goutte. Enfin, nous recommandons l'installation du nano système pendant les périodes pluvieuses lorsque le sol est humide et les forces d'aspiration du sol sont faibles ce qui augmenterait la durée du réservoir à irriguer et permettrait une économie d'eau considérable pendant le cycle de croissance des cultures.

Mots clés : Moistube, système d'irrigation enterré, économie d'eau d'irrigation, biomasse de matière sèche, forces d'aspiration du sol

تقييم إنتاج المحاصيل البديلة تحت الري بالنانو في المغرب (حالة محاصيل الكينوا و حشيشة البلوبانك تحت Moistube)

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ملخص

بدأت تقنية Moistube ، المعروفة على نطاق واسع باسم الري بالنانو ، في اكتساب شعبية مؤخرًا في المغرب مقارنة بأنظمة الري المدفونة الأخرى المصنوعة من الأنابيب المسامية. ومع ذلك، لا تزال هذه التكنولوجيا غير معروفة مع صعوبات التثبيت من قبل المتخصصين، مع عدد قليل من الاختبارات التوضيحية، ونادرًا ما يتم إجراء تجارب علمية لإثبات إمكانية تقليل استهلاك المياه بشكل أكبر مقارنة بالري بالتنقيط. في هذه الدراسة، قمنا بمقارنة أنظمة الري بالنانو والتنقيط من حيث توفير المياه وتأثيرها على نمو محصولين بديلين يتحملان إجهاد الملح والماء، وهما " الكنوا بدورة نمو واحدة " و " حشيشة البلوبانك مع عدة دورات النمو". وقد تم إعداد تصميم عاملي في الميدان لكل من المحصولين. تم تركيب نظامين مختلفين للري لكل محصول، نظام الري بالتنقيط العادي ونظام الري النانو (ن = 12). بالنسبة للكنوا، لم يكن هناك فرق بين كميات مياه الري المطبقة والكتلة الحيوية الجافة للجزء الجوي تحت الري بالنانو والري بالتنقيط فيما تم تسجيل تحسن ملحوظ في محصول الحبوب تحت نظام الري بالنانو. بالنسبة لحشيشة البلوبانك، كان توفير المياه أعلى بنسبة 26٪ و29٪ و19٪ تحت الري بالنانو مقارنة بنظام الري بالتنقيط لدورات النمو الثالثة والرابعة والخامسة على التوالي. ومع ذلك، لم تكن الكتلة الحيوية الجافة مختلفة بشكل كبير بين الري بالنانو والري بالتنقيط. زاد عدد الأيام بين ملء خزان الري بالنانو بمرور الوقت ليستقر بمعدل 6 أيام في الصيف و10 أيام في الشتاء. تشير هذه النتائج أن نظام الري بالنانو يمكن أن يكون فعالًا وفعالًا من حيث توفير المياه للمحاصيل ذات دورات النمو المتعددة مثل حشيشة البلوبانك. وهذا يقودنا إلى افتراض أنه يمكن توفير قدر أكبر من المياه لا سيما بالنسبة للمحاصيل الشجرية مع وجود مسافات كبيرة بين الصفوف. تشير النتائج أيضًا إلى إنتاج مبكر تحت الري بالنانو مقارنة بالري بالتنقيط. أخيرًا، نوصي بتركيب نظام النانو خلال فترات الأمطار عندما تكون التربة رطبة وتكون قوة شفط التربة منخفضة مما يزيد من مدة خزان الري ويسمح بتوفير كبير للمياه أثناء دورة نمو المحصول.

الكلمات المفتاحية: نظام الري المدفون، توفير مياه الري، الكتلة الحيوية للمادة الجافة، قوى شفط التربة

Introduction

In arid regions (46% of the total terrestrial surface (IPCC, 2019a)), the sustainable management of water resources is a challenge due to low and occasional rainfall which is causing water deficit, and affecting agricultural activities (IPCC, 2019b). According to the World Resources Institute, Morocco is among the top 20 countries facing "extremely high" levels of water stress (Luo *et al.*, 2015). This water stress level is expected to keep increasing under the Business-as-usual, Optimist and Pessimist scenarios by 2030 and 2040. The average water demand exceeds water supply by 3 billion cubic meters with 88 % of water uses in irrigation (Hssaisoune *et al.*, 2020). However, among countries with "extremely high" levels of water stress, Morocco is known for its exceptional water management plans to ensure a stable supply through a set of agricultural policies and strategies instituted since 1969. Under the Green Morocco plan, for example, water-saving irrigation systems, such as drip irrigation, are adopted by a large part of the farmers. The policy of generalization of the drip irrigation system has led to a marked improvement in the efficiency of the irrigation water use (Assouli *et al.*, 2018; Hssaisoune *et al.*, 2020). Buried porous tubes (PT) irrigation systems, also known as ‘’ Soaker hose, Leaky pipe, Ceramic pitcher, Semi-permeable membrane’’, have been developed and have been recently upgraded to further minimize water consumption while maximizing agricultural production (Tock and A’hern, 1982; Cai *et al.*, 2017; Kanda *et al.*, 2020a; Salisu *et al.*, 2021). Porous tubes are systems where water flows from the pores (nano, micro pores) throughout its entire length depending, particularly, on the water potential of the soil and the operating pressure (Teeluck and Sutton, 1998; Ashrafi *et al.*, 2002; Qingli, 2008; Janani *et al.*, 2011). They exist under different commercial names on the market but the principle of operation is the same. They continuously supply water to the crop at a certain percentage of the soil's field capacity (Herrera et al., 2020; Kanda, Senzanje, et al., 2020b). The differences between the various types of PT are in particular the manufacturer material (semi-permeable pipe, recycled material pipe, textile pipe, etc.), the number of pores per square centimeter (cm^2), the diameter and elasticity of the pores, reuse duration, possibility of collection during ploughing, etc.

In Morocco it is the Moistube (Qingli, 2008; Zou *et al.*, 2017), commonly called nano tube, which is the typical system known among other types of porous tubes. The Moistube is a pipe made of flexible semi-permeable membranes whose pores are in the nanometric range with approximately 100,000 nanopores per cm^2 with a pore diameter range of 10 to 900 nm (Kanda, Niu, et al., 2020). Being a relatively new technology having been developed in less than 10 years ago, there are not many studies carried out on that system. The meta-analysis carried out by Dirwai et al. (2021) found only 49 articles directly or indirectly related to Moistube technology (excluding articles from predatory journals and articles not published in English), 59% of which were carried out in China where the technology has emerged. Overall, these studies focused on themes such as Moisture depth and discharge, the geometry of the wet soil, clogging, fouling, and fertigation. Only 25% of these studies are related to yield response and water use efficiency with contrasting results recording increases, decreases, and similar yields and water use efficiency for few crops (mainly tomato) compared to drip irrigation. Africa is only represented by South Africa in terms of

scientific production (9 papers) and Morocco was reported to use the technology without publication in peer-reviewed journals. To our knowledge, some demonstration trials have been carried out by farmers on lemon, olive, avocado and tomato in Morocco. We also found a review poster (Lamrahli *et al.*, 2018)showing variable yields with over 20% water saving using the Moistube, and a graduate thesis (ES-saady, 2018) showing low yield and excessive water loss for tomato crop.

The contrasting results which have been reported show that in Morocco the PT technology remains unknown and that additional studies are necessary to control the management parameters of the system. We first carried out laboratory experiments to examine the water dynamics and discharge of two soil types at different pressure heads and at different bulk densities (Data part of a new manuscript). The findings helped in determining the appropriate parameters to correctly design the Moistube irrigation system for the field experiments. In this paper we present field experiments carried out at the Regional Centre for Agricultural Research of Agadir, Morocco. We investigated the effect of the Moistube and drip irrigation on water saving and on the growth of "Quinoa" (*Chenopodium quinoa Willd*) and "Blue Panic (*Panicum antidotale Retz*)" two water stress and salinity-tolerant alternative crops adapted to fragile environments. We also examined the number of tank refills and their durations under Moistube irrigation during the growth cycles. After presenting the key outputs we draw important research implications for practice.

Materials and methods

Site and preparation work

The field trials were carried out at the INRA experimental station of Melk Zhar which is located at the Municipality of had Belfaâ, (Southern Morocco; 30° 6 N, 9°36 W). The site's soil is sandy a subtropical brown soil on sandy and deep limestone sands (Table 1) and the climate of the area is generally dry with average annual temperatures of around 19 ° C, the average maximal and minimal temperatures reaching 27 ° C and 11 ° C respectively. The absolute maxima can, however, exceed 48 ° C in summer and absolute minima can drop to -2 ° C in winter. Rainfall is erratic in space and time and varies between 70 and 350 mm per year, thus leading to a significant water deficit in terms of both surface water and groundwater resources.

Two irrigation systems were tested, the standard drip system and a low-pressure subsurface irrigation system (Moistube) containing nanopores. The assessment was carried out on “Quinoa” (Chenopodium quinoa) and “Blue panicum” (Panicum antidotale Retz) crops, so-called drought and salinity-tolerant alternative crops typical of arid areas. Both crops were tested given the growing socio-economic importance it attracts particularly in marginal environments of Morocco. The species used were collected after varietal selection tests carried out in 2017-2018 at the INRA experimental station of Laâyoune located in the irrigated perimeter of Foum El Oued (Hirich *et al.*, 2021a). These species are characterized by their resistance to harsh environmental conditions and their performance in term of grain and plant biomass yield. Land preparation started on 01/06/2020 and the installation of the two irrigation systems lasted 1.5 months. Direct sowing, as a common practice for quinoa, started on 27/02/2020 at a density of 8-9 g per 20 m^{-2}, and the harvest started on 06/11/2020. Blue panicum was first sown in the nursery on 20/02/2020 then transplanted onto plots on 20/03/2020 at a density of 10 plants m^{-2} (0.2 x 0.5 m). Blue panicum is a perennial grass, the harvest started on the 26/5/2020 and was carried out on several mowing, we are presenting here the results of the first five consecutive cuts. The various preparation, installation and maintenance operations of both Quinoa and Blue panicum are summarized in Table 2.

Experimental design

A factorial design was carried out on a total net area of 480 m^2 for each of the two crops (Figure 1). Two different irrigation systems were installed; the standard drip system and the Moistube irrigation system; in 12 replicates each (12 elementary plots of 20 m^2 for each irrigation system type). For each replicate plot, spacings between rows and between plants were 0.5 m and 0.2 m respectively. The characteristics of the drip irrigation emitters used are : turbulent flow, nominal declared flow of 4.00 L h^{-1}, average flow 4.04 L h^{-1}, 14.20 mm internal diameter, distance between dripper of 0.4 m and 20.00 mm h^{-1} of precipitation. In the drip system, an average flow rate of emitters in the system (closest and most distant emitters) was measured at the start of each growth cycle. Regular pumps were used for drip irrigation and the crop water requirements were calculated by multiplying the ETo with crop coefficients (WR = Kc × ET0), then daily applied. The amounts of irrigation water were applied by subtracting the rainfall from the estimated water requirements. ETo was estimated using pan evaporation methods (class A pan installed at the Melk Zher experimental station)

(Allen *et al.*, 1998). Kc values from three key growth stages were used to make a rough estimate of the water requirements of both quinoa (0.52 for the initial stage, 1.00 for the development and mid-season stage and up to 0.70 during the late season to harvest) (Garcia *et al.*, 2003; Razzaghi *et al.*, 2012) and blue panicum (an average Kc over all growing cycles of 0.7 for the initial stages, 1.25 for the devolvement and mid-season stages and 1.0 for late stages) (Ismail and El-Nakhlawy, 2018). The Kc (s) of blue panicum, however, vary from one growth cycle to the next and have been used accordingly (Ismail and El-Nakhlawy, 2018). The Kc values of the main growing stages were logged into a spreadsheet then extrapolated to generate a daily crop coefficient curve in accordance with the different growing stages length. It should be noted however that the values of Kc differ according to the environment, for the various genotypes, and the densities of plantation making their assignment difficult (Stanschewski *et al.*, 2021). Irrigation water amounts were applied by subtracting any rainfall from the water requirements that were estimated. For the Moistube irrigation system, laterals were placed at 20 cm depth and the nanopores discharge was mainly controlled by the applied water pressure head then by the soil suction which is related to the daily climatic variation and soil moisture. Thus, irrigation water tanks were set at 4.7 m height to give an operating pressure head of 4.6 bars.

A set of measures were carried out to monitore the physiological parameters of plants, water quality, and the dynamics of soil characteristics under each irrigation system. In this paper, we only present the dry matter and grain biomass yields as well as the applied irrigation water amounts of quinoa and blue panicum under the two irrigation systems. The applied irrigation water amounts s were recorded by meters installed at the outlet of the tanks and within the plots for each irrigation system. Data were analyzed using a general linear model analysis of variance (one-way ANOVA) and p-values of 0.05 were used as the threshold for significance. Data were tested for normality and homogeneity of variances and all computations were made using SPSS (IBM Corp. Released 2016, version 24).

To explore the number of tank refills and their duration under nano-irrigation over the period of the growth cycles, we plotted a case of recorded data of an area of 80 m^2 of blue panicum irrigated with a reservoir of 1.5 m^3. This would give us an overview of the evolution of irrigations over time when the equilibrium between soil suction and Moistube discharge is reached and would explain the yields and efficiency of the system for the crops.

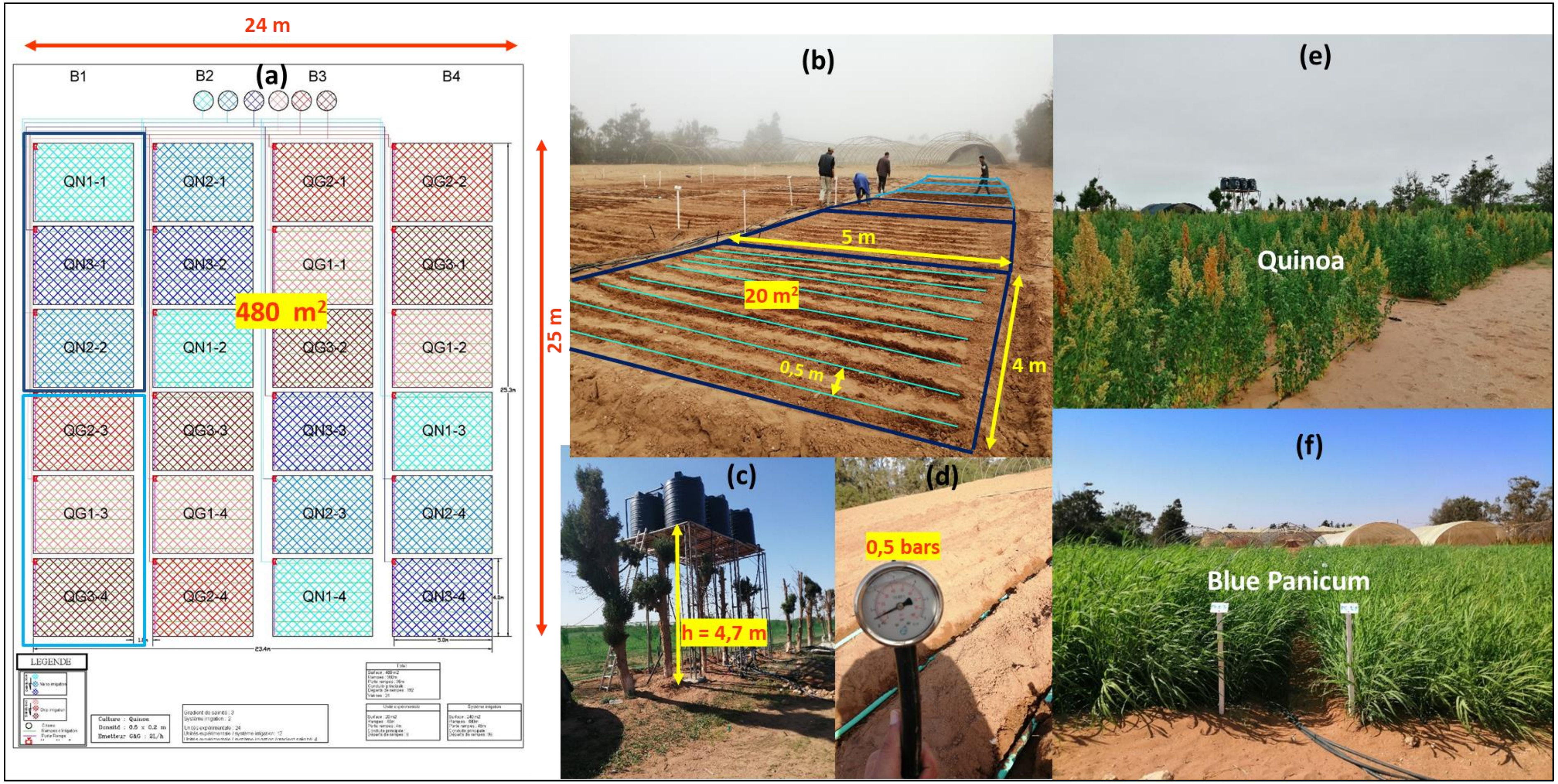

Figure 1: The field experiment set-up. (a) shows the experimental design carried out on a total net area of 480 m^2 for each of the two crops. The blue and brown plots in (a) show the Moistube and drip system plots respectively. (b) is the actual representation of the frame in dark blue and light blue to the right of (a). The green rows in (b) are a graphical representation of the buried Moistube laterals. (c) show the irrigation water tanks set at 4.7 m height to irrigate the Moistube plots and (d) is the corresponding operating pressure head. (e) and (f) are the “Quinoa” and “Blue panicum” crops on which the experiment was carried out.

Table 1: Physical and chemical properties of the soils at 30 cm depth in the field experiment (*n* = 4, mean ± standard deviation).

pH[1]	Organic matter[2] (%)	Electrical conductivity (dS m^{-1})[3]	Soil dry bulk density (g cm^{-3})[4]	Available phosphorus P_2O_5 (ppm)[5]	Potassium K^+ (ppm)[6]	Total limestone[7]	WHC (cm^3 cm^{-3})[8]	K_{sat} (cm day^{-1})[9]	Clay (%)[10] < 2 µm	Silt (%)[10] 2-50 µm	Sand (%)[10] 50-2000 µm	Textural class
7.85 ± 0.11	0.59 ± 0.32	0.15 ± 0.69	0.20 ± 0.03	31.02 ± 11.97	293.55 ± 41.06	14.05 ± 0.85	0.26 ± 0.02	186.38 ± 48.98	8,80 ± 1,52	8.47 ± 1,56	82.99 ± 1,57	Loamy Sand

[1] Determined using a ratio of 1: 2.5 (soil: water).
[2] Soil organic matter content determined by the Walkley-Black chromic acid wet oxidation method.
[3] Electrical conductivity on 1:5 soil: water.
[4] Bulk density corer with rings of 100 cm^3
[5] Available phosphorus using the Olsen method.
[6] The exchangeable bases with ammonium acetate extract.
[7] The total carbonate using the Bernard calcimeter test analyses.
[8] Soil water holding capacity was measured in accordance with ISO 11268-2:1998.
[9] The saturated hydraulic conductivity using the Muntz method.
[10] The particle size analysis using the hydrometer method.

Table 2: The various preparation, installation and maintenance operations and their dates during Quinoa and Blue Panicum growing cycle.

Quinoa		Blue Panicum	
Operations	**Date**	**Operations**	**Date**
Plots ploughing	06/Jan/2020	Plots ploughing	06/Jan/2020
Cover crop	07/Jan/2020	Cover crop	07/Jan/2020
Staking and plotting	08/Jan/2020	Staking and plotting	09/Jan/2020
Start of installation of Nano (Moistube) and drip irrigation systems	13/Jan/2020	Start of installation of Nano (Moistube) and drip irrigation systems	13/Jan/2020
Quinoa sowing	27/Feb/2020	Blue panicum seedlings in the nursery	20/Feb/2020
		Beginning of blue panicum emergence	26/Feb/2020
		Blue panicum transplantation	20/Mar/2020
Start of weeding	30/Mar/2020	Start of weeding	31/Mar/2020
Hand weeding	14/Apr/2020	Hand weeding	15/Apr/2020
Start of Quinoa harvest	11/Jun/2020	Blue panicum 1st cutting	26/Mai/2020
		Blue panicum 2nd cutting	06/Jul/2020
		Blue panicum 3rd cutting	01/Oct/2020
		Start of harvesting of the seeds of Blue Panicum from the 3rd cut	14/Sep/2020
		Blue panicum 4th cutting	15/Dec/2020
		Blue panicum 5th cutting	20/April/2021

Results

Applied irrigation water amounts, dry biomass and grain yield of quinoa

Quinoa is a short growth cycle plant compared to blue panicum. Figure 2 presents the Mean of the applied irrigation water amounts of Quinoa under Nano irrigation and Drip irrigation. The results show no significant difference between applied irrigation water amounts when growing quinoa under buried irrigation system and under drip irrigation (p = 0.115; Figure 2). No sign of stress was observed on the shoots during the growth of the plant and at the end of the experiment. The dry matter biomass was higher in the treatments under Nano irrigation than under drip irrigation system (Figure 3). However, this increase was not significant (p = 0.191). Contrary to the results of the dry biomass yield, the grain yield of the quinoa crop showed a highly significant increase under Nano irrigation than under drip irrigation system (p = 0.0049; Figure 4). An early harvest was carried out on plots under Nano irrigation than drip irrigation.

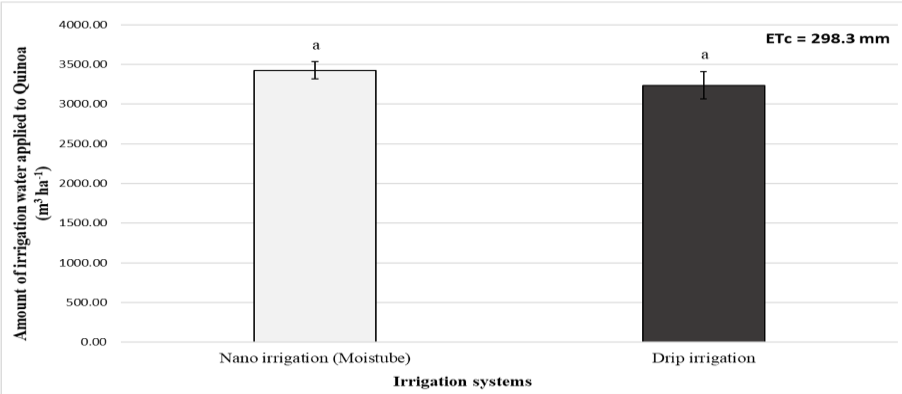

Figure 2: Mean of amounts of irrigation water applied to Quinoa under Nano irrigation and Drip irrigation. ETc is the calculated water requirements during the crop's growth cycle. Columns with the same letter over them are not significantly different (n = 12, error bars = standard deviations).

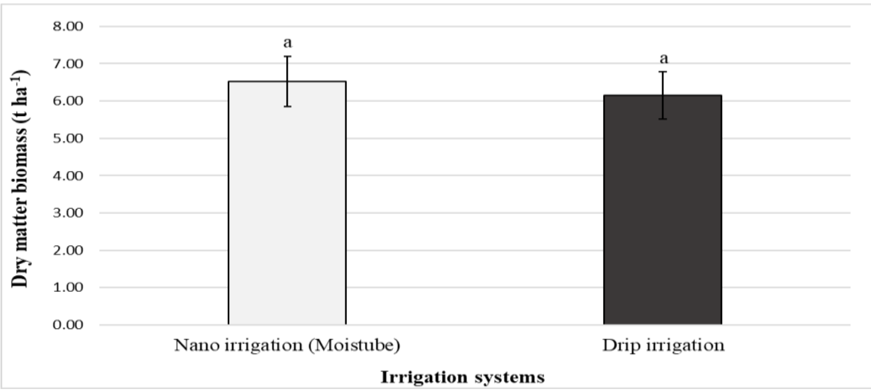

Figure 3: Mean dry matter biomass of Quinoa under Nano irrigation and Drip irrigation. Columns with the same letter over them are not significantly different (n = 12, error bars = standard deviations).

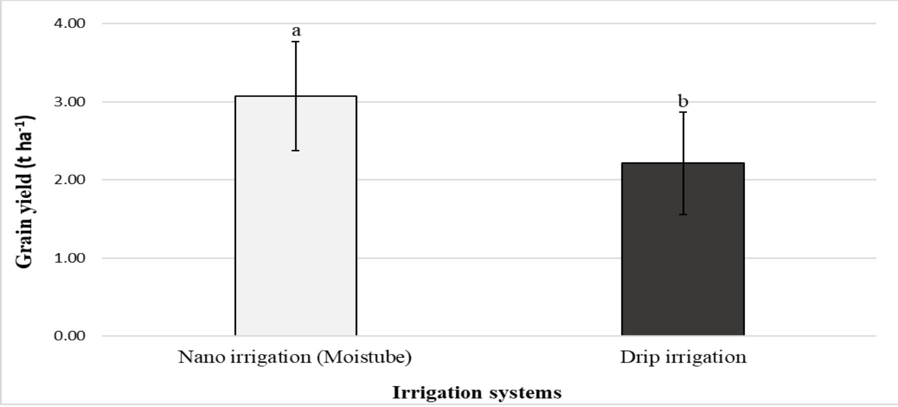

Figure 4: Mean grain yield of Quinoa under Nano irrigation and Drip irrigation. Columns with the same letter over them are not significantly different (*n* = 12, error bars = standard deviations).

Applied irrigation water amounts and biomass yield of blue panicum

Blue panicum is a long-cycle forage plant with several cuttings. The results of the 5 cutting cycles in terms of applied irrigation water amounts and biomass yield are shown in Figures 5 and 6. The applied irrigation water amounts of blue panicum were initially significantly higher in nano-irrigation than in drip irrigation during the first and second cutting cycles. The applied irrigation water amounts were then significantly higher in drip irrigation compared to nano irrigation treatments for the 3rd, 4th and 5th growth cycles (Figure 5). The amount of water used for irrigation during each growth cycle was significantly different for the nano-irrigation and for drip irrigation treatments. This amount of water was the highest in the first growth cycle of blue panicum and then decreased in subsequent growth cycles, significantly for the 2^{nd} 4^{th} and 5^{th} cycles.

The dry matter biomass of Blue panicum at the first cut (Figure 6 A) was not different between the nano irrigation and drip irrigation systems treatments. Although the yield in the nano system became higher compared to the drip irrigation treatment for the following cuts (except for the 3rd cut), the differences were not significant.

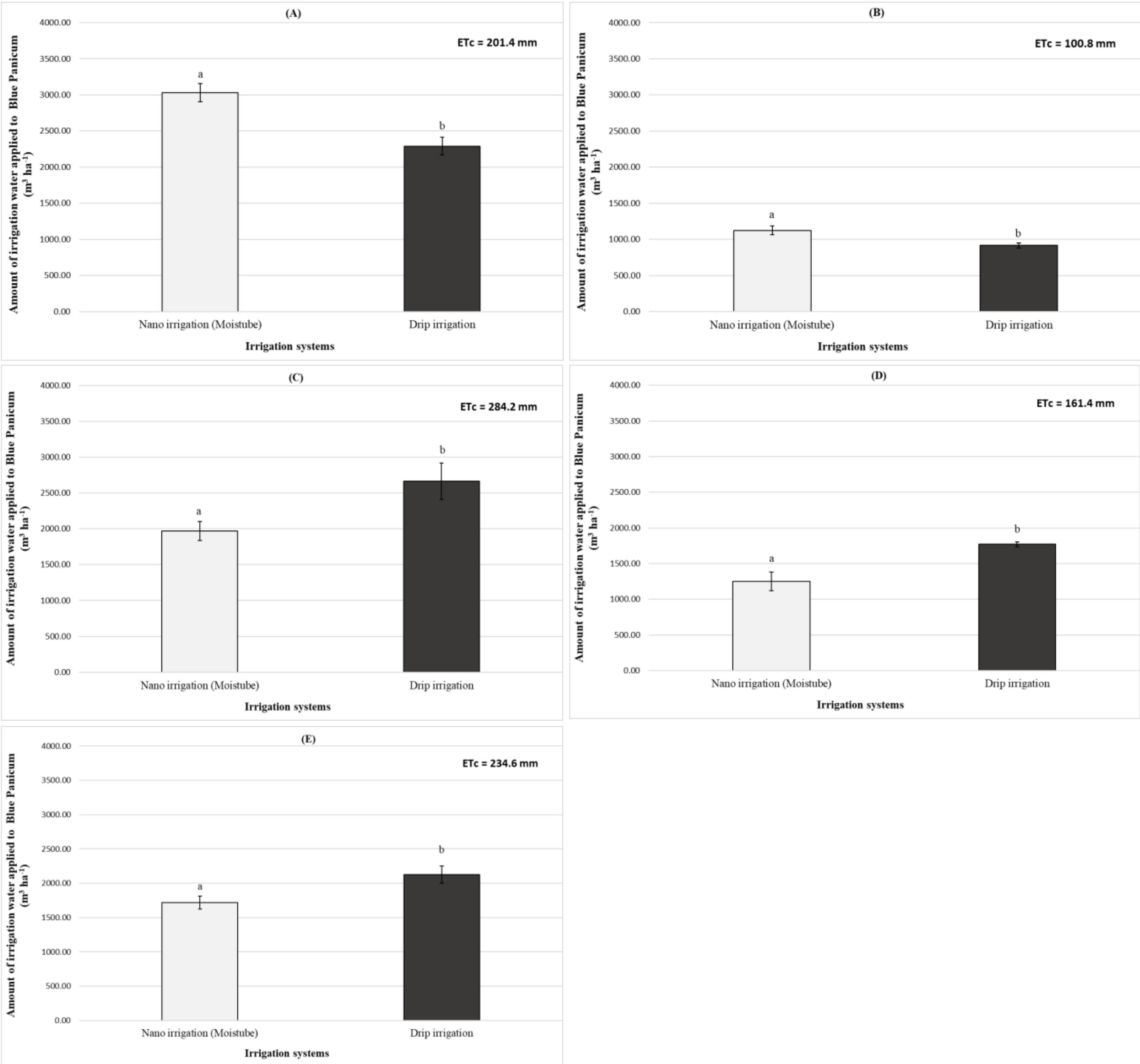

Figure 5: Mean of amounts of irrigation water applied to Blue panicum under Nano irrigation and Drip irrigation for the 1st cutting (A), 2nd cutting (B), 3rd cutting (C), 4th cutting (D) et 5th cutting. ETc is the calculated water requirements during the crop's growth cycle. The grains of blue panicum were collected in the 3rd and 5th growth cycle which impacted the cycles lengthen for shoot harvest and therefore the amount of water applied compared to the ETc. Columns with the same letter over them are not significantly different (*n* = 12, error bars = standard deviations).

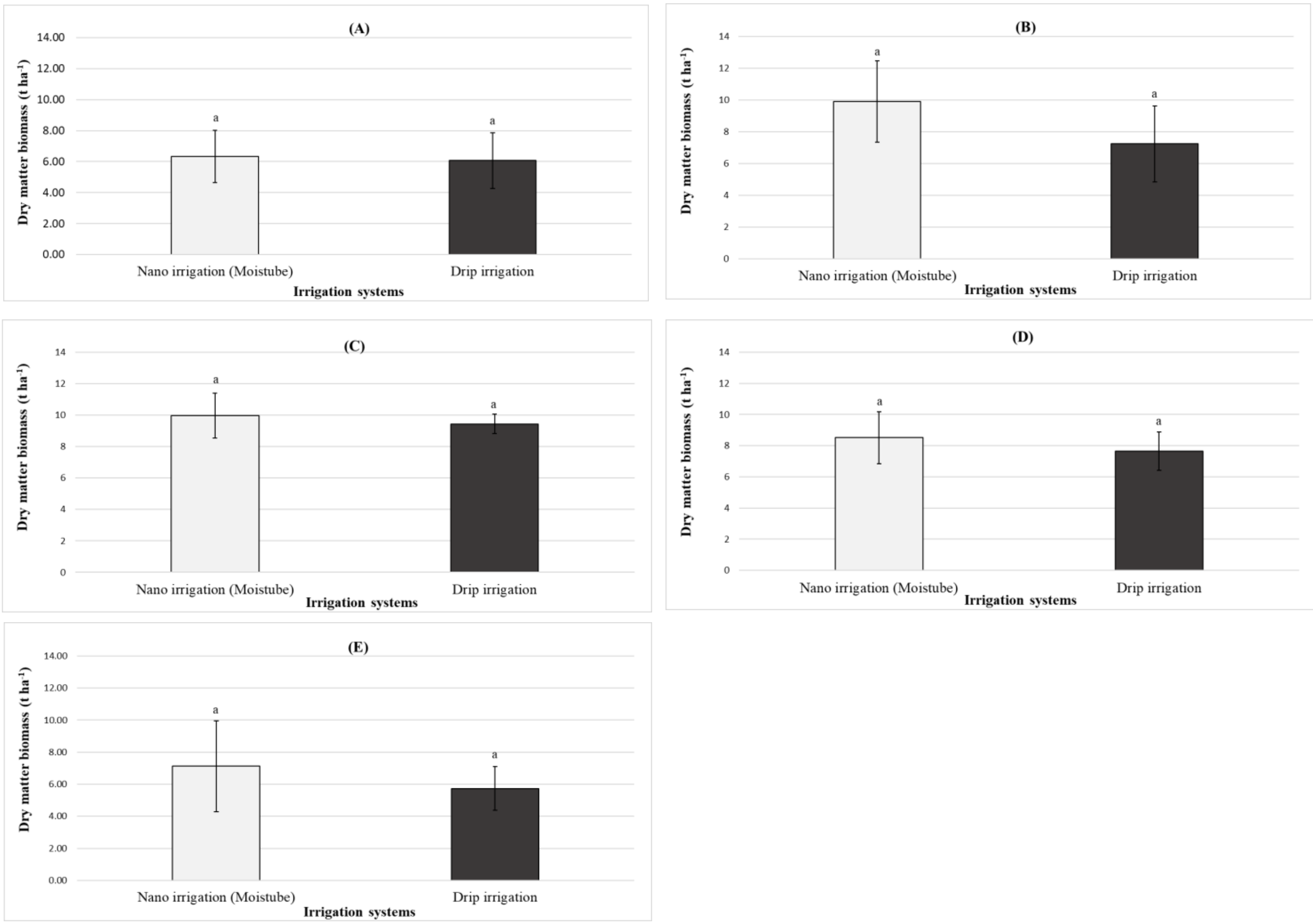

Figure 6: Mean dry matter biomass of Blue panicum under Nano irrigation and Drip irrigation for the 1st cutting (A), 2nd cutting (B), 3rd cutting (C), 4th cutting (D) et 5th cutting. Columns with the same letter over them are not significantly different (n = 12, error bars = standard deviations).

Tank irrigation duration under Nano system (Moistube)

The number of tank refills (X axis) and their durations (Y axis) over the time of an area of 80 m^2 (4 plots of 20 m^2 each) of blue panicum under the nano system are shown in Figure 7. At the start of the experiment, the irrigation of 80 m^2 with a 1.5 m^3 tank lasts less than 24 hours (less than 8 hours for the very first irrigation). The duration of irrigations of a filled tank increased over time to reach 5 days at the end of the 1st growth cycle of bule panicum. It then stabilized at 6 days on average during the 2nd and 3rd growth cycles. Over the period of late autumn 2020 and winter 2021 during the 4th and 5th growing cycles, the number of days required until refilling the tank increased further to reach an average of 10 days and a maximum of 12 days in late April 2021.

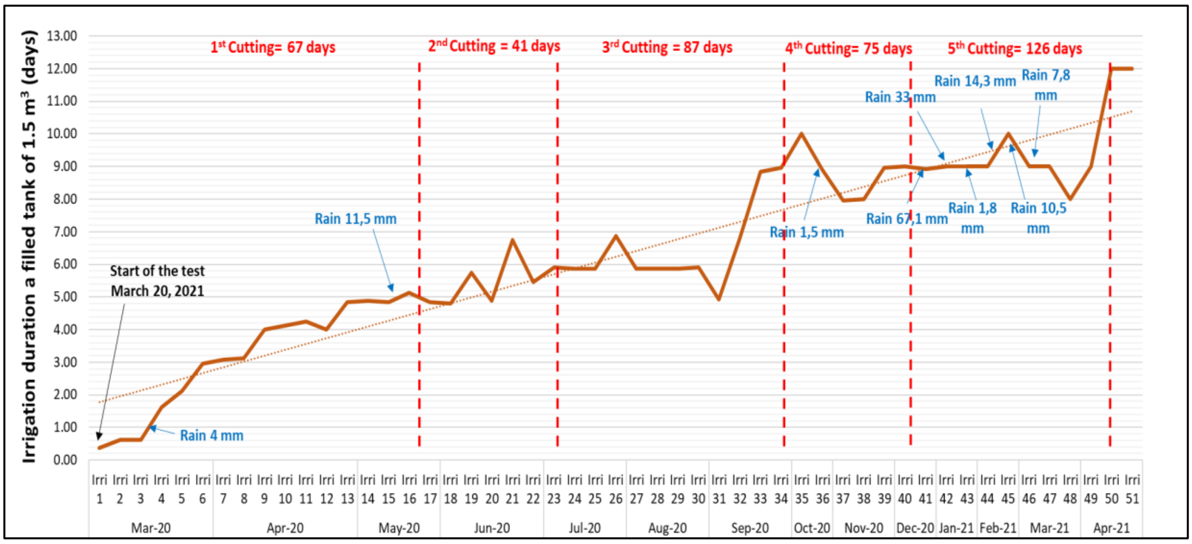

Figure 7: Evolution of the duration of the irrigation of an area of 80 m^2 of blue panicum with a filled tank of 1.5 m^3 under the system Moistube. The letters *''Irri 1, Irri 2, etc.''* on the X axis indicate the number of tank refills over the months and growth cycles. The red dotted lines indicate the dates and length in days of a growth cycle until cutting. The blue arrows indicate the dates and the amount of rain during the period of the experiment.

Discussion

Our initial hypotheses were that the yield of grain and dry biomass would increase with a net water saving under nano irrigation treatment. At the end of our experiment, our data supported our first hypothesis for Quinoa experiment in terms of grain yield, but they did not fully support the second part of our hypothesis for both crops. For Quinoa the yield of grain and dry biomass ranges are consistent with findings of previous studies (FAO and CIRAD, 2015; Hirich *et al.*, 2021b; Liu *et al.*, 2021). After 90 days experiment, our results show similar dry biomass under nano and drip irrigation (Figure 3). This result is consistent with the results for quinoa in terms of applied irrigation water amounts in both systems. Qualitative observations over the course of the experiment, showed a faster emergence, development and growth of the crop under the nano-irrigation system (Moistube) than under the drip system. The measured contents of proline and of chlorophyll pigments and leaf area (Data part of a new manuscript) were different between both systems. This suggests that despite the insignificant differences in the applied irrigation water amounts, quinoa is less stressed under nano-irrigation treatment than under drip irrigation. As a result, a homogeneous harvest was achieved in a short timeframe for the nano plots compared to the drip irrigation plots. This would have given good conditions and enough time for the grains of quinoa under nano-irrigation to grow better and weigh more. Therefore, the grain yield was significantly greater under nano irrigation at applied irrigation water amounts similar to that of the drip system (Figure 4). The results would suggest an earlier production under nano irrigation compared to drip irrigation.

The Moistube continuously moistens the soil through the nanopores in proportion to the demand and has been reported for water savings ranging from 13% to 38% (depending on the crops) greater than a drip irrigation system (Xue *et al.*, 2013; Lyu *et al.*, 2016; Yin *et al.*, 2017). Although it was installed in a way as to allow better water use, both irrigation systems showed no difference in terms of the applied irrigation water amounts under the quinoa crops (Figure 2). Similar trends were roughly obtained for blue panicum, but solely for the first and second growth cycles (Figure 5 A and B). Water savings were then approximately 26%, 29%, and 19% higher under the nano-irrigation than with the drip irrigation system for the 3rd, 4th and 5th growth cycles respectively. The number of tank refills and their duration per growing cycle (Figure 7) can largely explain the results obtained in terms of water saving for quinoa and blue panicum. Figure 7 clearly shows that when the blue panicum were transplanted to the plots at the start of the experiment (Irri 1 to Irri 3 of the X axis of Figure 7), the soil was still dry and the 1.5 m^3 tank did not even hold half a day for 80 m^2. Over time, as the soil becomes wetter and suction forces decrease and only tank height pressure forces dominate, the irrigation duration of a filled tank increases to a maximum of 12 days of irrigation by the end of the 5th growth cycle. Therefore, we had a high irrigation water amounts applied for the first cuts of the blue panicum, as there were soil matrix suction forces (pore-water pressure) and net normal stress (atmospheric pore-air pressure) changes (Rahardjo *et al.*, 2019) and a significant less irrigation water was applied for blue panicum by the fifth growing cycle (figure 5). This could also explain the insignificant differences in the applied irrigation water amounts under the two irrigation

systems for quinoa with a growth cycle of only 90 days (Figure 2). It would further explain as well the contradicting results found in literature regarding water use efficiency of the first harvesting for crops (tomato, corn, winter wheat, etc) in nano system compared to micro irrigation (Xue *et al.*, 2013; Lyu *et al.*, 2016; Zhang *et al.*, 2017; ES-saady, 2018). Poor control of system management parameters such as soil dry bulk density, Moistube depth, pressure head and soil texture could also explain these contrasting results (Zhang, 2013; Niu *et al.*, 2017a b). In practice, these finding suggest that the nano-irrigation system could be effective and efficient in terms of water saving for long-cycle crops such as blue panicum. We assume that a greater water saving could be achieved particularly for tree crops with large lateral row spacings compared to denser laterals for other crops.

Figure 7 also shows that at the balance between the blue panicum water requirements, the soil suction and the atmospheric soil pore-air pressure, the optimal irrigation duration of a filled tank is 6 days in summer and 10 days in winter for a tank of 1.5 m^3 on 80 m^2 of a loam sandy soil with a dry bulk density of 1.20 g cm^{-3}. We therefore recommend the installation of the nano system during rainy periods when the soil is wet and the suction forces are low which would lead to a rapid equilibrium between the water needs of the crop, the atmospheric and the soil matric suctions, which in turn affect the duration of irrigation reservoir.

The dry matter biomass annual yield of blue panicum was in line with what was reported by previous studies (Heuzé *et al.*, 2016; Salehi, 2020). The yields however, did not follow the same trend as for the applied irrigation water amounts during growth cycles and were similar between both irrigation systems. The difference in length of growing cycles (Table 2, Figure 7) largely affected the yields, the amount of consumed water under each irrigation system and consequently the percentage of water savings under the nano-irrigation relative to the drip irrigation system. The difference in length of growing cycles was attributed to the effect of growing seasons, late harvest (especially for the 3rd growth cycle, for which we waited longer to collect more mature seeds for subsequent experiments) and occasionally due to logistic limitations. Although the dry matter biomass of blue panicum was similar for both nano and drip irrigation over the growing seasons, the seeds collected at the end of the 3rd growth cycle (Data part of a new manuscript) were significantly higher in the nano irrigation system than in drip irrigation system, which is in line with our previous findings for Quinoa (Figure 4). This result supports our previous hypothesis of an earlier seed yield under nano irrigation compared to drip irrigation, despite similar dry biomass yields.

Conclusion

In this study, we looked at the potential of nano-irrigation versus drip irrigation system to save water and help increasing yields of quinoa and blue panicum crops. We have demonstrated that the nano-irrigation system could save water better than drip irrigation, however, this is only true for multi-growth-cycle crops (e.g., arboriculture, forage crops, etc.) and when key installation parameters have been optimized. Although the dry matter biomass of quinoa and blue panicum was not significantly different between the two irrigation systems, both crops reached maturity earlier under nano irrigation than by drip irrigation. This resulted in a significant increase in grain yield under nano irrigation. In this experiment, we examined the evolution of the number of tank refills and the irrigation duration of a filled tank under the nano system. The results are consistent with the nano system saving water in the subsequent growth cycles of the crops compared to the first ones. We also showed that the number of tank refills and the irrigation duration of a filled tank are a function of the initial state of the soil and on seasonal changes which also play an important role in the balance between the crop's water requirements, the atmospheric and the soil matric suctions. This highlights that caution should be exercised when installing the nano irrigation system during hot seasons when the soil is dry and the atmospheric demand is high, which can have a more dominant effect on water consumption. To better understand the processes under the nano-irrigation system and their implications, further investigations in terms of water quality and different crop rooting strategies are needed including. Large-scale experiments are required (e.g., larger plots, longer Moisture laterals, use of probes) for a finer upscaling of the system.

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References

Allen R., Pereira L., Raes D. and Smith M. (1998). Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. FAO. 300th édition. D05109 pages.

Ashrafi S., Gupta A D A S., Babel M S., Izumi N. and Loof R. (2002). Simulation of infiltration from porous clay pipe in subsurface irrigation. Hydrological Sciences Journal. 47 (2). p. 253–68. https://doi.org/10.1080/02626660209492928

Assouli O., el BILALI H., ABOUABDILLAH A., HARBOUZE R., el JAOUHARI N., CHAOUI M. and BOUABID R. (2018). TRANSITION FROM SURFACE TO DRIP IRRIGATION INMOROCCO: ANALYSIS THROUGH THE MULTI-LEVELPERSPECTIVE. AGROFOR International Journal. 3 (3). p. 10. https://doi.org/https://doi.org/10.7251/AGRENG1803142A

Cai Y., Wu P., Zhang L., Zhu D., Chen J., Wu S. and Zhao X. (2017). Simulation of soil water movement under subsurface irrigation with porous ceramic emitter. Agricultural Water Management. 192. p. 244–56. https://doi.org/https://doi.org/10.1016/j.agwat.2017.07.004

Dirwai T L., Mabhaudhi T., Kanda E K. and Senzanje A. (2021). Moistube irrigation technology development, adoption and future prospects: A systematic scoping review. Heliyon. 7 (2). p. e06213. https://doi.org/10.1016/j.heliyon.2021.e06213

ES-saady S. (2018). Etude comparée du système d’irrigation de nano-irrigation vis-à-vis du système d’irrigation au goutte-à-goutte, pour une culture de tomate de plein champ. (Taroudant) 46 pages.

FAO. and CIRAD. (2015). State of the Art Report of Quinoa in the World in 2013. FAO. 605 pages.

Garcia M., Raes D. and Jacobsen S-E. (2003). Evapotranspiration analysis and irrigation requirements of quinoa (Chenopodium quinoa) in the Bolivian highlands. Agricultural Water Management. 60 (2). p. 119–34. https://doi.org/https://doi.org/10.1016/S0378-3774(02)00162-2

Herrera P J., Tejeda M V., Riverol M L H., Cisneros Z E., Cun G R. and Sarmiento G O. (2020). Riego localizado mediante tuberías porosas. Revista Ingeniería Agrícola. 10 (3). p. 3–9.

Heuzé V., Tran G. and Sauvant D. (2016). Feedipedia, a programme by INRAE, CIRAD, AFZ and FAO. . https://www.feedipedia.org/node/413. (cited September 7, 2021).

Hirich A., Choukr-Allah R., Ezzaiar R., Shabbir S A. and Lyamani A. (2021a). Introduction of alternative crops as a solution to groundwater and soil salinization in the Laayoune area, South Morocco. Euro-Mediterranean Journal for Environmental Integration. 6 (2). p. 52. https://doi.org/10.1007/s41207-021-00262-7

Hirich A., Rafik S., Rahmani M., Fetouab A., Azaykou F., Filali K., Ahmadzai H., Jnaoui Y., Soulaimani A., Moussafir M., el Gharous M., Karboune S., Sbai A. and Choukr-Allah R. (2021b). Development of Quinoa Value Chain to Improve Food and Nutritional Security in Rural Communities in Rehamna, Morocco: Lessons Learned and Perspectives. Plants. 10 (2). https://doi.org/10.3390/plants10020301

Hssaisoune M., Bouchaou L., Sifeddine A., Bouimetarhan I. and Chehbouni A. (2020). Moroccan Groundwater Resources and Evolution with Global Climate Changes. Geosciences. 10 (2). https://doi.org/10.3390/geosciences10020081

IPCC. (2019a). Desertification. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems . 249–343 pages.

IPCC. (2019b). Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,. 630 pages.

Ismail S M. and El-Nakhlawy F S. (2018). Measuring Crop Water Requirement and Crop Coefficient for Blue Panic Crop Under Arid Conditions Using Draining Lysimeters. Irrigation and Drainage. 67 (3). p. 454–60. https://doi.org/https://doi.org/10.1002/ird.2230

Janani A., Sohrabi T. and Dehghanisanij H. (2011).Pressure variation impact on discharge characteristics of porous pipesIn. Ed. ICID. 8th International Micro Irrigation Congress. p . 284–96.

Kanda E K., Niu W., Mabhaudhi T. and Senzanje A. (2020a). Moistube Irrigation Technology: A Review. Agricultural Research. 9 (2). p. 139–47. https://doi.org/10.1007/s40003-019-00448-0

Kanda E K., Senzanje A. and Mabhaudhi T. (2020b). Modelling soil water distribution under Moistube irrigation for cowpea (VIGNA unguiculata (L.) Walp.) crop*. Irrigation and Drainage. 69 (5). https://doi.org/10.1002/ird.2505

Lamrahli D., Abouabdillah A. and Bouabid R. (2018). Efficience des systèmes d'irrigation localisée : goutte à goutte, irrigation souterraine et nano-irrigation.

Liu M., Yang M. and Yang H. (2021). Biomass production and nutritional characteristics of quinoa subjected to cutting and sowing date in the midwestern China. Grassland Science. 67 (3). https://doi.org/10.1111/grs.12307

Luo T., Young R S. and Reig P. (2015). Aqueduct projected water stress country rankings. 1–16 pages.

Lyu W., Wenquan N., Jun G., Yuan L., Xiaoyang Z. and ZHANG R. (2016). Effects of moistube depth and density on tomato yield and quality in solar greenhouse. Chinese Journal of Eco-Agriculture. 24 (12). p. 1663–1673.

Niu W., Lü W., Gu J., Liang B., Guo L. and Guan Y. (2017a). Effects of moistube depth and spacing on soil water and salt transports of tomato in solar greenhouse. Transactions of the Chinese Society of Agricultural Engineering. 33 (19). p. 131–40.

Niu W., Zhang M., Xu J., Zou X., Zhang R. and Li Y. (2017b). Prediction Methods and Characteristics of Flow for Moistube. Nongye Jixie Xuebao/Transactions of the Chinese Society for Agricultural Machinery. 48. p. 217–24 and 241. https://doi.org/10.6041/j.issn.1000-1298.2017.06.028

Qingli Y. (2008). Research Prospect of the Water-saving Irrigation by Semi-permeable Film. Journal of Water Resources and Water Engineering.

Rahardjo H., Kim Y. and Satyanaga A. (2019). Role of unsaturated soil mechanics in geotechnical engineering. International Journal of Geo-Engineering. 10 (1). https://doi.org/10.1186/s40703-019-0104-8

Razzaghi F., Plauborg F., Jacobsen S-E., Jensen C R. and Andersen M N. (2012). Effect of nitrogen and water availability of three soil types on yield, radiation use efficiency and evapotranspiration in field-grown quinoa. Agricultural Water Management. 109. p. 20–9. https://doi.org/https://doi.org/10.1016/j.agwat.2012.02.002

Salehi M. (2020). Hypersaline Water for Alternative Crop Irrigation in Iran. In Emerging Research in Alternative Crops. Springer, Cham. 1st.

Salisu A., Wayayok A., Abdallah A F. and Kamal R Md. (2021). Discharge Characterization and Variability Determination along Shorter Sections of Soaker Hose Pipe for Soil Column Experiment. Basrah Journal of Agricultural Sciences. 34. p. 92–9. https://doi.org/10.37077/25200860.2021.34.sp1.10

Stanschewski C S., Rey E., Fiene G., Craine E B., Wellman G., Melino V J., S. R. Patiranage D., Johansen K., Schmöckel S M., Bertero D., Oakey H., Colque-Little C., Afzal I., Raubach S., Miller N., Streich J., Amby D B., Emrani N., Warmington M., Mousa M A A., Wu D., Jacobson D., Andreasen C., Jung C., Murphy K., Bazile D., Tester M. and on behalf of the Quinoa Phenotyping Consortium. (2021). Quinoa Phenotyping Methodologies: An International Consensus. Plants. 10 (9). https://doi.org/10.3390/plants10091759

Teeluck M. and Sutton B G. (1998). Discharge characteristics of a porous pipe microirrigation lateral. Agricultural Water Management. 38 (2). p. 123–34. https://doi.org/https://doi.org/10.1016/S0378-3774(98)00060-2

Tock R Wm. and A'hern D W. (1982). Considerations for manufacture of irrigation pipe. Advances in Polymer Technology. 2 (3). p. 177–85. https://doi.org/https://doi.org/10.1002/adv.1982.060020306

Xue W., Niu W., Zhang Z. and Zhang K. (2013). Effects of the tomato growth and water use efficiency in sunlight greenhouse by moistube-irrigation. Agricultural Research in the Arid Areas. 31 (6). p. 61–6.

Yin Y., Shen L., Guo Y. and Zhang C. (2017). The effect of different Moistube spacing of alternate micro-irrigation on water spinach growth in greenhouse. Water Saving Irrigation. 42 (9). p. 1–4.

Zhang J. (2013). Experimental Study on Characters of Wetted Soil From Line-Source Infiltration in Moistube Irrigation. (China).

Zhang M., Niu W., Lu Z., Li Y., Wang J. and Qiu X. (2017). Effect of moistube-irrigation on crop yield and water use efficiency. Chinese Journal of Eco-Agriculture.

Zou X., Quan T., Zhou M., Yang Q L. and Shi Y. (2017). Progress and prospects of moistube irrigation technology research. Bulletin of Soil and Water Conservation. 37 (4). p. 150–5.