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COMPARATIVE WATER AND N FERTILIZER UTILIZATION IN FERTIGATION v/s SOIL APPLICATION UNDER DRIP AND MACRO SPRINKLER SYSTEMS OF SPRING POTATOES UTILIZING ^{15}N IN CENTRAL BEQAA, LEBANON

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Abstract

The experiment aimed at studying the impact of type of fertilizer application and irrigation techniques on the yield parameters of spring potatoes by using ^{15}N. In 1997 and 1998, a potato crop (Spunta) was planted in a clayey soil in Tell Amara, Central Beqaa, in a randomized block design. It consisted of five treatments and four replicates. The goal of the research was to study the effect of three rates of N fertigation (N1 = 240, N2 = 360, N3 = 480 kg N/ha for 1997 and N1 = 120, N2 = 240, N3 = 360 kg N/ha for 1998) on potato performance and production, comparing full fertigation with conventional fertilizer application and irrigated with drip and macro sprinkler. Water demands and irrigation were scheduled according to the mean annual potential evapotranspiration in 1997 and Class A pan in 1998, and monitored by the neutron probe and tensiometers. The results show that, at harvest, both crops followed the same yield pattern. The highest tuber yield was obtained from N1 and the lowest from N3. These values were 58 ton/ha for 1997 and 32.5 ton/ha for the 1998 trial. The 1998 spring crop was more efficient in terms of N utilization. The reduction of N input in N1 resulted in 90% N-fertilizer recovery. In the treatment with soil N application, drip irrigation saved up to 50% of water and improved the efficiency of removed N. Starting from the 89th day after planting, sprinklers caused a significant difference in NO3- concentration leached beyond 60 cm depth. Thus, fertigation was superior with regard to fertilizer and water saving and it decreased the risk of N building up in the soil and shallow groundwater resulting in pollution.

1. INTRODUCTION

In Lebanon cash crops are fertilized by soil application of complex, low solubility fertilizers and irrigated by macrosprinklers. The average yields of most crops are relatively low: 40 ton/ha for citrus and 20–25 ton/ha for potato [1,2]. In 10 years, the total water consumption in Lebanon is expected to reach 3,400 million m^3 [3]. The average available surface and ground water is less than 300 million m^3 [4]. Nutrient and water use efficiency can be improved through fertigation with micro irrigation systems [5]. The efficient use of irrigation water and fertilizers is essential to keep food supply in balance with the increasing demand on environmentally sound practices [6]. Increasing crop production with the improvement of its quality and reduction in the cost is becoming a problem for the sustainability of agriculture in Lebanon. This implies increasing both fertilizer and water use efficiencies.

Such conditions also apply to potato, as an important cash crop in Lebanon. It is a major winter crop on the coastal area, and spring and summer crop in the Beqaa Valley. The area which is cultivated with potato in Lebanon is 14,580 ha [7], of which 67.4% is located in the Beqaa Valley.

The rates of fertilization and irrigation of cash crops in Lebanon are not based upon the results of local research and conclusions. In fact, farmers apply 1,700 kg/ha of compound NPK (300 kg N/ha) fertilizers split into two applications and irrigated for 8–12 hours/week with macro sprinklers, regardless of the crop development stage, weather conditions, the soil type and expected yield. This could result in overfertilization and excessive irrigation contributing to lower water and fertilizer use efficiency and possible ground water contamination by nitrate. The implementation of fertigation on potato is an actual and important issue to secure higher yields with better quality on an economically and environmentally safe ground. For these reasons, this study was conducted aiming at establishing the N demands, water and fertilizer use efficiencies of spring potato in the main growing region of the Beqaa valley, as affected by N input, methods of fertilizer application and irrigation technique.

2. MATERIALS AND METHODS

A field experiment involving the use of labelled N fertilizers with the heavy isotope ^{15}N and aiming at studying the impact of different rates of N on the yield of the Spunta H (Hettema) potato variety was undertaken. The trials were conducted on a non-calcareous clay, 0–2%, montmorillonitic Typic Xerorthent soil (Table I) at the National Institute for Agronomic Research (Tell-Amara station) in the Central Beqaa Valley, Lebanon, in the spring of 1997 and 1998. For both seasons, sowing was conducted in early May and tubers harvested towards the end of August.

TABLE I. SOIL CHARACTERISTICS OF THE EXPERIMENTAL SITE

Location	Depth (cm)	pH (1:2.5)	EC (dS/m)	Clay	Silt (%)	Sand	O.M (%)	P (mg/kg)	K	Total N (%)
Tell-	0–20	8.0	0.44	42	32	25	1.2	28	360	0.147
Amara	20–40	7.9	0.44	42	32	25	1.1	28	360	0.147
Station	40–60	8.0	0.46	42	32	25	1.0	28	370	0.123

The practice of the Lebanese farmers consists of irrigating potatoes through macro sprinklers (nozzles 5/32 or 5/36 and discharge 1.6 m^3/hour), for 8 hours, once a week, between sowing and emergence. During the next fifteen days, the duration of irrigation is increased until 10 hours weekly to reach, in general, 12 hours/week during the rest of the season. So, Ncs (N control sprinkler) was fertilized similarly to Ncd (N control drip) but it was irrigated according to the practice of the farmers.

2. 1. Treatments

Irrigation was scheduled according to the mean annual potential evapotranspiration [8] in 1997 and Class A-pan in 1998. The crop fractions were applied according to [5].

The treatments of the 1997 trial consisted of 3 N application rates: N1 = 240 kg N/ha, N2 = 360 kg N/ha and N3 = 480 kg N/ha (Table II). Based on the results of the first year, the rates of N were reduced in the 1998 trial to become: N1 = 120, N2 = 240, N3 = 360 kg N/ha. For comparison of the two irrigation techniques, two control treatments were included in the study and both received the same N fertilization rate as N2 but as soil application. One of the treatments was irrigated with the macro sprinkler (Ncs), while the other was irrigated with a drip system (Ncd).

The concentrations of P and K were kept fixed in all treatments and were equivalent to 200 and 400 kg/ha, respectively. The design of both experiments was a RBD, with 5 blocks and 4 replicates. The dimensions of each plot were 4.5 × 9 m. In each plot 6 rows were planted at a density of 25 × 75 cm. i.e., a total of 216 plants/plot of which 144 plants were effective.

2. 2. Isotope studies

The use of labelled fertilizers provides a direct method for the evaluation of N and P uptake by different plant species [9]. In each plot, a small area (microplot) was designated for ^{15}N

application. Microplots or isotope plots usually cover the smallest possible area to obtain a representative sample for the estimation of the isotopic parameters [10]. Microplots, with an area of 1.125 m^2 each, consisting of 6 plants in 1997 and 1.5 m^2 and 8 plants in 1998, were chosen from the middle rows. Microplots were fertigated with ~1.5% ^{15}N atom excess, applied as ammonium sulfate. For data collection and estimation of N fertilizer recovery, only the protected plants were chosen: 2 in 1997 and 4 in 1998.

TABLE II. METHODS OF FERTILIZER APPLICATION AND IRRIGATION TECHNIQUES

Treatments	Irrigation system	Fertilizer application	N (kg/ha) 1997	N (kg/ha) 1998	P (kg/ha)	K (kg/ha)
Ncs	Macro Spray	Soil	360	240	200	400
Ncd	Drip	Soil	360	240	200	400
N1	Drip	Fertigation	240	120	200	400
N2	Drip	Fertigation	360	240	200	400
N3	Drip	Fertigation	480	360	200	400

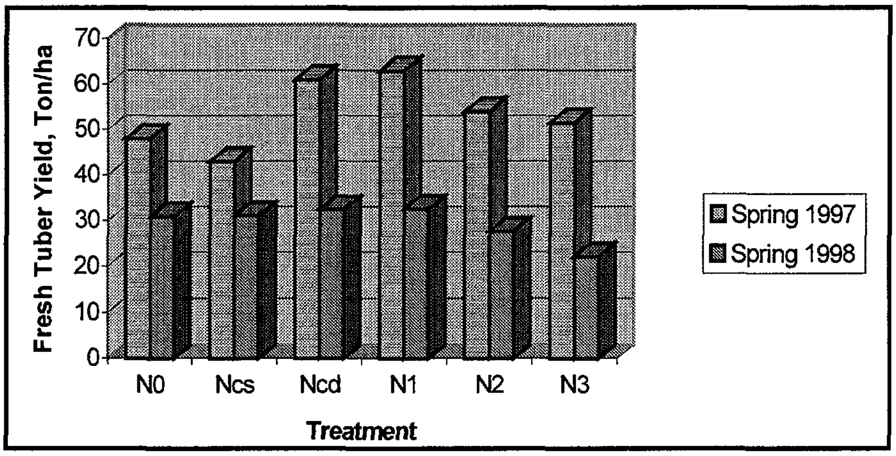

FIG. 1. Fresh tuber production at physiological maturity of fertigated spring potatoes in Central Beqaa, Lebanon.

3. RESULTS

3. 1. Tuber fresh yield

In both trials, the fresh tuber production at physiological maturity followed the same pattern (Fig. 1). However, no significant difference was among the treatments. In both cropping years, N1 and Ncd gave a slightly higher yield. This trend indicates the possibility of reducing the N input under potato in the Beqaa plain, where the built up of soil N could be mobilized and used as additional reserve, beside the N present in the irrigation water.

The results imply the possibility of a more efficient use of nutrients and water by fertigation or by a simple shift to localized irrigation techniques. Beside, as long as no significant increase of yield with higher inputs was obtained, there is a rational or a potential for decreasing the water and N doses applied to potatoes in the Beqaa Valley. This must help water saving, reducing the cost of production and preventing hazards related to the buildup of nutrients in the soil and their possible transfer to the groundwater.

3.2. Tuber size and specific gravity

The best commercial tubers were obtained by the lowest N input in both years (Table III), with the dominance of the elite category (>50% in 1997 and >40% in 1998).

As at maturity, this was influenced by the N fertilization rate. According to the results, a low N input reduced the life period of the plant and accelerated the maturity of the tubers, whereas high N levels had a delaying effect on plant senescence. However, the specific gravity values were not significantly affected by an increasing N level, suggesting a comparable level of tuber maturity. But, excess water could have resulted in a lower dry matter (DM) content, as it decreased by 2.2% in the treatment irrigated by sprinklers as compared to the drip system, in 1997 only (Table IV). The comparison of the mean DM and SG values of all treatments irrigated by drip with those values obtained from the macro sprinkler treatment demonstrates a possible trend between the irrigation practice and these important yield components.

TABLE III. DISTRIBUTION OF MARKETABLE TUBERS (% OF TOTAL)

Treatment	Ncd		N1		N2		N3	
	97	98	97	98	97	98	97	98
<4 cm	13.0	7.71	10.0	9.93	12.2	11.25	13.1	10.49
4–6 cm	36.0	52.85	32.5	45.74	41.2	51.76	33.8	49.22
>6 cm	51.0	39.44	57.5	44.33	46.6	36.99	53.1	40.29

TABLE IV. MEAN TUBER CHARACTERISTICS AS AFFECTED BY THE METHOD OF IRRIGATION

Characteristics	Drip		Sprinkler	
	1997	1998	1997	1998
Specific gravity	1.08	1.07	1.07	1.06
Dry matter (%)	20.2	16.65	18.0	16.25
Starch content (%)*	13.8	10.40	11.8	10.05

*: Conversion from specific gravity according to [11].

As reported in the literature, increased levels of N fertilizers results in a decreased dry matter and starch content [12,13,14]. The results show that these criteria did not lead to a significant difference with regard to the way of fertilizer application. However, the irrigation techniques and water amount revealed a trend of priority for the drip systems.

3.3. Dry matter production

With different N rates, ways of fertilizer application and irrigation techniques, the dry matter production showed a trend of decrease with the excess N input (Table V). For the same N rate and application, the drip irrigated treatments showed a priority in terms of dry matter accumulation in the tubers.

TABLE V. TUBER DRY MATTER PRODUCTION OF SPRING POTATOES (kg/ha) WITH DIFFERENT MANAGEMENT OF WATER AND NUTRIENT INPUTS

Treatment	N0	120 kg N/ha	240 kg N/ha	360 kg N/ha	480 kg N/ha	Ncs	Ncd
1997	9192	--	11788	9511	10149	7898	11072
1998	5022	5460	4506	3714	--	5059	5215

3.4. Interactions between water applied, consumed water and dry matter production

The amount of water applied by fertigation through the drip system was 497 mm (93.19 L/plant) for the 1997 spring potato and 495 mm (92.81 l/plant) for 1998 (Table VI). The treatment with the macro sprinkler system, widely practiced by Lebanese farmers, received 839 mm (157.3 L/plant) and 879 mm (164.81 L/plant) for 1997 and 1998, respectively. This result illustrates the possibility of water saving. As an intermediate phase towards full fertigation practices, the reliance of drip irrigation coupled with the same fertilizer application technique could be an alternative.

Efficiency of water application and use

With the expected future scarcity of water, it is crucially important to plan land use considering water availability and crop water consumption in close relation to farmers' income. A comparison between both irrigation systems shows an extremely higher water application for the production of one unit of dry matter with the sprinkler system as compared to the drip system (Fig. 2).

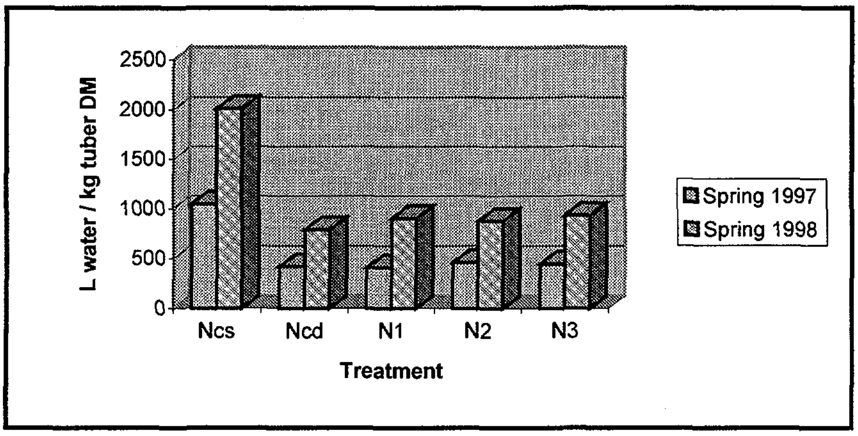

FIG. 2. Amount of applied water to produce one unit of consumable product for spring potato in Central Beqaa, Lebanon

Therefore, productivity was significantly higher for the latter. Consequently, more important water losses occur under the macro sprinkler system (Table VII).

Water saving to produce the same tuber dry matter of the spring crop varied about 100% in both trials. These results suggest a further saving on the recommended water input as this amount is far below the recommended value (750 mm) and actually applied amount (~840 mm) of water for the spring crop, according to the practice of farmers. This was a further improvement on previous research showing that the water demand of potatoes did not exceed 650 mm [15].

TABLE VI. WATER REQUIREMENTS OF SPRING POTATO IN CENTRAL BEQAA, LEBANON

Days After Sowing							Total (mm)
Spring	1–15	16–30	31–45	46–60	61–75	75–105	
Crop Fraction*							
	0.4	0.7	0.9	0.8	0.7	0.7	
Applied Water by Drip (l/plant)							
Spring 97	7.8	15.15	20.96	18.80	15.33	15.16	497.0
Spring 98	8.01	13.96	19.43	19.84	16.73	14.84	495.0
Applied Water by Sprinkler (l/plant)							
Spring 97	21.6	23.6	35.4	23.6	23.6	23.6	839.0
Spring 98	17.14	18.86	34.0	36.0	29.4	29.4	879.0

- [5]

TABLE VII. WATER APPLICATION AND CONSUMPTION (mm) BY POTATO IN THE 1998 SPRING SEASON IN CENTRAL BEQAA, LEBANON

Treatment	Applied Water	Effectively applied (ef) water	Consumed Water	Leached Water mm	Leached Water % from (ef)
Ncs	879	615	343.3	271.7	44.2
Ncd	495	445	404.5	40.5	9.1
N2	495	445	350.8	94,2	21.2

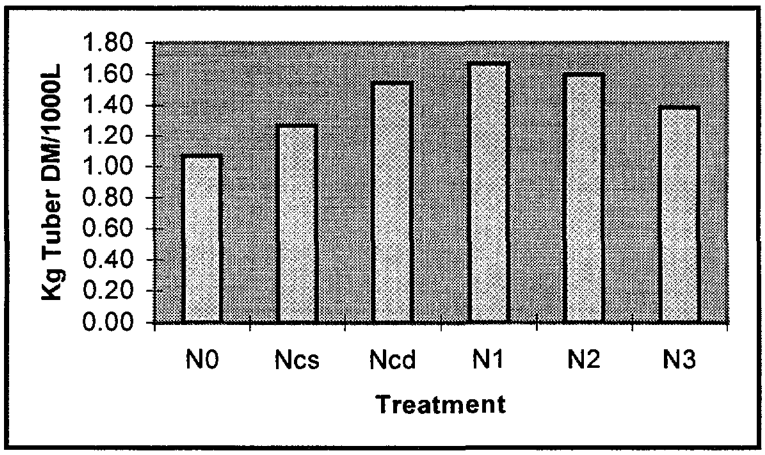

FIG. 3. Efficiency of consumed water per unit tuber dry matter production for spring potato in central Beqaa, Lebanon (1998).

However, calculation of the efficiency in relation to the consumed amount of water revealed the least consumed water per unit dry matter production for the lowest N input in 1998. The highest consumption was observed for N0 (Fig. 3). It seems that in the absence of N, the crop transpiration increased. Within the current soil fertility background and the nitrate content in the irrigation water, a more efficient use of consumed water was noticed for the lowest N application rate (N1).

3.5. Aspects of nitrogen use efficiency

3.5.1. Nitrogen content

The total N content in the potato plants at physiological maturity showed significant differences only for the aboveground parts of the 1997 season (Table VIII).

TABLE VIII. TOTAL N CONCENTRATION (% DRY MATTER) IN POTATO AT PHYSIOLOGICAL MATURITY

Treatments	Foliage		Tubers	
	1997	1998	1997	1998
Ncs	2.53 b	4.89	1.07	2.48
Ncd	2.93 a	3.64	1.37	2.02
N1	3.35 a	3.60	1.53	1.09
N2	3.61 a	4.34	1.61	2.19
N3	3.99 c	4.59	1.52	2.21

Means within a column followed by the same letters are not statistically different at the 5% level.

The excess N input (N3 = 480 kg N/ha, in 1997) resulted in a different accumulation of N in the above-ground parts and not in the tuber yield, causing a delayed maturity in N3 with an important vegetative growth. This fact could have slowed down the translocation of nutrients to the sink. However, with a lower fresh tuber production, the 1998 trial showed an increase in N concentrations in both parts of the potato crop.

A lower N concentration was noticed in Ncs of the 1997 trial, due to reduced water use efficiency following the overirrigation by the macro sprinkler system. As a possible consequence, plants in Ncs had a vigorous growth reflected by the dilution effect on the N concentration in the aboveground parts. This resulted in an N concentration as low in Ncs as 0.45% in the consumable product with, however, no significant difference in comparison with N2. Such an effect was confirmed in the 1998 trial where 240 kg N/ha for Ncs presented a reverse picture.

Consequently, the potato cropping system with 360 kg N/ha applied to the soil and irrigated with the macro sprinkler system may only increase the cost of production. Considering the current land use and practices at the farmers' level, a relatively low efficiency of water and fertilizers might result in a low net return. This could threaten the sustainability of agriculture in Lebanon.

3.5.2. Fertilizer N utilization

With equal amounts of nutrients, N2 and Ncd were more efficient than Ncs (Tables IX and X). The amount of water applied with the drip was 44% less than that applied with the macro sprinkler (Table VII), confirming once more the efficiency of the localized system in controlling water and nutrient supply. Moreover, since it can efficiently be applied in all types of areas - undulating terrain, rolling topography, hilly areas, shallow soils and water scarce areas – a concerted policy should be formulated to increase the area under drip irrigation by taking into account both the availability of irrigation water and the demographic expansion [16].

TABLE IX. NITROGEN REMOVAL AND RECOVERY BY THE OVER GROUND PARTS OF SPRING POTATO (Mean values from 4 replicates)

Cropping System	Treatment	DM yield (kg/ha)	N yield (kg/ha)	Ndff %	Fertilizer N yield (kg/ha)	% Fertilizer N Utilization*
	Ncs	3924.5a	109.9a	38.70a	42.3a	11.8a
	Ncd	4250.4a	128.0a	49.20a	63.3a	17.6a
Spring	N1	2445.5a	081.2a	38.51a	31.3b	13.0a
1997	N2	2517.5a	089.2a	44.30a	38.1a	10.6a
	N3	2152.8a	087.3a	50.80a	44.9a	09.4a
	Ncs	3609.5	183.3a	52.7a	92.8	38.7a
	Ncd	2906.0	107.2ab	28.9b	34.0	14.2b
Spring	N1	2487.7	88.15ab	63.2a	55.6	46.3a
1998	N2	2835.8	123.3ab	57.4a	68.8	28.7ab
	N3	2896.9	135.1ab	62.1a	86.4	24.0ab

- Within each cropping season, values followed by the same letter have no statistically significant difference.
*- %Fertilizer N Utilization is the ratio of fertilizer N yield to the N rate of application.
- %Ndff: N derived from fertilizer.

TABLE X. NITROGEN UPTAKE AND RECOVERY BY POTATO TUBERS.

Cropping System	Treatment	DM yield (kg/ha)	N yield (kg/ha)	Ndff %	Fertilizer N yield (kg/ha)	% Fertilizer N Utilization*
	Ncs	7979.2	111.0	38.2a	42.5	11.76
	Ncd	8266.6	108.3	46.5a	51.6	14.32
Spring	N1	7076.6	108.8	23.5b	26.6	11.09
1997	N2	8387.9	135.0	41.5a	56.0	15.55
	N3	5512.6	081.5	50.1a	40.9	08.51
	Ncs	4364.8	106.2	48.1a	50.5ab	21.1b
	Ncd	6260.0	122.3	29.5b	35.8b	15.0b
Spring	N1	5474.6	109.3	50.8a	52.6ab	43.9a
1998	N2	5617.8	122.1	51.8a	63.7a	26.5b
	N3	5308.4	116.8	55.8a	64.3a	17.9b

* % Fertilizer N Utilization is the ratio of fertilizer N yield to the N rate application.
- % Ndff: N derived from fertilizer

On the other hand, the N1 (120 kg N/ha) treatment in the 1998 trial appeared to be more attractive than both treatments receiving the middle level of N (Ncs, Ncd and N2) in terms of fertilizer utilization. This rate was also more suitable from the economical as well as the public health and environmental point of view. It is worth mentioning the low fertilizer N yield and fertilizer N utilization of the Ncd treatment in the 1998 trial. It seems that applying the full N dose (240 kg N/ha) to the soil resulted in an expansive use of soil N with higher water consumption.

Thus, in soils containing enough residual N to ensure, beside the N present in water, a reasonable yield, research should aim for the lowest effective rates of N maintaining the soil fertility and producing a high yield with appropriate quality. In this study, the 1998 spring crop was more efficient than the 1997 one in terms of N use, as clearly shown by the high fertilizer N recovery (90%) with the lowest N rate. Elsewhere, it has been demonstrated that the potato crop can make successful use of the soil reservoir: up to 70% of the total removed N, even with the application of both ammonium and nitrate fertilizers [17]. Taking into consideration other N sources, recommendations for the use of N carriers should be oriented and adapted for meeting both crop and site requirements.

Trials run in Lebanon showed that to get a modest yield of 28 tons/ha, an amount of 100 kg N/ha was necessary. An additional tuber yield of 6 tons/ha required an increase in N input of 20%, without any modification in the applied P and K [18]. An excess rate of fertilizer-N did not significantly contribute to higher yields and negatively affected some tuber qualities [14]. In many temperate areas, N is the nutrient the most likely to be limiting on most soil types and in most seasons [19]. Concerning the soils of the Middle East Region the available N, as ammonium and nitrate, is so low that soils easily respond to N fertilization [20]. A tuber yield of 50 ton/ha requires as much as 250 kg N/ha as total N uptake in both tuber and plant vegetative parts [21]. Potato yields of up to 70 ton/ha could be obtained under irrigated conditions and an N application of 300 kg N/ha would be economically justifiable [22].

3.6. Nitrate in the soil and soil solution

With the use of modern irrigation, fertigation became a promising means for maintaining N concentrations in the soil within the rooting zone, throughout the growing period, at desirable levels, without undue losses by leaching [23]. This is especially important with regard to possible nitrate leaching and contamination of the ground water. Indeed, increasing rates of N results in higher soil nitrate residues. This is in agreement with other results [14]. The fluctuation of NO_3^- was affected not only by the rate of N application, but also by the way of fertilizer application and irrigation techniques. With drip irrigation NO_3^- was maintained within the root zones while it was intensively leached with macro sprinkler irrigation (Table XI).

Study of the nitrate levels in the soil solution by tensionics gave, starting from the 89th day after planting, a significant difference between the NO_3^- leached beyond the root zone, under macro sprinkler irrigation than from the fertigated and drip irrigated treatments (Fig. 4). The NO_3^- concentration in these treatments, between 60 and 80 cm depth, did not present a significant fluctuation around the values noticed in N0 and N1.

This could result in a higher yield and better quality products than by conventional irrigation means [24]. The NO_3^- accumulation or leaching is important not only for the quality of the consumed product (Table XII), but also for the quality of soils and underground water.

4. DISCUSSION AND CONCLUSION

Trials with fertigation of potato demonstrated that a constant N-concentration in the final solution provided a better yield [25]. The uptake efficiency of mineral nutrients, notably N, was increased substantially through fertigation [23, 26]). This is particularly relevant to the nitrate form of N, which is not retained in the soil and therefore moves with other soluble salts to the wetted front. This mobility can best be overcome by application of nitrate-N with every irrigation at a concentration adequate to satisfy the crop requirement for N from one irrigation to the other [27]. In addition, fertigation provides the means to monitor and change the ratio NO_3^-/NH_4^+ during the season, which could avoid environmental problems associated with the contamination of groundwater.

TABLE XI. RESIDUAL SOIL NO_3^- (mg/kg dry soil) AS INFLUENCED BY THE TREATMENTS.

		Final NO_3^- mg/kg dry soil					
Soil Depth (cm)	Initial NO_3^-	N0	N1 240 kg N/ha	N2 360 kg N/ha	N3 480 kg N/ha	Ncd	Ncs
			1997				
0–20	11	28.85a	47.31a	95.45a	121.89a	35.94a	32.29a
20–40	13.5	11.91a	35.15a	47.5a	54.47a	20.66a	59.39a
40–60	11.5	11.59c	16.16b	26.6b	34.55b	31.02b	41.74a
			1998				
Soil Depth (cm)	Initial NO_3^-	N0	N1 120 kg N/ha	N2 240 kg N/ha	N3 360 kg N/ha	Ncd	Ncs
0–20	8.23	18.22b	16.30b	82.36a	88.71a	34.77b	26.48b
20–40	10.56	8.68b	12.13b	21.09b	91.47a	12.93b	20.61b
40–60	8.66	8.45b	10.10b	14.84b	28.82a	7.15b	12.54b

- Values at the same depth, followed by the same letters are not significantly different at 5% level.

TABLE XII. MEAN NO_3^- CONTENT (mg/kg fresh tuber) IN FRESH POTATO TUBERS

Year	N0	120 kg N/ha	240 kg N/ha	360 kg N/ha	480 kg N/ha	Ncd	Ncs
1997	62.14b	--	130.2a	144.6a	158.7a	126.7a	107.6a
1998	55.13b	111.5ab	178.4a	198.2a	--	112.3ab	177.2a

Values followed by the same letters are not significantly different at 5% level.

The superiority of fertigation over other practices was clear from the yield and efficiency of N and water use at the lowest rate of N application. It is well understood that owing to a high initial investment, most of the farmers are reluctant to adopt the drip method of irrigation for crops, which give a smaller remuneration [16]. However, given the high savings in water in our experiments (up to 50%), one of the future tasks of the extension programs would be the shifting to modern irrigation techniques with the introduction of subsidy on drip materials that could be produced locally. But, pressurized water must be provided to farmers with a water meter at the gate of the farm at reasonable prices. This should encourage the economic and efficient use of water.

Even the simple practice of soil fertilizer application coupled with the improvement of water management through drip in Ncd reduced losses associated with an overirrigation and it increased the profit from the N-fertilizer, removed N and consumed water. Given other sources of N (soil reservoir, water), the lowering of N input under potato from 300 to 120 kg N/ha would be beneficial for the Lebanese Farmers, as it provided 90% of fertilizer N utilization with no significant impact on tuber yield and lower NO_3^- leaching hazards. By reducing the cost of production, Lebanese products would be competitive on the regional market.

For these reasons, fertigation of spring potato in Central Beqaa, Lebanon, is a promising perspective allowing a more efficient and thus economic use of inputs, water and fertilizer savings, reducing the cost of production and causing less potential risk hazards for the soil and groundwater pollution with nitrate.

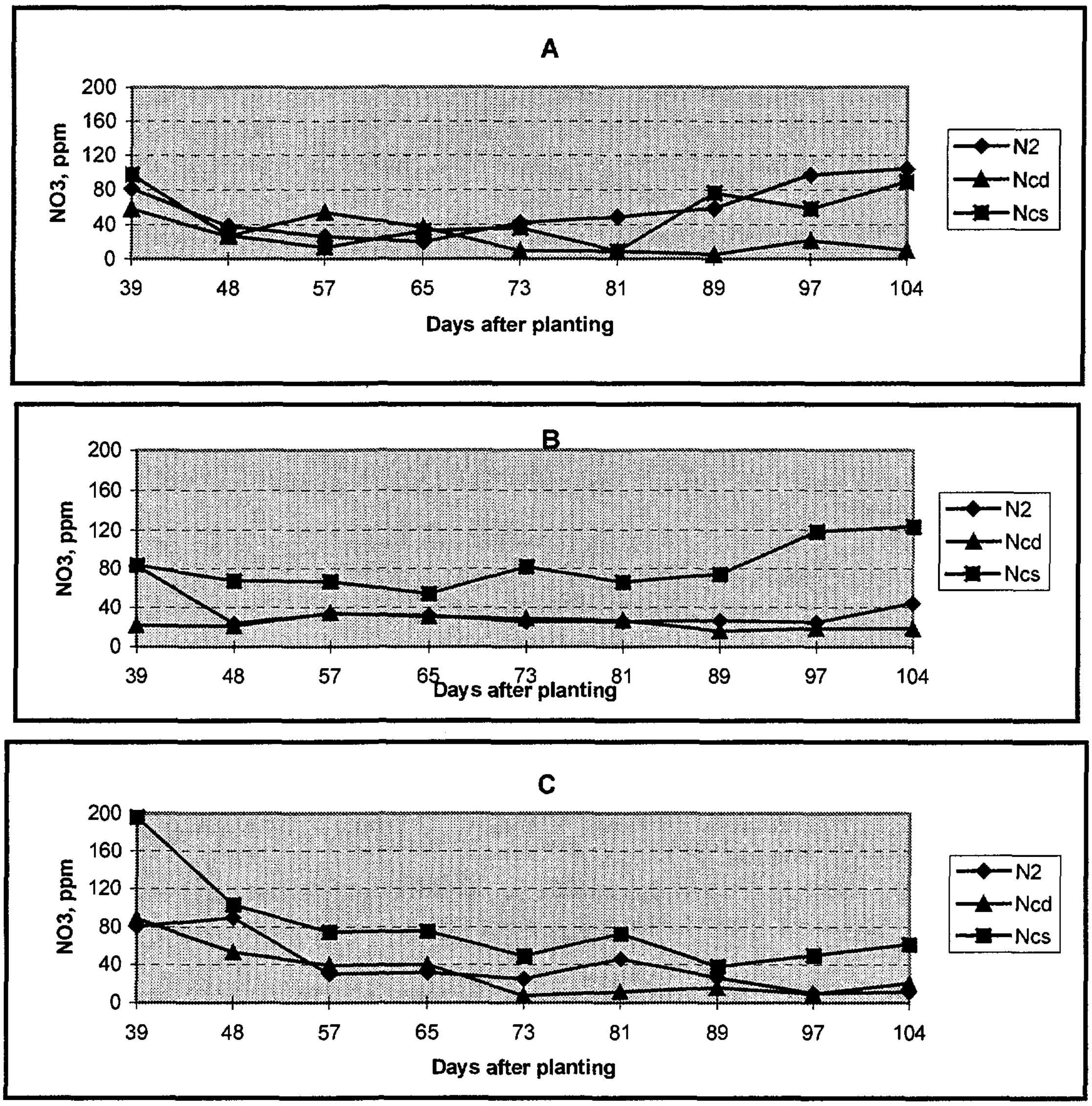

FIG. 4. Average concentration of NO_3^- in the soil solution measured by tensionics placed at different depths: (A) -40 cm, (B) -60 cm and (C) -80 cm.

REFERENCES

[1] Saade, R (1992). Le Commerce. Le Quarentième Rapport Annuel. Dossier 1992.

[2] FAO (1993). Year book, vol. 47.

[3] Fawaz, M (1992). Water resources in Lebanon. National Seminar on water resources in Lebanon. 27–28 November, 1992 Beirut.

[4] Saad, F (1995). Available water in Lebanon. Training Course on the use of modern irrigation system. Beirut, October 19–22, 1995.

[5] Papadopoulos, I. (1996). Use of saline and brackish waters for irrigation in Cyprus. Mediterranean colloquim on protected cultivation, October 6–9, 1996. Marocco: A 6.1 - A 6.22.

[6] Papadopoulos, I. (1993). Regional Middle East and Europe projection Nitrogen Fixation and water balance studies. Amman, Jordan, 18–27 October, 1993. RER /5/004 - 0,5. 62 p.p.

[7] Ministry of Agriculture (1997). Current Statistics on Agriculture. Beirut, Lebanon. Number 77, table 1.

[8] Nimah, M. (1992). Needs in irrigation water in Lebanon. UNESCO National Seminar on water in Lebanon, 27 - 28 November, 1992.

[9] Danso, S.K.A. (1995). The role of biological nitrogen fixing plants. Proceedings of an Int. Symp. on nuclear and related techniques in soil plant studies on sustainable agriculture , FAO - IAEA. Vienna: 205 - 224.

[10] Zapata, F (1990). Field experimentation in isotope-aided studies (IAEA). Training course series no: 2. Use of nuclear techniques in studies of soil plant relationships : 35–40.

[12] Perrenoud, S. (1983). Potato: fertilizers for yield and quality. International Potash institute Bulletin. N.8. 84 pp.

[13] Lisinska, G; Leszcznski, W and H. Malkiewicz (1989). Effect of planting dates and nitrogen fertilization on chemical composition of potato and quality of chips. Poland 1990. Nr: 184 : 61–73

[14] Soaud, A.A., G. Hofman,. and O. Van Cleemput. (1990). Nitrogen fertilization and potato growth. Pedologie, 40: 257–271.

[15] Abou Khaled, A., S. Sarraf and N. Vink (1969). Evapotranspiration in the central Beqaa, with reference to the Irrigation of potatoes and onions. Magon, IRAL, 26: 28 pp.

[16] Narayanamoorthy, A. (1997). Beneficial impact of drip irrigation: A study based on Western India. Water Resources Journal. December, 1997: 17–31.

[17] Soaud, A.A., O. Van Cleemput. and G. Hofman. (1992). Uptake and balance of labelled fertilizer nitrogen by potatoes. Fertilizer Research, 31: 351–353.

[18] FAO (1968). Enquète pédologique et programme d' irrigation connexes. Liban FAO 1968 volume III, Irrigation. 94 pp.

[19] Harris, P.M. (1992). Mineral nutrition of potato. The potato crop. Edited by Paul Harris, Chapman and Hall. London: 163 - 213.

[20] Ryan J., Musharrafieh G., and Barsumian A., (1980). Soil fertility characterisation at the Agricultural Research and Education Center of the American University of Beirut. Publication Nr. 64. pp 47.

[21] Papadopoulos, I. (1997). Fertigation of irrigated Crops: Step by Step Approach. Seminar on Fertigation Management. Beirut, April 12, 1996.

[22] Fuehring, H. D. and A. A. Ghurayyib (1969). Fertilizers for irrigated potatoes in the Bekaa plain of Lebanon. F.A.S., A.U.B., Publication N 36.

[23] Papadopoulos, I. (1988). Nitrogen fertigation of trickle irrigated potato. Fertilizer Research, 16: 157 - 167.

[24] Darwish T. M. (1995). Implementation and Perspective of Fertigation in Crop Production in Lebanon. Proceeding of the Short Advanced Course on Fertigation. FAO/RNE, CIHEAM/IAM-B and LEBANESE UNIVERSITY. Nov. 26– Dec.3, 1995: 207– 220.

[25] Hamdy, A. (1995). Fertilizers and their efficient use. Advanced short course on fertigation, Nov. 26– Dec. 3, 1995. FAS-UL. Beirut Lebanon: 83 - 138.

[26] Phene, C.J., J.L. Fouss and D.C. Sanders (1979). Water - nutrient - herbicide management of potatoes with trickle irrigation. Am. Pot. J., 56: 51– 59.

[27] Papadopoulos, I. (1989). Report on fertigation consultancy mission in Egypt. FAO of the United Nations, Rome, 1989 31pp.