ANALYSIS OF SEED AND WARE POTATO PRODUCTION SYSTEMS AND YIELD CONSTRAINTS IN ARGENTINA

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Propositions

1. In Argentina the yield gap between actual and potential yield of potato is mainly caused by unsuitable physiological seed quality and limited water and nutrient supply.
   This thesis.

2. Proportion of potential yield achieved by a potato crop depends on the physiological age index of the seed tubers; therefore the physiological age index is a useful input parameter in simulation studies.

3. Under Argentinian conditions, the periods between haulm killing and harvest and between harvest and beginning of the storage period of potato must be shortened in order to delay seed tuber ageing, especially when seed tubers must produce medium-late and late crops.
   This thesis.

4. Applications of plant growth regulators can modify the effects of physiological age of seed tubers on treated potato crops.
   This thesis.

5. Tierra del Fuego island is a safe haven for seed potato production. Its potential should be preserved.
   This thesis.

6. Argentina has the potential to become an important exporter of seed and ware potatoes.

7. Allelopathy can be used for weed control in agricultural and forestry systems.
   Caldiz, D.O. & L.V. Fernández, 1999. In: Recent Advances in Allelopathy. F. A. Macías, J.C.G. Galindo, J.M.G. Molinillo & H.G. Cutler, eds. Servicio de Publicaciones Universidad de Cádiz-International Allelopathy Society, Cádiz, Spain, pp. 237-248.

8. The epiphytic weed *Tillandsia recurvata* L. can be used as an indicator of environmental pollution by sulphur dioxide.

9. Benzyl aminopurine applied at anthesis, can delay senescence and improve grain quality in wheat.
   Caldiz, D.O., J. Beltrano, L. V. Fernandez, S.J. Sarandon & C. Favoretti, 1991. Plant Growth Regulation 10: 197-204.

10. He who knows a lot always asks for advice.
    Anonymous.

Propositions belonging to the PhD thesis of Daniel O. Caldiz,
Analysis of seed and ware potato production systems and possible yield constraints in Argentina.
Wageningen University, June 19, 2000.

ABSTRACT

Caldiz, D.O., 2000. Analysis of seed and ware potato production systems and yield constraints in Argentina. PhD Thesis, Wageningen University, Wageningen, The Netherlands, i-xvi + 197 pp., English, Dutch and Spanish summaries.

The aim of this thesis is to analyze the seed and ware potato production systems in Argentina and their possible yield constraints in order to develop specific strategies to increase seed quality and tuber yield.

This thesis starts with a survey of the actual potato production systems in Argentina carried out during 1994/95 and updated in 1999. Argentina currently produces well over 2 million tonnes of potatoes per annum on just over 100,000 ha. The survey also describes the acreage and production in different areas, agro-ecological conditions in each of these areas, yield constraints and perspectives for yield improvement. It also presents data on area, production and yield for each growing season and characterizes the seed and ware production systems in these areas in terms of weather based on long-term meteorological data and soils based on digitized soil maps for the whole country. In each of these areas yield determining, yield limiting and yield reducing factors are identified. High temperatures during planting and harvest time are the main yield determining factors as they affect crop growth and/or seed and ware quality. Also high temperatures during storage may be detrimental to the quality of stored seed or ware. Water and nutrient supply and physiological age of the seed are the main yield limiting factors in different seed and ware potato areas. Virus diseases, early (*Alternaria solani*) and late (*Phytophthora infestans*) blight are the main yield reducing factors in some areas. Strategies to solve problems of improper physiological age and virus infection are analyzed later in this thesis in order to obtain further improvements in yield and quality.

A simulation study at national and regional levels (1) characterizes agro-ecological zones for potato production; (2) establishes potential growing seasons; (3) estimates the potential yields of the crop in these zones and seasons, and, at a regional level, also for different planting dates; and (4) discusses how these results match with reality and how they can be used for the benefit of the potato industry.

Two models are used in these studies; the SUBSTOR-POTATO model for yield prediction and the LINTUL-POTATO model for a yield gap analysis.

The SUBSTOR-POTATO model is calibrated and validated using Argentinian data sets from experimental results from different sites and years. Cultivar-specific coefficients are

obtained during calibration and validation is based on several independent sets of field data, including cvs Huinkul, Kennebec, Mailén and Spunta. The observed and simulated values show good agreement within normal ranges of tuber yields. The particular behaviour of the input parameter maturity date is also considered, in order to properly assess tuber yield. A genetic coefficient for the duration of tuber bulking needs to be included in the model in order to obtain proper yield values under Argentinian conditions.

A yield gap analysis is carried out with data from five different agro-ecological potato growing zones by comparing potential yield data obtained with the LINTUL-POTATO simulation model with the actual and attainable yields. This analysis is used to identify the possible factors determining, limiting or reducing yield in each of the areas considered and to analyse options for further yield improvement. Special emphasis is put on the yield limiting effect of the physiological age of seed tubers, water and nutrient management, and the quality and yield reducing effects of virus diseases. Results show, for the regions studied, that the actual yield is still far below the attainable and potential yields, due to suboptimal light interception by the foliage, poor seed quality, and lack of early (*Alternaria solani*) and late blight (*Phytophthora infestans*) control.

Based on these results a physiological age index (PAI) that combines both the effect of chronological and physiological age of seed tubers is developed. PAI calculation is based on different key-dates of the life cycle of a seed tuber, which are easy to assess, i.e. the haulm killing date of the seed crop (T_0) and the end of the incubation period of seed tubers, measured under standard conditons. The PAI is: T_1/T_2, where T_1 is the time from haulm killing date (T_0) to possible planting date and T_2 the time from T_0 to the end of the incubation period. The PAI expresses physiological ageing of seed potato tubers within a range from 0 for physiologically young to 1 for old tubers. To test the PAI, existing data are re-evaluated and re-elaborated and specific experiments on the effects of seed origin and storage conditions for different cultivars have been performed during 1994/99. The effects of seed origin, seed supply and seed flow are also analyzed in terms of the effects of the physiological age of seed tubers on subsequent crop performance and yield. A survey on seed supply and seed flow evaluates the effects of different origins and storage systems upon crop growth and yield under practical conditions. The effects of physiological age on yield can be mainly attributed to improved light interception. PAI correlates well with the proportion of potential yield attained in different planting seasons.

Different strategies may help to overcome the effect of yield limiting and quality and yield reducing factors, such as the physiological age of seed tubers and virus diseases. Application of plant growth regulators such as gibberellic acid and benzyl aminopurine modifies the effect of the physiological age of seed tubers on the progeny crops. Especially benzyl aminopurine is promising in overcoming the negative effect of old seed tubers on crop growth and yield. The development of a seed production system on the isolated island of Tierra del Fuego in the southern part of the country proves to be a sound strategy to multiply basic seed or to carry out initial multiplications in breeding programmes. Presence of nematodes, aphids and virus proves to be very low and growing and storage conditions allow the production of young seed. Seed yields and physiological quality are acceptable, and the seed is very healthy, with virtually no viral, fungal or bacterial infections.

The study shows how a highly complex potato production system, like the Argentinian one, can be surveyed and analyzed. The survey work is complemented with the use of a Geographic Information System and simulation model approaches which improve our understanding of the possibilities for increasing future crop production by expanding the area cropped with potatoes and/or yield. The use of a yield gap analysis is also a useful and comprehensive tool to identify and rank yield defining, yield limiting and yield reducing factors for those agro-ecological zones where the potato is currently grown. With these procedures, the physiological age of seed tubers and virus diseases are identified as the most relevant factors limiting and reducing yield. Specific strategies are developed to counteract their limiting and reducing effects upon seed quality and tuber yield.

The approach of this thesis does not only applied for the specific situation of the potato crop in Argentina, but this framework could be successfully applied to other crops or production systems elsewhere.

Key-words: *Solanum tuberosum* L., potato production, potential yield, agro-ecological zoning, growth regulators, yield gap analysis, physiological age, seed quality, seed supply, yield improvement strategies

To my lovely wife, Adriana

To Gonzalo, Agustina, Rocío and Felipe

who share with me the gift of life

FOREWORD

This thesis is a partial product of my work on potato during the last 10 years. The idea of using some of my research results for a PhD thesis first occurred during Dr. Anton J. Haverkort's first visit to Argentina in December 1993. Dr. Haverkort, my co-promotor, cooperated with me in preparing the first outline of the PhD project and introduced me in the use and application of potato modelling. He also discussed that first approach with Dr. Paul C. Struik who acted as Promotor. Anton, thank you for your encouragement and enthusiasm and for your critical and useful comments during these years.

During my first stay at Wageningen, in 1994, I also received kind advice regarding modelling from Dr. Peter Kooman, and especially from Ing. Willem Stol from Plant Research International, Wageningen University and Research Centre; the efforts of both of them were and are greatly appreciated. I also thank Dr. Daniel Rodríguez, FAUBA, Argentina, and Mrs. H.H. van Laar, Wageningen University, for helping me during my stay at Wageningen in March 2000.

This thesis combines a lot of laboratory and field work. The laboratory work was carried out at the Instituto de Fisiología Vegetal, INFIVE, Facultad de Ciencias Agrarias y Forestales, Universidad Nacional de La Plata (UNLP), La Plata, Argentina, where I work since 1977. During this project I also had to go on teaching graduate and post-graduate courses, dealt with other academic responsibilities and supervised several students who partially cooperated in this study. I would also like to express my sincere thanks to Prof. José Beltrano for his support; to Prof. Olga Peluso and Mr. Pedro Subeldía and Mr. Alberto Rebuffo, for their cooperation in different aspects of this work and to Ing. Ftal. Fernanda Gaspari, co-author of some of the papers of this thesis, for being so helpful with the modelling work and the use and application of computer programs. I also thank Francisco Ayala, Pablo Courreges, Natalia Curcio, Corina Graciano, Fernando Marco, Andrés Massigoge, Alejandro Moreno Kiernan, Mariana Nomdedeu, Sergio Tenenbaum and Emilio Vera from the Facultad de Ciencias Agrarias y Forestales, UNLP, and Joost Hinderink and Jeroen van Soesbergen from Wageningen University, for their work in the laboratory and at the field during the period they stayed at INFIVE.

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I express my gratitude to Mr. M. Garrido, from *Ea. El Picaflor*, Lobería and to Mr. M. Gruntdzieg for allowing the use of their farms for the field trials performed during 1988-90, respectively; to Mr. L. Preto, *Ea. Río Pipo*; Mr. P. Suárez, *Ea. María Behety* and Mrs. Solange Bilbao from *Ea. Inés* for their cooperation during the field trials in Tierra del Fuego, 1991-95; to Luis Asis, Sergio Cardinali and Antonio y José Martínez for providing seed, storage facilities and their fields at Villa Dolores, Córdoba, during 1997-2000; and to Aldo and Arnaldo Bujaldón for also providing seed, support and fields at their incredibly large farms in Malargüe for my experiments during 1998-2000.

My most special acknowledgements are due to my friend and colleague Mrs. Laura Fernández. Laura, you not only did excellent work in collecting and analyzing samples and data, preparing the figures for final publication and taking care of the students, but you also shared with me the long trips inland Argentina and were always there when needed.

Several experiments of this thesis were granted by the project BID 802 OC/AR PID: 665, SECYT, ANPCyT, Argentina; thanks are due to Lic. María Wagner, the project agent, for her cooperation in this respect. Moreover, I would also like to thank Wageningen University for the PhD Sandwich Program Fellowship that financed my trips to and stays at Wageningen and the Stichting Broekemafonds for partially grant the publication of this thesis. I also acknowledge Potato Research for the permission to use the papers published therein in this thesis.

Last but not least my special thanks are due to Dr. P.C. Struik, my Promotor, not only for sharing with me his incredible knowledge and ideas about the potato crop but also for his patience, the time devoted to this project and his kind advice in other non-academic subjects; Paul, working with you was a real pleasure. I very much enjoyed your stories and our project discussions during our trips inland Argentina and I hope we can do some other research work in the near future.

También quiero agradecer, una vez más a mi esposa y a mis hijos, a quienes está dedicada esta tesis, por la paciencia, el amor y la comprensión que han tenido conmigo en todos estos años, tanto durante mi trabajo en casa como por los numerosos y frecuentes, cortos y largos viajes por la Argentina y el exterior. Les pido disculpas por el tiempo que no les dediqué como consecuencia de esta tesis y espero compensarlo, aunque sea parcialmente, en el futuro.

Finally, I hope that the work presented in this thesis will encourage research in this field of study and will stimulate technicians and farmers to improve the technological level of growing and storing potatoes to increase yield and quality.

NOTE

Chapters 2.1., 3.1, 3.2, 5.1 and 5.2 of this thesis have been published by Potato Research. Chapter 2.3 is based on a Research Report. Chapters 2.2, 3.2 4.1 and 4.2 have been submitted for publication. The presentations of the chapters in this thesis differ from the original publications in the following ways:

- The titles and running titles have been adapted.
- The *References* of the individual papers have been combined into one single list.
- Acknowledgements are given in the Foreword.
- Minor alterations have been made in the text, tables and figures, to standardize the presentation.

CONTENTS

SECTION 1

GENERAL INTRODUCTION

1. GENERAL INTRODUCTION

The potato (*Solanum tuberosum* L.) originated in the Peruvian Andes (Ugent & Peterson, 1988). It was found in Colombia, Perú, Bolivia and in the northwest of Argentina by the Spaniards around 1524, who introduced it into Europe, probably from the northern Colombian region (Hawkes, 1967), as early as 1565 (Thornton & Sieczka, 1980). From Spain it spread all over Europe, first as a botanical curiosity and later, during the mid-eighteenth century, as an important food crop. In Argentina, the Indians already grew potatoes in the Andean valleys since the Inca period (L. Lanfranconi, personal communication, 1998) but the first record of large-scale potato cultivation is from 1872/73 with an area of 2361 ha (Caldiz, 1994). From those times the crop markedly expanded all over the country, where at present, about 100,000 ha are grown in different areas and seasons, for seed, ware or processing purposes.

Actual and potential potato yield

The fact that the crop is grown in different areas and seasons all over the country during the whole year induces a flow of seed potato tubers from different cultivars, from different seed production areas to other ware and processing growing areas. Seed potatoes are grown at sea level in coastal areas or in the mountains, while ware potatoes are grown from the northern provinces of Salta, Tucumán and Santiago del Estero (26° SL) to the southern province of Chubut (44° SL). Thus crops are grown in different soils and under different weather conditions, but also at different levels of technology. For example, irrigation is carried out in furrows, using traditional sprinkler systems or by central pivots. The production systems will be analyzed by means of an extensive survey, analyzing area, yield and production and identifying different yield determining, yield limiting and yield reducing factors. Within the yield limiting factors, the physiological age of seed tubers appears as one of the most limiting ones either for seed or ware production while within the yield reducing factors, virus diseases is one of the main quality and yield reducing factors. Hence, both factors are being particularly considered in this study.

The potato production systems are highly diverse and seed supply systems are complex, due to the large size of the country, the distance between seed and ware areas and the variation in agro-ecological conditions prevailing among zones (Table 1.1). Geographic Information Systems (GIS) and simulation models could greatly contribute to the analysis of the system. GIS are extensively used for land evaluation, either at regional (van Lanen et al., 1992; Stoorvogel, 1995; Bouma, 1998) or global scale (Stol et al., 1991). A GIS (Eastman, 1993) will be used to perform an agro-ecological characterization of the potato production for the whole country.

Simulation models are used at different aggregation levels for research, instruction, yield prediction and decision support (Penning de Vries & Rabbinge, 1995); for the potato crop, several models are in use to simulate plant growth and crop productivity under limiting and non-limiting conditions (Haverkort & MacKerron, 1995). Simulation models (LINTUL-POTATO, Kooman, 1995; SUBSTOR-POTATO, Griffin et al., 1992) will be used to predict yield (SUBSTOR-POTATO) and to estimate the potential yield of the crop and to carry out a yield gap analysis (LINTUL-POTATO).

Table 1.1. Planting, harvesting time, technological level, seed age and yield variation for different potato growing seasons in Argentina.

Growing season	Location	Planting	Harvesting	Technological level variation	Seed age	Yield
Early	Tucumán[1]	June	October	Low-Medium	Too young/old	High
Mid-early	Córdoba[2]	August	December	Low-Medium	Suitable/Too young	High
Mid-late	Bs. Aires[3]	October	February	High-Very high	Suitable/Too old	Low
Late	Córdoba[2]	February	June	Low-Medium	Too young	High

(1) Also in Formosa, Salta and Santiago del Estero; (2) also in Santa Fé and north of Buenos Aires province; (3) also in Mendoza, Río Negro and Chubut. See also Figure 2.1.3.

Physiological age of seed tubers as a limiting factor in seed quality and crop yield

The physiological age of seed tubers is one of the limiting factors in potato production (Caldiz & Gaspari, 1997). Several agro-ecological and management factors affect the physiological age of a seed tuber and thus affect the future crop, such as temperature, storage length and pre-planting treatments (Struik & Wiersema, 1999). In Argentina, although seed tubers of almost 50 cultivars are grown in different areas, 90% of the potato crop is based on cv. Spunta (Fernández et al., 1999) which is highly sensitive to physiological ageing (Caldiz, 1991). Seed from this and other cultivars need to be stored for different periods until being used in the following crop. Moreover, crop, post-harvest and storage conditions differ considerably between areas (Escande et al., 1985, 1986). Ware crops are grown year around, but different sites and seasons have different requirements for seed age, depending on the length of the growing period available, the crop type and the potential yield. Seed tubers flow from different seed growing areas to different ware potato areas; moreover, seed tubers suffer from different stresses during the crop, post-harvest and storage phases; their physiological ageing is not controlled and the impact of physiological age on crop growth and yield hardly considered.

Virus diseases as a reducing factor of seed quality and crop yield

Virus diseases greatly reduce seed tuber quality (Ortego, 1995) and yield of the progeny crop (Caldiz et al., 1985). In Argentina, seed potatoes are grown in isolated areas to avoid or reduce virus infection. However, in these areas other diseases and pests occur and seed obtained is not always of the proper physiological age due to environmental or management conditions (Caldiz et al., 1999). Maintenance of a seed production system requires a continuous supply of virus-free material, multiplication in isolated areas with low aphid population pressure and permanent phytosanitary control of the seed crop and its progenies (Hille Ris Lambers, 1980; Escarrá, 1989; Nemecek, 1993; Zamudío, 1996; Struik & Wiersema, 1999). If these measures are not taken the self-sufficiency regarding seed production, could be jeopardized.

Strategies to improve yield

Crop production could be increased by extension of the cropped area, improvement of yield per hectare or by both. In Argentina, various key-aspects in potato growing have been improved during the last 20 years, but there are still several yield determining, yield limiting and yield reducing factors that merit attention. To study all of them is beyond the framework of this study, but I selected, based on the analysis and survey recently carried out by Caldiz & Struik (1999) an important yield limiting factor (physiological age of seed tubers) and an important yield reducing factor (virus diseases), for detailed consideration in this study. Both factors are aspects of seed tuber quality.

Different approaches can be followed to modify or improve the physiological age of seed tubers, like adapting planting date, length of cropping season, haulm killing date and (especially) storage conditions. Another strategy would be to overcome negative effects of improper physiological age of the seed tubers by applications of plant growth regulators to the crop grown from this seed. However, seed quality depends on both physiological and phytosanitary aspects and because ot the latter one the use of virus-free seed is essential.

Virus diseases reduce seed quality and yield (Caldiz et al., 1985). Therefore, seed tubers are produced in isolated areas using basic disease-free starting material. Seed producers select suitable planting dates, perform roguing and kill the haulm early (Struik & Wiersema, 1999). The use of new and isolated areas for seed potato production could play an important strategic role in the future, either for basic seed production and/or building up a seed supply of new genotypes.

Approach and objectives of this study

This thesis aims to provide a framework for the analysis of different cropping systems in different agro-ecological zones using the example of the potato. The Argentinian potato production system presents, due to its complexity (Table 1.1), an excellent opportunity to test the power of the combined use of survey work, GIS, simulation models and yield gap analysis to identify future crop opportunities and actual yield defining, yield limiting and yield reducing factors. Based on this approach, suitable and specific strategies can be developed to improve yield and quality.

Until now, no attempts have been made to analyze the potato production system in Argentina, to survey and characterize the crop in the different growing areas and seasons, and to identify possible yield determining, yield limiting or yield reducing factors. Moreover, no attempt has been made either to study the possibilities to expand the crop, either in terms of area and/or yield per unit area or to develop specific strategies to overcome yield constraints such as the improper physiological age of the seed.

The objectives of this project are:

(1) to carry out a complete survey of the potato production system in order to identify yield determining, yield reducing or yield limiting factors in the main growing areas (Section 2, Chapter 2.1). The results of this survey will be used for a further analysis of the factors affecting yield and the effects of different seed origins and seed flows on physiological age, crop growth and tuber yields;

(2) to perform a simulation study using GIS and growth and yield simulation models to estimate possibilities of expanding crop frontiers and to define the potential yield of the crop in different agro-ecological zones (Section 2, Chapter 2.2 and 2.1). This is done at the national level, while at the regional level, potential yield is also analyzed for its spatio-temporal variation. Due to the great variations in technological level, seed quality, stress factors, altitude, conditions and growing seasons, the framework proposed for the analysis of this production system will be an important test for this methodology;

(3) to test the suitability of the SUBSTOR-POTATO simulation model to predict yield under Argentinian conditions (Section 3, Chapter 3.1) which will allow to test different management strategies;

(4) to carry out a yield gap analysis by comparing actual and attainable yields with the potential yield established with the LINTUL-POTATO simulation model (Section 3, Chapter 3.2); these results will be also used to carry out a more in-depth analysis of yield defining, yield determining and yield limiting factors;

(5) to develop a physiological age index (PAI) to analyze the influence of physiological age as a yield limiting factor in Argentinian potato production (Section 4, Chapter 4.1);

(6) to study the effect of seed origin, seed supply, seed flow and physiological age on crop growth and yield in different areas in order to analyze their effects on the proportion of the potential yield achieved (Section 4, Chapter 4.2);

(7) to develop strategies to overcome physiological (Section 5, Chapter 5.1) and phytosanitary yield constraints (Section 5, Chapter 5.2); and

(8) to identify possibilities for further improvement of the crop, mainly based on the use of seed of suitable age, improved water and nutrient management and control of leaf diseases.

Achievement of these objectives will not only contribute to a better understanding of the Argentinian potato production systems and their constraints, but will also contribute to establish an analytical framework for future use in different crops and regions. At the end of this thesis the proposed approach will be discussed.

SECTION 2

ACTUAL AND POTENTIAL POTATO PRODUCTION IN ARGENTINA

CHAPTER 2.1

SURVEY OF POTATO PRODUCTION AND POSSIBLE YIELD CONSTRAINTS

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2.1. SURVEY OF POTATO PRODUCTION AND POSSIBLE YIELD CONSTRAINTS

Summary

Potato is the most important horticultural crop in Argentina. Its commercial cultivation started in 1872/73 and production greatly increased due to area and yield increases. This paper surveys the actual potato production in Argentina and describes and quantifies distribution of crop area and production and the agro-ecological conditions in each growing area. Yield constraints are identified and possibilities for further yield improvement are discussed. The survey established that important yield improvements were achieved in the country during the last 20 years, mainly due to the use of high quality seed, new cultivars, improved fertilizer and irrigation techniques, and better control of pests and diseases. Suggestions are made to further improve potato yield in the different growing areas.

2.1.1. Introduction

Argentina is located in the southern region of South America, ranging from 22 to 56° S and from 54 to 72° W. It rises from sea level in the east to the high Andean mountains in the west to a maximum of about 7000 m above sea level. The magnitude and diversity in altitude of the country accounts for the occurrence of many different climatic zones [BWk, BS, Cfa, Csb and ET, according to the Köppen classification, (Petterssen, 1976)] where many different crops can be grown, including: maize, sorghum, wheat, sunflower, soybean, flax, and many forage and horticultural crops. Table 2.1.1 shows the land distribution, acreage and production of some crops; among the horticultural crops, potato is the most important (INTA Balcarce, 1980).

Although there are evidences that during the Inca period the Indians grew potatoes in the Andean valleys of northwestern Argentina (L. Lanfranconi, personal communication, 1998), the first record of large scale potato cultivation is from 1872/73 with an area of 2361 ha (Caldiz, 1994). The crop was started in the area of the current city of Santa Fe (SL 31° 23') and later on it spread towards the southeast of the Buenos Aires province where the first crops were planted in 1886 with cv. Violeta, named after its violet skin colour (Anonymous, 1954). Later, other cultivars derived from introductions from the USA and Europe were grown, such as Tomatera (1911) from Germany, Redonda (1915) derived from the American cv. Early Rose, Blanca (1915) from cv. White Rose and Chaqueña (1925) derived from Spaulding Rose. The latter two cultivars disappeared in 1935-36 due to severe virus infection (Sívori, 1951) and also because of lack of interest from the commercial growers (Anonymous, 1954). By that time the introduction of seed from different cultivars was very important. Munck (1940) reported results of 59 cultivars grown in the period 1935/36-1939/40 at different locations.

Mendiburu (1986) considered that the history of the production of seed potatoes in Argentina can be divided into four periods: (1) beginning of crop production in the late 1800s–1936: local seed production with local or imported cultivars; (2) 1937–1955: only imported seeds used; (3) 1955–1985: use of both local and imported seeds; (4) 1985–present: self sufficiency.

Table 2.1.1. Land use and area and production of different crops in Argentina.

Land use[1]		Area
Total area		3,761,274 km^2
Continental area		2,791,810 km^2
Cultivated area		29,300,000 ha
Forest woodland and natural forest		63,300,000 ha
Natural and other grazing land possible to cultivate		131,100,000 ha
Non-farming area (mountains, rivers, lakes, etc.)		49,000,000 ha
Crop[2]	Area (ha)	Production (tonnes)
Wheat	7,344,000	15,983,000
Maize	3,926,000	14,496,000
Soybean	6,648,000	11,013,000
Sunflower	3,048,000	5,021,000
Sorghum	802,000	2,552,000
Potato	101,790	2,275,000

(1) Data from Ediciones Aguilar (1992) and (2) from SAGPyA (1997).

Currently, the use of imported seed is restricted to initial introductions of those cultivars required by the food processing industry that are not available in the country. For further information the reader is referred to Caldiz et al. (1999) who recently discussed the evolution of the seed potato production system in Argentina. Although several authors have discussed the potato production situation in Argentina (Mendiburu & Lucarini, 1980; Anonymous, 1989; Haverkort & Caldiz, 1994; Huarte & Inchausti, 1994, Huarte, 1996), no attempts have been made to analyze for each potato producing area the agro-ecological conditions that may determine, limit or reduce yield. Caldiz (1983) discussed several factors that could affect production but referred to seed crops exclusively. He concluded that among other production factors, use of fertilizers and irrigation, planting dates, seed degeneration rate, distance to the ware production zones and presence of pest and diseases were important. However, in the period 1983-1996 circumstances have changed considerably and both ware and seed potato production systems merit a renewed, comprehensive analysis to identify future possibilities for yield improvement. Moreover, in a recent national workshop it was recognized that the degree of importance of factors limiting and/or reducing growth and yield in the different regions needs to be identified and the yield reductions caused by these factors need to be quantified (Huarte, 1994). Hence, the purpose of this paper is to analyze the actual potato production in Argentina. It considers: (1) acreage and production in different areas; (2) agro-ecological conditions in each of these areas; (3) identification of yield constraints and (4) possibilities for further yield improvement.

2.1.2. Materials and methods

Although the survey was carried out during 1994/95, all statistics in this paper are the latest ones available. The data on area, production and yield were obtained from the Secretary of Agriculture (SAGyP, 1995, SAGPyA, 1997), FAO (FAO, 1995) or were provided by several local sources from different provinces, such as INTA Extension Agencies and Experimental Stations belonging to each province (J. Ortego, personal communication, 1994; N. Zamudio, personal communication, 1994; L. Lanfranconi, personal communication, 1994). These are presented in tables or figures, and when pertinent, differences between sources are discussed. Soil data were obtained from the Secretary of Agriculture Soil Maps (SAGyP, 1989; 1990) and soil classification was done according to the Soil Survey Staff (1992). Long term meteorological data were obtained from the National Meteorological Service (Servicio Meteorológico Nacional, 1992) and from FAO (FAO, 1990). These data were used to characterize the agro-ecological conditions of each area.

The identification of different factors influencing yield was based on, either local, and current information, or previous publications, as quoted in the following sections. In potato, as in other crops, yield is determined or defined by various factors, which were grouped according to Penning de Vries & Rabbinge (1995). Daylength, incoming radiation, temperature, carbon dioxide concentration and cultivar are Yield Defining or Determining Factors (YDF) and the potential yield of a crop depends on them. Water, nutrients and physiological age are Yield

Limiting Factors (YLF) that can be modified by growers through cultural practices, such as application of inputs, and determine the gap between potential and attainable yields (Figure 2.1.1). Diseases, weeds and pests are considered Yield Reducing Factors (YRF) and consequently lead to lower yield when they are present; these factors determine the gap between attainable and actual yields. For each production area the main YDFs, YLFs and/or YRFs are mentioned and when pertinent, strategies to improve yield are discussed.

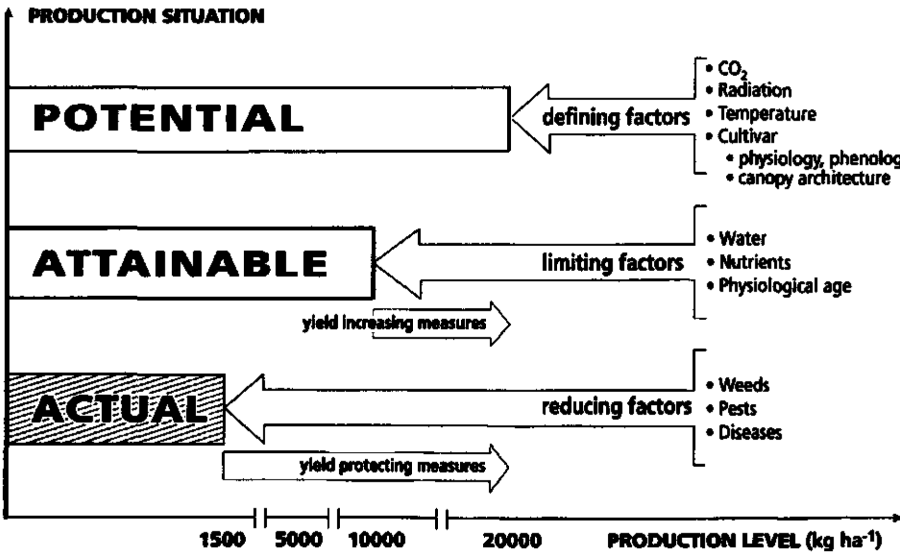


Figure 2.1.1. Overview of actual, attainable and potential yield levels in relation to reducing, limiting or defining yield factors. Modified from Penning de Vries and Rabbinge (1995).

2.1.3. Results and discussion

Area, production and yield in the country

Since the beginning of the crop in the late 1800s, the area markedly increased to over 200,000 ha during the 1950s. In the following 20 years it decreased by more than 50% and later stabilised around 120,000 ha. At present the cropping area is 102,000 ha (Figure 2.1.2a). The production markedly increased to almost 3.1 million tonnes during the 1980s, due to constant increases in tuber yield per hectare (Figure 2.1.2b). During the period 1872-1922 tuber yield was almost constant, while in the period 1934-1994 it increased by over 250 kg ha^{-1} yr^{-1}. During the period 1934-1990 the average yield increased by 61 kg ha^{-1} yr^{-1} for the world and 365 and 144 kg ha^{-1} yr^{-1} for North and South America, respectively.

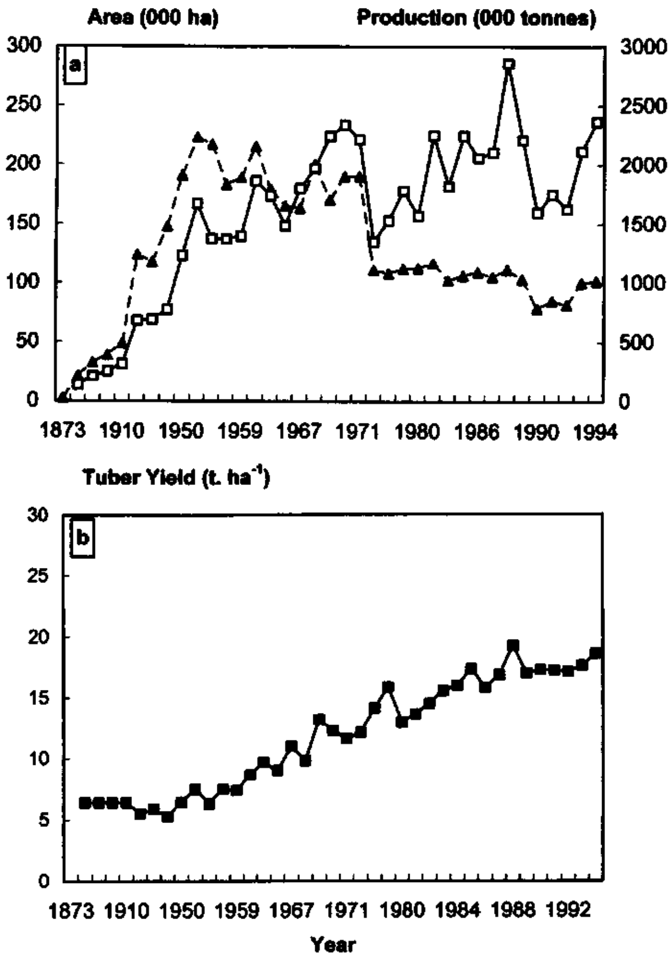


Figure 2.1.2. (a) Evolution of area (▲), production (□) and (b) tuber yield (■) in Argentina during the period 1873-1994.

For Asia and Africa values were 124 and 60 kg ha^{-1} yr^{-1}, respectively (FAO, 1995). Clearly, tuber yields in Argentina increased much faster than the averages, for the world, Asia, Africa and South America. Yield improvement during the 1980s can be attributed to the introduction of new cultivars, application of fertilizers and irrigation, and increased control of late blight (*Phytophthora infestans* Mont. De Bary) in the major growing areas (Mendiburu & Lucarini, 1980). More recently, further yield increases were obtained by the use of virus-free seed and the introduction of new, high-yielding cultivars (Escarrá, 1989; Caldiz & Beltrano, 1992).

Despite these yield increments, the actual national average yield of 20.3 t ha^{-1} [22.8 t ha^{-1} for 1995/96, according to recent data form the Secretary of Agriculture (SAGPyA, 1998)] is far below the potential yield of the crop for the different regions. For example, in the southeast region of the Buenos Aires province, which by 1993/94 accounted for 40% of the total potato acreage (SAGyP, 1995), the average actual yield is 27.3 t ha^{-1}, while the potential yield, estimated according to van der Zaag & Burton (1978) is 88 t ha^{-1} (Cantos de Ruiz, 1988). These and other yield differences will be analyzed in detail in the following pages.

Area, production and yield in the main potato growing provinces

Seed and ware potato growing areas. Seed crops are grown during summer from October-November to February-March, either in highland valleys such as Tafí del Valle, Tucumán; Las Estancias, Catamarca; Sierras Grandes, Córdoba and Malargüe, Mendoza, or in coastal areas (Figure 2.1.3), as the southeast of the Buenos Aires province (Haverkort & Caldiz, 1994) and Tierra del Fuego Island (Caldiz et al., 1999). The cropping area varies from 200 to 1500 ha in different locations but tuber yields are quite similar in all cases (Table 2.1.2). Probably the early haulm killing that is practised in this crop is responsible for this situation. Haulm killing is not common in the ware crop. In Argentina, ware and food processing potatoes are grown during the whole year in different regions of several provinces. Figure 2.1.3 and Table 2.1.3 show provinces where the crop is grown, crop type (early, medium early, etc.), actual growing seasons, area, production, actual average yield and cultivars used in the different areas. It is surprising to note that despite earlier defoliation of seed crops seed yields are higher than ware yields. This is probably because (1) seed growers are more highly specialised than ware growers; (2) the average tuber yield is based on a wide range of production levels including those from small farmers with low technological level. The most important ware crop is the medium late one, with a large area and high production and yield in the province of Buenos Aires. In this crop, higher yields are obtained than in other regions. These results differ slightly from those proposed by Huarte & Inchausti (1994) for the different zones, but nevertheless confirm that the actual average yield for the country is around 20 t ha^{-1}. In the medium late crop several cultivars are grown. According to the most recent reference (Rodriguez Quijano, 1989) the distribution in the mid-late 1980s was: Spunta (32%), Ballenera MAA (29%); Kennebec (14%), Huinkul (10%) and other cultivars (15%). In other areas, Spunta is by far the most dominant cultivar, 85-90% of cropping area (Fernández et al., 1999).

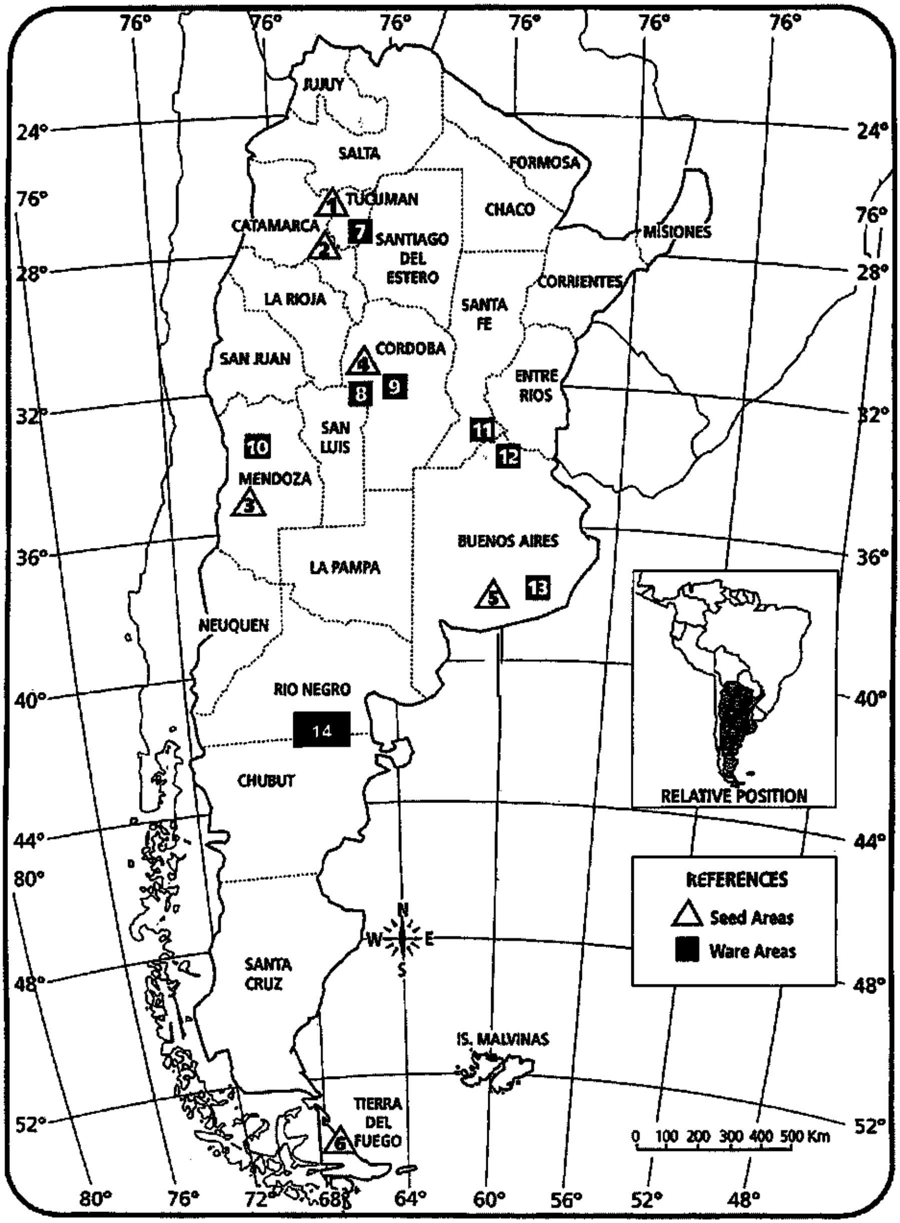


Figure 2.1.3. Location of seed and ware potato growing areas in Argentina.

Seed areas (Δ) : (1) Tafí del Valle; (2) Las Estancias; (3) Malargüe; (4) Sierras Grandes; (5) southeast of Buenos Aires; (6) Tierra del Fuego. Ware areas (■): (7) Concepción and Morteros, early; (8) and (9) Villa Dolores and Córdoba horticultural belt, respectively, medium early and late; (10) Tupungato and Uspallata, medium-early and medium-late; (11) and (12) Santa Fe and northeast of Buenos Aires, respectively, medium early and late; (13) southeast of Buenos Aires and (14), Río Negro and Chubut, respectively, medium-late.

Table 2.1.2. Seed potato growing provinces in Argentina. Actual growing period[1], area, production, average yield and potato cultivars used.

Province	Location	Actual Growing Period J A S O N D / J F M A M J	Area (ha)	Production (tonnes)	Yield ($t\ ha^{-1}$)	Cultivars
Tucumán[2]	Tafi del Valle		500	12,500	25.0	Spunta
						Bintje[3]
Catamarca[2]	Las Estancias		1,500	37,500	25.0	Spunta
	Kennebec[4]					
Córdoba[5]	Sierras Grandes		500	12,500	25.0	Spunta
Mendoza[6]	Malargüe		1,000	19,250	19.2	Spunta[6,7]
Mendoza[6]	Tupungato		266	5,320	20.0	Spunta
Mendoza[6]	Uspallata		207	4,347	21.0	Spunta
Buenos Aires[8]	Southeast		1,500	31,785	21.1	Spunta[8]
Total area, Total production, Average yield			5,473	123,202	22.3	

(1) All seed crops belong to the medium late type and are grown during summer (southern hemisphere). (2) from: N. Zamudio, personal communication, 1994. (3) data from Orell (1990), other cultivars: Jaerla, Russet Burbank, Achat. (4) data from Anonymous (1989), other cultivars: Jaerla, Mona Lisa, Huinkul, Ballenera. (5) from: L. Lanfranconi, personal communication, 1998), other cultivars: Kennebec and Bintje. (6) from: J. Ortego, personal communication, 1994. (7) data from Anonymous (1989), other cultivars: Kennebec, Huinkul, Pentland Crown, Mailén INTA. (8) data from Anonymous (1989), other cultivars: Ballenera, Kennebec, Huinkul, Chacay INTA, Frital INTA, Mailén INTA, Pampeana INTA, Primicia INTA, Russet Burbank, Shepody, Bright, Cardinal, Empire, Escort.

Table 2.1.3. Crop type, main potato growing provinces, actual growing period, area, production, average yield and potato cultivars used in Argentina for ware production.

Crop type	Provinces	Actual Growing Period J F M A M J J A S O N D	Area[1] (ha)	Production[1] (tonnes)	Yield ($t.ha^{-1}$)	Cultivars[2]
Early (Winter)[3]	Tucumán, Salta, Jujuy Chaco, Formosa		5,700	98,226	17.2	Spunta Pampeana Bintje
Medium Early (Spring)	Córdoba, N Bs. As. Mendoza, Tucumán, S. Fe		28,000	451,578	16.1	Spunta Kennebec Huinkul
Medium Late (Summer)	Buenos Aires, Chubut Mendoza, Río Negro		47,100	1,203,098	25.5	Spunta Kennebec[4]
Late (Autumn)	Córdoba, Tucumán S. Fe, Buenos Aires		20,990	312,691	14.9	Spunta
Total area, Total production, Average yield			101,790	2,065,593	18.4	

(1) From SAGyP (1995); (2) from Huarte & Inchausti (1994), in order of importance; (3) Southern hemisphere; (4) others cultivars grown are: Araucana, Ballenera MAA, Huinkul, Primicia, Pampeana, Sureña, Bintje, Russet Burbank, Achatt.

However, the increased interest in processing means that the area of other cultivars with higher dry matter content, such as Russet Burbank, Atlantic, Frital INTA and Shepody, will expand at the expense of cv. Spunta. During the last fifteen years the medium early and late crops have significantly increased, especially in the Córdoba province where at present, 14,200 and 19,500 ha are grown for the medium early and late crops, respectively (L. Lanfranconi, personal communication, 1998).

Area, production and yield for the main producing provinces, for the period 1980-1994, are shown in Figure 2.1.4. In this period the area in Buenos Aires decreased by more than 40% and total production by a similar proportion. Tuber yields increased at a rate of 800 kg ha^{-1} yr^{-1}; the 1994 average yield of 27.3 t ha^{-1} for the province is the country's highest (Figures 2.1.4a and b), while recent data established the average yield for the province at 31.04 t ha^{-1} (SAGPyA, 1998). Córdoba is the second most important potato producing province in the country, and in the period considered the area increased by more than 165% and the production by 356% (Figure 2.1.4c), associated with an increase in tuber yield per ha of more than 72% at a rate of 453 kg ha^{-1} yr^{-1} (Figure 2.1.4d). Sandy soils allow production of tubers with a good appearance and thus high price in the market which enhances the growers' interest in the crop. In Mendoza the area was reduced but due to a yield increase of 282 kg ha^{-1} yr^{-1} the total production was higher in the 1990s than in 1980 (Figures 2.1.4e and f). In Santa Fe area and production also decreased by more than 40%, while yields per hectare have levelled off since 1989. An increase of 92 kg ha^{-1} yr^{-1} was recorded over the entire period considered (Figures 2.1.4g and h). The severe reduction in yield and production in 1981 was attributed to the spread of *Ralstonia solanacearum*, favoured by the double cropping system and high temperatures (A. Escande, personal communication, 1981). In Tucumán, a province characterized by its early production during winter, area and production increased (Figure 2.1.4i), while tuber yields per hectare increased by 374 kg ha^{-1} yr^{-1} when data from 1980 with unusually high yields for that time are excluded (Figure 2.1.4j).

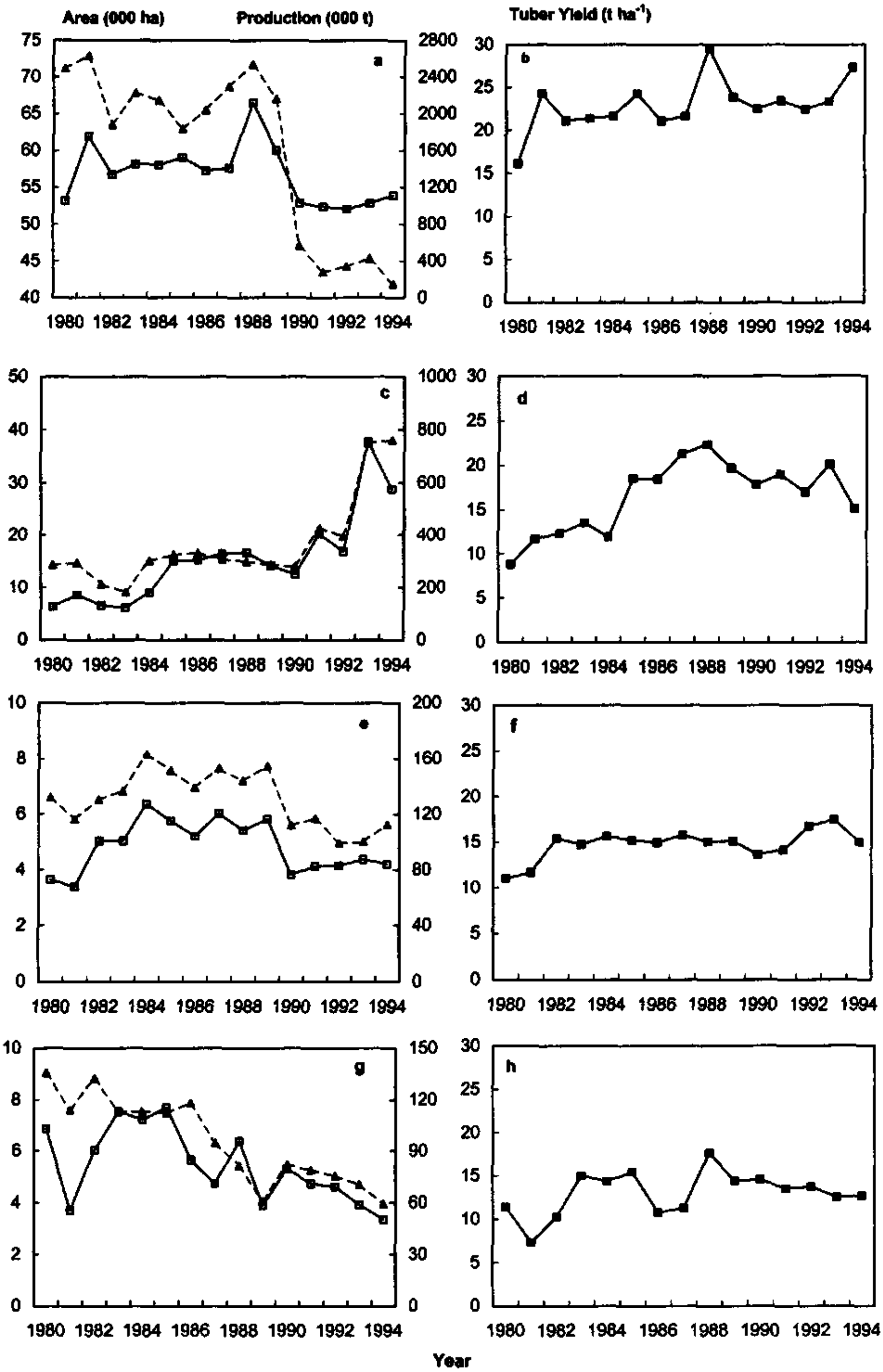
Agro-ecological characteristics of the seed and ware areas and possible yield constraints

An overview of soil characteristics is given in Table 2.1.4. For simplicity the characteristics of the areas and the possible yield constraints will be analyzed for each province, for the seed and ware crops separately, and only the most conspicuous and most important cases will be discussed.

Table 2.1.4. Soil types and main characteristics for the different seed and ware growing areas.

Provinces	Locations	Crop type	Soil type	Main characteristics				
				A layer (m)	O.M.[3] (%)	Drainage	Water Erosion	Eolic
		Erosion						
Buenos Aires	San Cayetano	seed	Typic Argiudols	> 1	5-7	good	none	none
	Tres Arroyos	seed	Typic Argiudols	> 1	5-7	good	none	none
	Balcarce	ware/ind[1]	Typic Argiudols	> 1	5-7	good	none	none
	Lobería	ware/ind	Typic Argiudols	> 1	5-7	good	none	none
	Miramar	ware/ind	Typic Argiudols	> 1	5-7	good	none	none
Catamarca	Las Estancias	seed	Typic Ustifluvents	0.80	1.5-3	excessive	light	none
Córdoba	Los Gigantes	seed	Typic Ustifluvents	0.50	1.5-2	good	none	light
	Córdoba belt	ware	Typic Haplustols	0.50	0.5-1	good	none	none
	Villa Dolores	ware/ind	Torriortentic Hap.	0.50	0.5-1	excessive	none	light
Mendoza	Malargüe	seed	Typic Torriorthens	n.a.[4]	0.5-1	good	none	none
	Tupungato	ware						
Tucumán	Tafí del Valle	seed	Typic Ustifluvents[2]	n.a.	0.5-1	excessive	medium	
	medium							
	Concepción	ware	Entic Hapludols	n.a.	n.a.	limited	none	none
	Morteros	ware	Typic Argiudols	n.a.	2-3	good	none	none
Tierra del Fuego	Río Grande	seed	Pachic Crioborolls	> 0.80	4-6	good	--	
	medium							

(1) ind, for industry; (2) rocks: 0-3%, neutral pH, (3) O:M., organic matter; (4) n.a. data no available.


Area (000 ha)
Production (000 t)
Tuber Yield (t ha^{-1})
a
b
c
d
e
f
g
h
Year

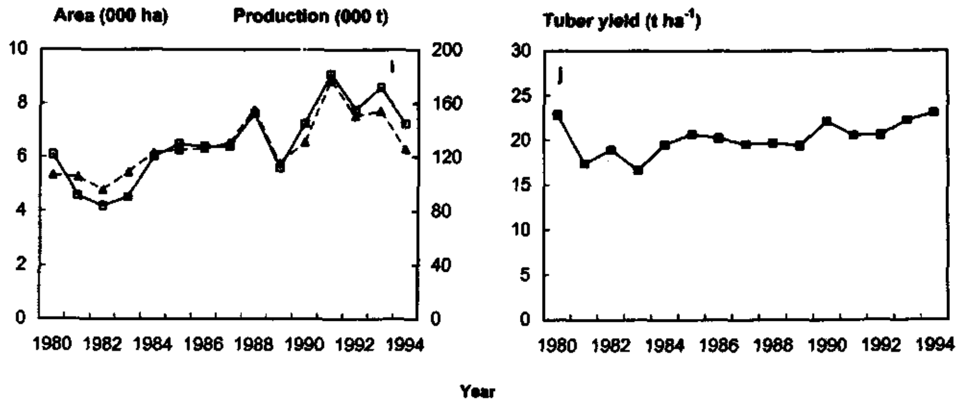


Figure 2.1.4. (a). Evolution of area (▲), production (□) and (b) tuber yield (■) in the most important potato producing provinces during the period 1980-1994. References: (a and b) Buenos Aires; (c and d) Córdoba; (e and f) Mendoza; (g and h) Santa Fe and (i and j) Tucumán.

Seed areas

As already mentioned, a detailed description of the seed potato production system in Argentina is presented elsewhere (Mendiburu, 1986; Caldiz et al., 1999); nevertheless some relevant aspects are also considered in this paper.

Tafi del Valle, Tucumán. The area was developed during 1970-1975 and approved as seed area in 1976 (Rojas et al.; 1975; 1979). It is located at 2,000 m above sea level and shows a Monsoon type climate, with heavy rains occurring during January-February. Main YLF is water availability during part of the growing season, whereas YRFs are severe attacks of late blight (*Phytophthora infestans*) and *Rhizoctonia solani*. The actual average yield is 25 t ha^{-1}.

Las Estancias, Catamarca. The valley is located in the area of El Pucará in the Aconquija Mountains at 1400-1660 m above sea level. Two thousand hectares can be cultivated from the 24,000 ha that form the Pucará. Ground water of high quality is available for irrigation. The area was developed by potato growers from the area of Concepción, Tucumán. It has different accesses, either from Concepción (90 km), Catamarca city (160 km) or Andalgalá (120 km). Fifteen hundred hectares are cultivated with seed potatoes during the summer period (October-March). Main YLFs are water availability during part of the growing season and unsuitable physiological age of the seed, while the occurrence of aphid flights and severe attacks of late blight (*Phytophthora infestans*) are major YRFs. The actual average yield is 23 t ha^{-1} (N. Zamudio, personal communication, 1994).

Malargüe, Mendoza. Malargüe valley is located in the SW of the province at 1,400 m above sea level and was recognized as a seed potato producing area in 1982 (Chiarlo, 1996). Rivers originating in the Andean Mountains provide water of good quality for irrigation for an area of 4000 ha. Potato crops are grown during the summer (October-March) in an area of 1,000 ha with an actual average yield of 19.5 t ha^{-1}. The main YDF is the dry, hot and persistent *zonda* wind that reduces the relative humidity to less than 15-20%. The main YLF is the physiological age of the seed due to inadequate storage (J. Ortego, personal communication, 1994) and the main YRFs are *Rhizoctonia solani, Fusarium* spp., *Streptomyces scabies* and the presence of *Meloidogyne* spp. in certain fields (Ortego, 1996).

Sierras Grandes, Córdoba. It is a new area of 500 hectares where healthy seed potatoes can be grown, but not much information is available about it. In this area potatoes are grown between 1,100-2,100 m above sea level in Yacanto de Calamuchita, Pampa de Achala, Pampa de San Luis, Pampa Olaen and Pampa del Pocho (L. Lanfranconi, personal communication, 1998). Another seed area is located to the north of Sierras Grandes in Ongamira (1,100-1,300 m above sea level). The seed can be used for the medium early crop planted in the *horticultural belt* of Córdoba and the Villa Dolores area with minimum costs of transport. In the future, lack of storage facilities in the area might become a problem.

The southeast of the province of Buenos Aires. At present seed potatoes are grown in San Cayetano and Tres Arroyos counties, where sea-winds are prevailing. Annually, 1,400 ha of seed potatoes are grown with an actual average yield close to 30 t ha^{-1}. Good soil quality (Table 2.1.4) and favourable environmental conditions enhance the production of high yielding crops. The area is one of the leading areas regarding technological development; technological progress was recently enhanced due to demands from the potato processing industry regarding the use of new cultivars and seed quality. Better efficiencies of water and fertilizer use could probably improve actual average yield. A YRF, concerning seed potato health is the ocassional presence of different aphids, responsible for virus transmission.

Tierra del Fuego Island. This is an isolated area in the southern part of the country with a characteristic oceanic cold climate. Occidental and persistent winds are predominant in the Magallanic Steppe, an arid environment, where only 10 ha have been grown in the *José Menéndez* farm. A recent paper by Caldiz et al. (1999) demonstrated, after three years of research, that the area is free from nematodes and the aphid population is very low. Crops must be grown from mid October-January in order to escape frosts. Main YDFs are long days during the summer period which delay tuber initiation, and risk of frost during the growing period. In the Río Grande area the persistent west wind damages foliage and scarce rainfall, less than 300 mm yr^{-1}, limited crop growth. The use of pre-sprouted and physiologically old seed is a pre-requisite to achieve acceptable tuber yield in such a short growing season and no YRFs have been identified. The results of Caldiz et al. (1999) indicated an average yield of 22 t ha^{-1}.

During the period 1960-1985 the cultivars Huinkul MAG and Ballenera MAA accounted for more than 80% of the Argentinian market. These cultivars have a long absolute dormant period (Caldiz, 1994), which allows them to be stored in *heaps in the field.* The situation changed when cv. Spunta was introduced, because seed tubers of this cultivar must be stored at 2-4 °C to reach the new planting season with a suitable physiological age (Caldiz et al., 1984, 1986). Hence refrigerated, and refrigerated and forced ventilated stores were developed. Actual seed storage capacity in refrigerated stores is 37,450 tonnes while in refrigerated and forced ventilated ones it is 40,850 tonnes (Caldiz, 1996a). However, this capacity is being continually and permanently increased, particularly because many growers or seed companies build their own stores.

Ware areas

Tucumán. In this province, ware production is mainly carried out at the sites of Concepción, Morteros, Aguilares and Famaillá at an altitude of 300-600 m above sea level. Local informers estimated yield to be approximately 16 t ha^{-1}. Three crops are grown: early (June-October); medium early (August-December) and late (February-June). In the early planting the YDF is the length of the growing season which is reduced by low temperatures at planting and high temperatures and heavy rains at harvest. For this crop, the YLF is the physiological age of the seed produced in the mountains (Tafí del Valle, Tucumán) in the medium late crop (October-March); the seed is too young to be successfully used in the early crop. A breeding programme carried out by INTA and the Obispo Colombres Experimental Station is trying to obtain new cultivars with a short absolute dormant period and early sprouting (Huarte, 1989). For the medium early crop the main YDF is the occurrence of heavy rains at harvest which shortens the growth cycle and consequently reduces tuber yield and the main YRF is the occurrence of *Phytophthora infestans*. Therefore, average yields for the ware crop were only 15.6 t ha^{-1} (N. Zamudio, personal communication, 1994) with a recent increase to 19.2 t ha^{-1} (SAGPyA, 1998).

Córdoba. This province is located in the semi-arid region of Argentina. The area surrounding the capital lies at 300-600 m above sea level and is known as the *horticultural belt*, (Lanfranconi, 1994). The area of Villa Dolores is at 600-900 m above sea level and soils are Torriortentic Haplustols from loessic origin, with eolic erosion during the winter dry period (C. Del Caso, personal communication, 1994). Both areas, the horticultural belt and Villa Dolores, are producing potatoes in autumm and spring, in a double cropping system, typical of mediterranean areas (Fahem & Haverkort, 1988). YDFs for this system are, for the late crop: long days and high temperatures at planting, and low temperatures and low irradiance at the end of the growing season, which reduce tuber growth. For the medium early (spring) crop YDFs are: short days at planting and high temperatures at the end of the crop and harvest, which cause severe losses in tuber quality and reduce storability of the tubers. YLFs for the late crop are: use of physiologically young seed, which leads to variable emergence, a problem enhanced by the use of cut seed and high temperatures at planting. In many cases whole potato fields must be re-planted (C. Del Caso, personal communication, 1994). Another limiting factor for the Villa Dolores area is the lack of arable land to improve crop rotation. The land use is currently dominated by rotations of winter cereals and grasslands and in Colonia Tirolesa located in Córdoba HB around 4,000 ha of potato are planted without irrigation within this rotation (L. Lanfranconi, personal communication, 1998). Clearance of new land in Villa dolores area is expensive and therefore the frequency of potato growing on the same piece of land is high. In many fields two potato crops are planted in the same field per year. YRFs are limited to the presence of *Meloidogyne* spp. (Villa Dolores), the perennial weeds *Sorghum halepense* (Villa Dolores) and *Cyperus rotundus* (*horticultural belt*), *Rhizoctonia solani* in the medium early crop and bacterioris in the late crop and to normal attacks of *Alternaria solani* and *P. infestans*. The actual average potato yields are 25 and 18 t ha^{-1}, for the spring and autumn crop, respectively (C. Del Caso, personal communication, 1994), but for the late crops attainable yields of 40 t ha^{-1} have been achieved (Caldiz et al., 1997).

Mendoza. This province is located in the western region of the country, in the area of the Andean Mountains. Ware crops are planted in two areas: Tupungato and Uspallata, in three different seasons: a medium early (August-December) and a medium late cropping season (December-March) in the lowlands of the area and an intermediate cropping season (October-January) in the highlands. Average yields for both zones are 20 t ha^{-1} (J. Ortego, personal communication, 1994). The main YLF is physiological age of the seed, due to lack of adequate storage systems. Storage in heaps in the field produces poor results, mainly in the case of cv. Spunta which is sensitive to physiological aging (Caldiz et al., 1984). Cold stores available are designed for fruits (apples, pears) and not for potatoes. Another YLF is the narrow rotation with nutrient demanding crops like carrot, garlic and onion.

Buenos Aires. The main area for potato production is located in the southeast region of the province between the mountain systems of Tandil and Ventania. The crop is grown during the summer period (October-March) and belongs to the medium-late type, as in other regions, such as Mendoza, Chubut and Río Negro. Probably one of the main factors limiting yield is the physiological age of the seed, either because it is inadequately stored or because it comes from different origins (Caldiz et al., 1984; Caldiz, 1991; Caldiz & Fernández, 1995). Another factor is the inefficient use of irrigation water. High temperatures during harvest (February-March) may, occasionally, reduce tuber quality and the shortage of storage capacity for the seed of early sprouting cultivars, such as Spunta and Kennebec, increases storage losses (Escande et al., 1985; 1986). In this area vertical soil tillage and use of crop residues to improve soil structure and keep soil moisture are increasing, while, due to the requirements of the food processing industry to avoid tuber greening, row distance is being modified to 0.85-0.95 m (Huarte, 1996). Huarte & Inchausti (1994) quoted an average tuber yield for the area of 30 t ha^{-1}.

Río Negro and Chubut. In these two provinces potatoes are grown during the summer period in the valleys of Río Negro and Chubut rivers. In Río Negro the crops are located around Choele Choel in the mid-valley. Sandy soils are suitable for potato production but they are low in organic matter and nutrient content and affected by wind erosion. Hence, irrigation and fertilization management are crucial to achieve high yields. Due to daylength (>18 h), temperature amplitude and high irradiance tuber dry matter percentages are higher than in other production areas. For example, in cv. Russet Burbank values of 23% dry matter were found while in other areas the average for this cultivar is around 20%; under these conditions yields higher than 40 t ha^{-1} were achieved (D.O. Caldiz, unpublished). At present 350 ha for the processing industry are being grown (M. Inchausti, personal communication, 1998). Isolation of these areas also allowed seed production of specific cultivars that are exported to Brasil (Anonymous, 1998). A detailed description of these areas is found elsewhere (Caldiz et al., 2000a).

2.1.4. Perspectives

Several key-improvements in potato production have been achieved during the last 10 years. These include: the self-sufficiency in seed supply achieved since 1985 (Escarrá, 1989); the development of new cultivars with a short absolute dormant period to be grown in the early season crop: clones 87.802.8 and 88.1000.4 obtained by the EEOC (Zamudio, 1996); the development of cultivars for the processing industry: Frital INTA and the potential of other cultivars such as: Kennebec, Ballenera MAA, Araucana INTA and Serrana INTA (Huarte, 1996); the adoption of soil conservation and weed management techniques (Lanfranconi, 1993); the production of organic seed crops in the Malargüe area (Ortego, 1996) and the increasing export market of seed and ware potatoes to MERCOSUR (Brasil, Paraguay and Uruguay) and other countries, Germany, Bolivia, Canada (Caldiz & Inchausti, 1996).

However, various different YLFs and YRFs, as discussed in this paper, should be considered in the future to obtain further improvements in yield and quality. The isolation of the seed areas and the exclusive use of certified seed in each of them require further controls; otherwise, the achievements of the last 10 years will be lost. The use of seed with suitable physiological age according to the different planting seasons and export requirements should be considered a pre-requisite to obtain higher yield under different situations; an improved management of the new cultivars and those required by the food processing industry, such as Shepody, Russet Burbank, Ranger Russet, Atlantic, Frital INTA and Keluné INTA is needed. The development of new production areas in patagonic river valleys, like the Río Negro and Chubut will require specific crop management, regarding improvements in soil structure, soil preparation, wind protection, irrigation and fertilization. Increases in storage facilities for seed, ware and processing tubers are needed at country level and further identification of YLFs or YRFs and assessment of the potential yield of the crop for the different areas are also required. In this respect work is in progress in order to assess the possibilities of expansion and potential yield of the crop in the country.

This case study of the potato production system in Argentina might be used as a model to analyze potato production in other countries, regions or continents in order to establish the actual yield of the crop, its constraints and future possibilities based on the introduction of new cultivars or different technological advances.

Disclaimer: The mentioning of the occurrence of yield reducing factors does not mean that produce (seed, ware or industry) that is sold on national or international markets carries pathogens or their survival structures.

CHAPTER 2.2

AGRO-ECOLOGICAL ZONING AND POTENTIAL YIELD OF THE CROP

submitted as:

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2.2. AGRO-ECOLOGICAL ZONING AND POTENTIAL YIELD OF THE CROP

Summary

Potato is the most important horticultural crop in Argentina and at present 100,000 ha are grown in different regions and seasons. The four possible growing seasons are defined as early (June-October), medium-early (July-November), medium-late (October-March) and late (February-June) and have already been characterized by assessing weather, soil and crop type, yield level and yield determining, yield limiting and yield reducing factors. However, there is scarce or no information on the possibilities of expanding actual crop frontiers, either at regional or national level and on the potential yield of the crop in different agro-ecological zones. Hence, in this work we (1) characterize agro-ecological zones for potato production; (2) establish potential duration of the crop cycle and potential growing seasons; (3) estimate the potential yield of the crop in these zones and seasons; and (4) demonstrate how Geographic Information Systems (GIS) for land evaluation and simulation models that establish potential yield of the crop can be used together to assess possibilities for increasing crop production at local, regional or national scales. Seven potential growing seasons ranging from <1500->3500 °Cd were identified for areas where one crop can be grown per year, whereas four areas were identified where there is a potential for a second crop of potatoes. In these areas and seasons potential tuber yields range from <10–20 t ha^{-1} dry matter. The study identified suitable soils and ascertained the corresponding potential duration of the growing seasons and the potential yield for each of the suitable sites and seasons.

2.2.1. Introduction

Potato is the most important horticultural crop in Argentina. The first record of its cultivation is from 1872/73 with an area of 2,361 ha. By 1895, 21,000 ha were cropped with potato and a maximum of 170,000 ha was reached in 1923/24 (Ratera, 1945). In 1934, the area was reduced to 148,000 ha and afterwards gradually stabilized at around 120,000 ha with constant increments of yield per ha of about 250 kg ha^{-1} yr^{-1} in the period 1934-1994 (Caldiz, 1994). At present, 100,000 ha are cropped with potato. The potential yield of the potato crop can be defined as the yield achieved by a certain cultivar in a particular environment when factors such as water, fertilizers, physiological age or crop management are not limiting and when no reducing factors, such as diseases, pests and weeds are present (Caldiz & Gaspari, 1997). These potential yields are high, in the range of 100-120 t ha^{-1} (Caldiz & Struik, 1999).

The crop is grown in different regions and seasons (Huarte & Inchausti, 1994; Caldiz & Inchausti, 1996). Growing seasons are early (June-October), medium-early (July-November), medium-late (October-March) and late (February-June). These seasons have recently been characterized by assessing weather, soil and crop type, yield level and yield determining, yield limiting and yield reducing factors by Caldiz & Struik (1999). Variations in potential yield among growing seasons and sites are large. It is useful to establish this variation and explain possibilities to increase hectareage in certain areas. Knowing the options to expand crop frontiers would allow: (a) to take political decisions on strategic development and investment at national or regional levels; (b) to establish a framework for discussion on ideotyping between breeders, ecophysiologists and agronomists; and (c) to develop specific crop management strategies.

At a global scale, which included Argentina, an attempt to identify and agro-ecologically characterize potato growing zones was made by Stol et al. (1991) and van Keulen & Stol (1995) at the request of the International Potato Center to plan research in those areas of Latin America, Asia and Africa where potato production is most promising. However, it is interesting to evaluate not only the possibilities to expand the crop but also to predict its potential yield for different growing seasons as was done by Stol et al. (1991), van Keulen & Stol (1995) and Haverkort & Kooman (1997) at the global level, and by van Haren (1998) and Hijmans (1999) for Ecuador and Peru. Moreover, given the annual growth of the world population of 90 million persons and the resulting increase in demand of staple foods such as cereals and tubers (Caldiz, 1996b), such approaches could contribute to explore future possibilities for food production and supply. However, with the exceptions already mentioned, and despite the importance and large yield variation of the potato crop for Argentina, no attempts have been made to establish an agro-ecological zoning for Argentina while data on potential yield are only partially available for certain areas (Cantos de Ruiz, 1988; Caldiz & Struik, 1999). Hence, for Argentina, there is little knowledge about the possibilities of expanding actual crop frontiers, either at the national or regionals levels, and on the potential yield of the crop for different agro-ecological zones. The Argentinian case is of especial interest because of its large variations in weather conditions, stress factors, altitude, seed age and technological level. Thus, it presents a real test for the combined use of Geographic Information Systems (GIS) for land evaluation and simulation models that establish the potential yield of the crop based on weather data.

The purpose of this work is (1) to characterize agro-ecological zones for potato production in Argentina, using specific Argentinian data sets rather than the unspecific global data sets used in previous studies; (2) to establish potential growing seasons and potential crop length in each of these zones; (3) to estimate the potential yield of the crop in these zones and seasons; and (4) to discuss how these theoretical results match reality.

2.2.2. Materials and methods

Soils and weather

Agro-ecological zonation was based on the approach of Stol et al. (1991) and van Keulen & Stol (1995) and was carried out without taking into account knowledge on current spread of the crop. A digitized version of the Atlas de Suelos de la República Argentina (Fundación ArgenINTA et al., 1995) was used to discriminate between suitable and unsuitable soils. Soil classification in this Atlas is based on Soil Survey Staff (1992), and is at the level of Orders, Sub-Orders and Great Groups. The study was performed at the Great Group level. Based on the detailed description given for each Great Group of soils in the Atlas de Suelos (Fundación ArgenINTA et al., 1995), we considered unsuitable for potato cultivation those mentioned in the Atlas with any or a combination of any of the following characteristics related to a specific Great Group of soils: low water permeability, water saturated, very low drainage, high Na content, hardpan, hardpan in sub-superficial profile, highly saturated in bases, destructed profile/s, saline soils, highly erosionated, too sandy soils, insoluble minerals (quartz, zirconium), mobile sands, no water retention, salts in top layer, high water table, limited top layer, very high Ca in the profile, high Ca in the top layer, very low pH, high Fe, high clay content, hydromorfism, rocky soils, superficial soils laying on rocks, soils in development, fragipan and high mountain soils. Hence, Greats Groups of soils with any or a combination of any of these characteristics were excluded from the soil data-base created for this particular work.

Long term weather data (10-30 years) for 97 weather stations distributed throughout the country were available from FAO (1990) and Servicio Meteorológico Nacional (1992). These data were organized in a data base containing monthly averages of the following variables: radiation (kJ m^{-2} day^{-1}), minimum and maximum temperature (°C), wind velocity (m s^{-1}) and rainfall (mm $month^{-1}$). For identification of the potential growing seasons and application of the crop growth model daily values of weather variables are required. These were derived from the mean monthly averages by assigning these values to day numbers at the middle of the months and subsequent linear interpolation.

Spatial distribution of the Great Groups of suitable soils was performed using the program ArcView 1.0 provided with the Atlas de Suelos de la República Argentina (Fundación ArgenINTA et al., 1995), while spatial distribution of the weather zones used in this work was done with the GIS IDRISI V. 4.0 (Eastman, 1993). Then, by means of tesselation, a map with different agro-ecological characteristics was defined, using as a central point for each zone the geographical location of the 97 weather stations already mentioned. Pixel size is equivalent to 33.64 (5.8 x 5.8) km^2. Despite the detailed level of the study, for simplification only a map of the country indicating areas covered with suitable and unsuitable soils is presented while a complete list of suitable and unsuitable soils is presented.

Identification of potential growing seasons and potential crop length

To identify the number and of potential growing seasons and the potential length of crop cycles the Gzones simulation model V. 1.0 was used (Stol et al., 1991). The temperature constraints for the identification of the potential growing seasons were:

- a daily minimum temperature above 5 °C;
- a daily maximum temperature below 30 °C;
- a minimum accumulated temperature requirement of 1500 °Cday (base temperature 2 °C);
- a maximum accumulated temperature requirement of 3000 °Cday (base temperature 2 °C).

The minimum requirement of 1500 °Cday matches the thermal time of a seed crop of 75-85 days, while the maximum requirement of 3000 °Cday matches the thermal time of a late-maturity cultivar of 140-150 days. The model scans the daily course of minimum and maximum temperatures throughout the year for the 97 different weather stations in order to identify periods with temperatures suitable for potato production, during which accumulated temperatures above a base temperature of 2 °C exceed the minimum temperature requirement (Stol et al., 1991).

If requirements for minimum or maximum temperatures were never met or only during a period that was too short to meet the minimum accumulated temperature requirement, the zone was classified as not suitable for production. If temperature conditions were suitable during part of the year, the first suitable day was identified and a planning procedure for 365 days was started. Planting date for the first growing season was set at the first suitable day, if daily minimum temperature was the constraint, or two weeks earlier if daily maximum temperature was the constraint. Growing seasons were terminated when the accumulated temperature was at least equal to the minimum and the minimum or maximum day temperatures reached a value outside the defined limits. If both maximum and minimum temperatures stayed within their defined limits then the growing season was terminated once the maximum value for accumulated temperature was reached (van Keulen & Stol, 1995). A second growing season was identified if temperatures were within the defined limits, either following a period of unsuitable conditions, or directly following the first growing season. As temperatures were the only selection criterion, the cropping calendar was not necessarily synchronized with rainfall or photoperiod. This approach is consistent with our definition of potential yield.

Calculation of potential yield

To calculate the potential dry matter production of the crop, for the different agro-ecological zones and growing seasons, we used the LINTUL-POTATO model as described elsewhere (Kooman, 1995). The model calculates potential yield for a certain period of time, assuming that crop growth does not take place when minimum temperatures are below 5 °C and maximum temperatures are above 30 °C. Simulation is based on: (a) incident Photosynthetically Active Radiation (PAR, 400-700 nm); (b) fraction of PAR intercepted by the crop and (c) radiation use efficiency (RUE) to convert light into dry matter. Phenological crop development is driven by accumulated temperature, development stage determines dry matter partitioning and haulm growth defines the pattern of intercepted PAR. The model has been calibrated and validated for different cropping situations in the world (Kooman & Haverkort, 1995). The model simulates the interception of radiation since the moment of 50% emergence through senescence. We assumed that 50% emergence occurred 15 days after planting and that plant density was 5 plants m^{-2}, a normal plant density in Argentina. RUE was set at a constant value of 2.8 g MJ^{-1} based on the results of Echeverría et al. (1992) and Saluzzo (1994) for Argentinian conditions, although lower values and values exceeding 4 g MJ^{-1} have been reported (e.g. Haverkort & Harris, 1987). Tuber yields are calculated by multiplying the total biomass produced by the harvest index. The harvest index is derived from the average temperature during tuber growth. In potato, more dry matter is allocated to the haulm with increasing average temperatures (Midmore, 1990; van Dam et al., 1995). Up to 15 °C the harvest index remains constant at 0.8 and decreases at higher temperatures (Stol et al., 1991). The model estimates potential yield when water and nutrient supplies are not limiting and when no reducing factors such as weeds, pests and diseases occur. If conditions are not ideal the crop suffers from stress and crop growth and dry matter distribution are affected. In this study water-limited yields were not considered because it is considered that for Argentinian conditions additional irrigation is needed to obtain profitable yields.

To run the model certain weather data are required: daily global radiation, minimum and maximum temperature. This information was obtained from the database created for the agro-ecological study (FAO, 1990; Servicio Meteorológico Nacional, 1992). The dry matter concentration in the tuber was assumed to be 20%; to convert tuber dry matter yields into fresh tuber yields, dry matter yields must be multiplied by 5.

2.2.3. Results and discussion

Agro-ecological zoning and identification of potential growing seasons and potential crop length

The area covered by soils suitable for potato production, as identified with the criteria already mentioned, is shown in Figure 2.2.1, while a complete list of suitable and unsuitable soils is presented in Table 2.2.1. None of the soils, defined with the procedure used in this study, as unsuitable for potato cultivation, are actually cropped with potatoes in Argentina. Areas recognized as unsuitable for potato production included those in the western part of the country belonging to the Andean mountains, those subject to flooding in the northeast or in the central-east of the province of Buenos Aires, or those with rocky soils.

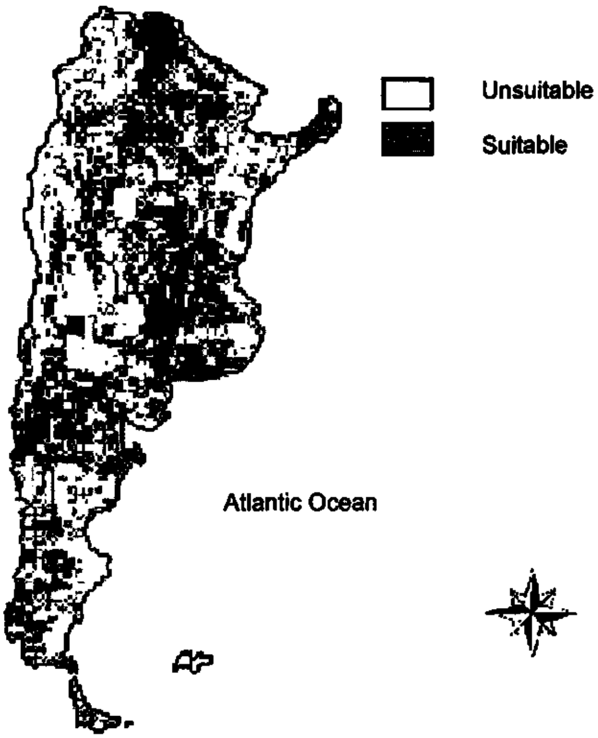


Fig. 2.2.1. Suitable and unsuitable soils for potato production in Argentina.

Areas where the crop is currently grown were indeed identified as suitable; examples are: the southeast and northeast of the province of Buenos Aires, the central part of the country in the province of Córdoba and areas located in the provinces of Tucumán, Mendoza and Río Negro (Figures 2.1.3 and 2.2.1). Our results did not fully match those of Stol et al. (1991) and van Keulen & Stol (1995) for Argentina because in the present study 50 different Great Groups of suitable soils were identified, based on a variety of characteristics, whereas Stol et al. (1991) and van Keulen & Stol (1995) only defined 8 different soil classes using texture as the sole criterion. The present results at a high level of detail will allow a more specific use of the whole study as it is presented elsewhere for different Argentinian provinces (Caldiz & Gaspari, 1998; Caldiz et al., 2000a). Moreover, these results show that there are still enormous possibilities of increasing the cropping area, provided other resources are supplied. Seven different groups for the potential duration of the crop cycle ranging from <1500 °Cday to >3500 °Cday were identified (Figure 2.2.2a). An important area in the central-east part of the country, certain areas close to the Andean mountains and an area in the southern part of continental Argentina and in Tierra del Fuego island were identified as unsuitable for potato growing.

The central-east area was unsuitable due to the high summer temperatures or low winter temperatures registered, which prevented identification of a sufficiently long growing season. Areas close to the Andean mountains in the northeast or in the southern part of the country were not suitable due to low temperatures. Tierra del Fuego island was also too cold, but (seed) potatoes are grown there albeit with a high risk of frosts during crop growing as recently found by Caldiz et al. (1999). Most of the growing seasons identified in this study, especially those in coastal areas or in the central part of the country, fit with those identified by Stol et al. (1991) and van Keulen & Stol (1995).

In most of the provinces of Río Negro, Chubut and Santa Cruz potential duration of growing seasons was in the range <2750 °Cday to >3500 °Cday, although in some of these areas the crop cannot be grown without certain protective measures due to the high incidence of several yield limiting factors such as strong and persistent winds (Caldiz et al., 2000a). A second growing season ranging from <2000 °Cday to >2500 °Cday was possible in the northwest, the central part and the eastern part, and the north of Buenos Aires and the south of Santa Fé (Figure 2.2.2b). These areas, especially those in the central and eastern part of the country are actually double cropping areas where autumn crops are grown from February till June and spring crops are grown from July till November (Caldiz & Haverkort, 1994).

Table 2.2.1. Suitable and unsuitable Great Groups of soils for potato production[1].

Suitable	Unsuitable	Reasons for rejection
Order Alfisols		
Kandiudalfs	Albaqualfs	low permeability, water saturated
Haploxeralfs	Natraqualfs	low permeability, high Na
Hapludalfs	Durustalfs	hardpan
Haplustalfs	Eutroboralfs	highly saturated with bases
Kanhpludalfs	Natriboralfs	high Na in the profile
Paludalfs	Fragiaqualfs	hardpan, limited drainage
Paleustalfs	Glossaqualfs	destructed profile
Palexeralfs	Natrudalfs	high Na in the profile
Rhodudalfs	Natrustalfs	high Na in the profile
Order Aridisols		
Calciorthids	Durargids	hardpan
Camborthids	Natrargids	high Na in the superficial layer
Haplargids	Salorthids	saline soils in low areas
Nadurargids		
Paleargids		
Paleorthids		
Order Entisols		
Torrifluvents	Criorthents	highly erosionated
Torriorthens	Endoacuents	water saturated
Udifluvents	Epiacuents	water saturated
Udipsamments	Fluvacuents	water saturated
Udorthents	Hyddraquents	water saturated
Ustifluvents	Quarzipsamments	insoluble minerals
Udipsamments	Xeropsamments	too sandy soils, no water retention
Xerofluvents	Torripsamments	mobile sands
	Psammacuents	too sandy soils, no water retention
	Ustorthens	very limited drainage
Order Histosols	All great groups of soil unsuitable	water saturated
Order Inceptisols		
Cryochrepts	Cryaquepts	very low drainage
Cryumbrepts	Fragiochrepts	fragipan
Dystrandepts[2]	Cryandepts[2]	high mountain soils
Dystrochrepts	Hydrandepts[2]	water saturated
Eutrandepts[2]	Fragiaquepts	fragipan
Eutrochrepts	Endoaquepts	very low drainage, high water table
Haplumbrets	Andaquepts[2]	very low drainage
Ustochrepts	Halaquepts	high Na content, salts in top layer
Vitrandepts[2]	Haplaquepts	in development
	Humaquepts	low drainage

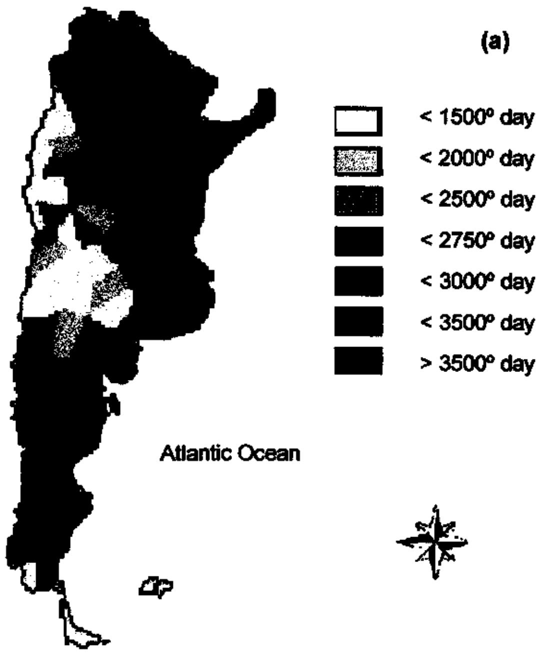
Continued on next page.

Suitable	Unsuitable	Reasons for rejection
Order Molisolls		
Argialbolls	Natralbolls	high Na content, hydromorphism
Argiaquolls	Cryaquolls	water saturated, very cold soils
Argiudolls	Argiaquolls	high clay content in the profile
Argiustolls	Haploxerolls	limited top layer, laying on rocks
Calciustolls	Argixerolls	limited top layer
Cryoborolls	Calciaquolls	high Ca in the top layer, low areas
Haplaquolls	Duraquolls	hardpan, no root growth
Haploborolls	Durustolls	hardpan in subsuperficial profile
Hapludolls	Argiborolls	high superficial clay content
Haplustolls	Natrustolls	high Na content
Paleudolls	Calcixerolls	high Ca in the profile
Paleustolls	Natraquolls	high Na content
Rendolls		
Order Oxisols	All great groups of soils unsuitable	
		low pH, high Fe
Order Spodosols	All great groups of soils unsuitable.	
		limited top layer
Order Ultisols		
Hapludults	Paleaquults	high clay content, hydromorfism
Kandihumults		
Kandiudults		
Kanhapludults		
Paleudults		
Order Vertisols	All great groups of soils unsuitable	
		high clay content, low drainage

(1) List according by Soil Survey Staff (1992); (2) only listed in the Atlas de Suelos de la República Argentina (Fundación ArgenINTA, 1995).

Estimation of potential yield

The use of the LINTUL-POTATO simulation model allows the identification of six different potential yield zones with ranges starting from <10 until >20 t ha^{-1} dry matter for either the first or the second of the identified growing seasons (Figures 2.2.3a and b). Potential yield values obtained in this study are in general agreement with those estimated by Stol et al. (1991) and van Keulen & Stol (1995).



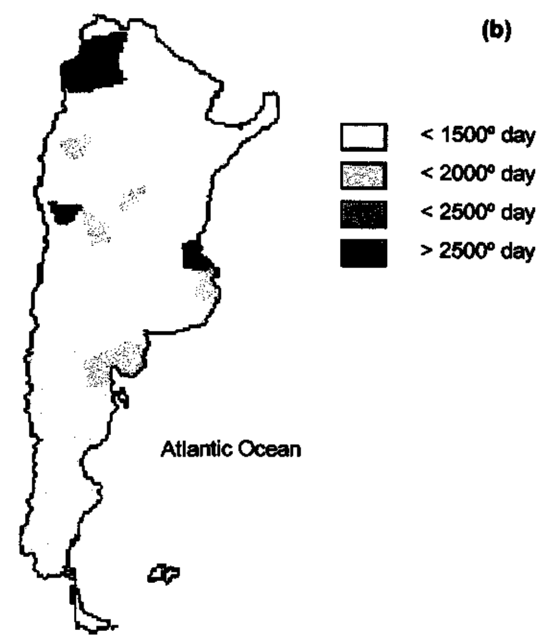
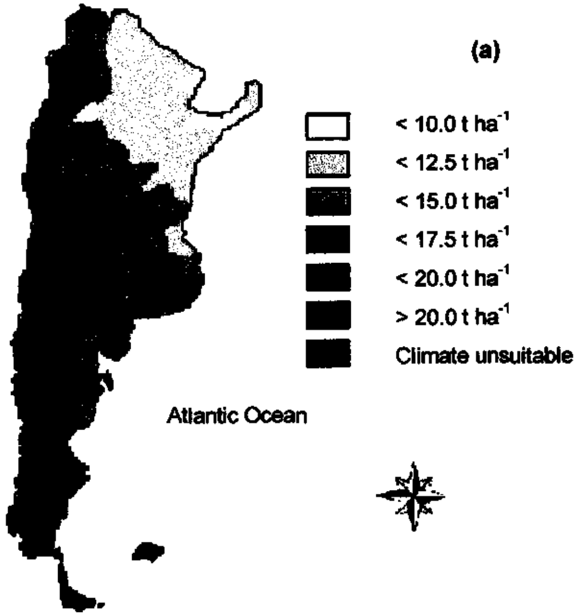


Fig. 2.2.2. Potential duration of crop cycle for (a) the first and (b) second growing season.



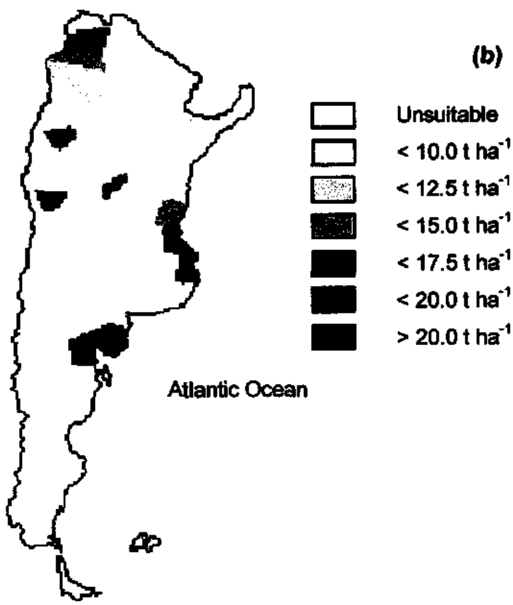


Fig. 2.2.3. Potential tuber dry matter yield of the crop as estimated by the LINTUL-POTATO model for (a) the first and (b) second growing season.

Potential yields were higher for the first and longer (Figure 2.2.3a) growing season than for the second (shorter) season (Figure 2.2.3b). High values were achieved in areas close to the sea, for example the southeast of Buenos Aires (the typical potato growing area in Argentina), and the southern part of the country, as found in previous work (Stol et al., 1991; van Keulen & Stol, 1995). Potential yields >20 t ha^{-1} dry matter were also found in other areas in the northwest and in the central-west part of the country (Figure 2.2.3a) where radiation is very high and temperatures proved suitable for crop growing (FAO, 1990; Servicio Meteorológico Nacional, 1992). For the longer growing season some potential yield values were close to or even higher than the maximum of 140 t ha^{-1} estimated by Kunkel & Campbell (1987) for Washington State (USA) and in most cases proved similar to those calculated for northwestern Europe by Stol et al. (1991) and van Keulen & Stol (1995). Earlier potential yield estimations following van der Zaag & Burton (1978) showed that 88 t ha^{-1} could be achieved in the southeast region of the province of Buenos Aires (Cantos de Ruiz et al., 1988). However, Huarte and Cacace (1998) mentioned for this region that 100 t ha^{-1} have been obtained in experimental plots, while Caldiz & Struik (1999) assessed with LINTUL-POTATO a potential yield of 126 t ha^{-1}.

In contrast, the mean actual yield for the region is only 30 t ha^{-1}, illustrating that the gap between actual and potential yield is still very large. Probably differences between actual and potential yield can be attributed to unsuitable water and fertilizer management (Huarte, 1996) and to the detrimental effects of foliage diseases, i.e. *Phytopththora infestans* and *Alternaria solani,* which reduce intercepted radiation. Similar yield gaps were also found in other areas, for example, in the north, in the province of Tucumán, actual average yield is around 18 t ha^{-1} (Caldiz & Struik, 1999) while potential yield estimates are above 60 t ha^{-1} (Figure 2.2.3a). In this case, these differences could be attributed to the poor physiological status of the seed used, to unsuitable water and fertilizer use and early crop killing to avoid harvest under very wet conditions (N. Zamudio, personal communication, 1996).

In Argentina, seed tubers are produced in different areas with different soils and environmental conditions, which results in a wide range of seed age (Caldiz, 1991). Physiological age is an important yield limiting factor (van der Zaag & van Loon, 1987; Caldiz, 1991; Caldiz & Fernández, 1995), mainly due to its effect on ground cover duration which is closely related to tuber yield (Allen & Scott, 1980). Hence, management of seed age should be improved in order to match, in each zone, the available growing period (O'Brien et al., 1983). The gap between actual:potential yields is still wide but improvement in seed management, water and fertilizers and control of leaf diseases could contribute to reduce it.

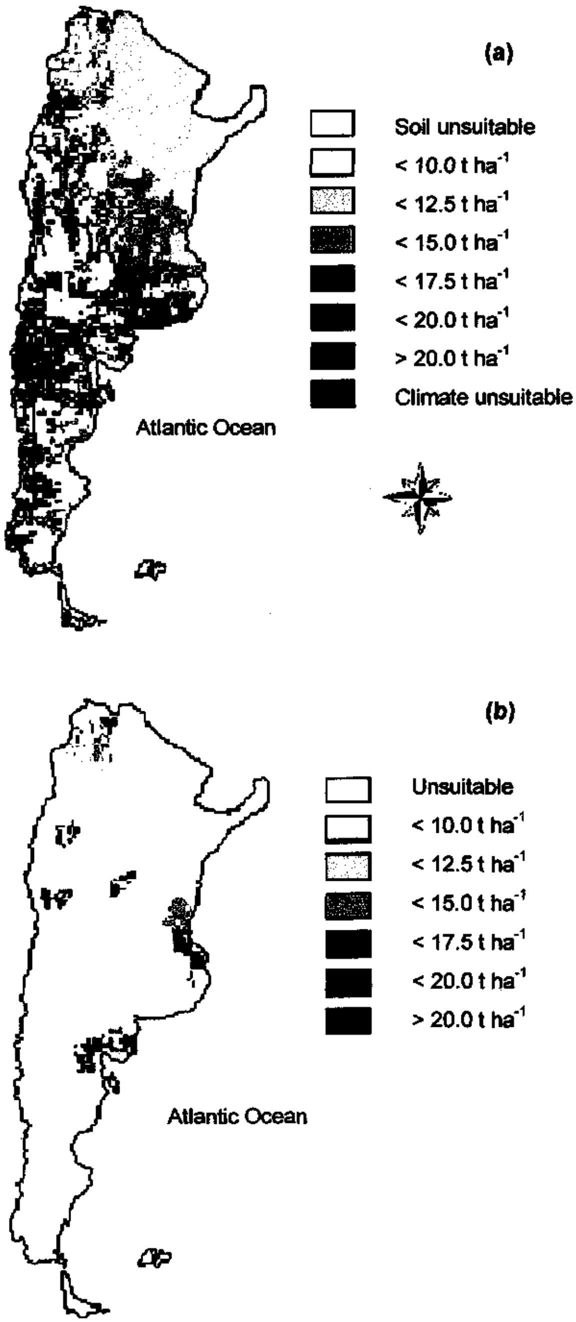


Fig. 2.2.4. Potential tuber dry matter yield of the crop as estimated with the LINTUL-POTATO on suitable soils for (a) the first and (b) second growing season.

However, it would be interesting to analyze this gap, for each zone, by assessing (a) extra costs of prolonging the crop cycle (fungicides, water and nutrients) and (b) associated problems related to harvest delay (rainfall and low temperatures), that could probably result in reductions in harvestable tubers and quality (Caldiz & Gaspari, 1997).

Finally, Figures 2.2.4a and b show potential yields on suitable soils for different agro-ecological zoning and different seasons. These maps clearly show those areas where the crop can be grown and what yields can potentially be achieved. Based on these two maps specific trials should be carried out to establish water and nutrient requirements and to identify yield reducing factors in each of theses zones. As four different planting seasons (early, medium-early, medium-late and late) are performed during the whole year, based on the present results, further work could be carried out to identify those areas with largest yield gaps or, at a high level of detail, identify optimum planting dates for achieving the highest potential yield within a certain agro-ecological area (Caldiz & Gaspari, 1998; Caldiz et al., 2000a).

These findings suggest that the potato industry should consider to develop production areas in the southeastern part of the country and in some mountain-valleys in the west, where in all cases water is available.

CHAPTER 2.3

AGRO-ECOLOGICAL ZONING AT THE REGIONAL LEVEL: SPATIO-TEMPORAL VARIATION IN POTENTIAL YIELD IN THE SOUTHEAST OF THE PROVINCE OF BUENOS AIRES

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2.3. AGRO-ECOLOGICAL ZONING AT THE REGIONAL LEVEL: SPATIO-TEMPORAL VARIATION IN POTENTIAL YIELD IN THE SOUTHEAST OF THE PROVINCE OF BUENOS AIRES

Summary

Almost 40% of the potato production in Argentina takes place in the Province of Buenos Aires, mainly in the southeast. However, for this and other zones there is not enough detailed information available regarding the possibilities of expanding actual crop frontiers or the potential yield level of the crop. This paper provides an agro-ecological characterization of the southeast of the Buenos Aires province and estimates the spatio-temporal variation in potential yield of the crop in this region. Agro-ecological zoning was carried out by means of a Geographic Information Systems (GIS) based on soil type and long-term weather data available for the area. The potential yield of the crop for different planting times, was established using the LINTUL-POTATO model (Kooman, 1995), which is based on interception and utilization of radiation. Maximum potential yield values of 130 t ha^{-1} were estimated for the September planting in Coronel Suárez. Important yield differences exist between the different agro-ecological zones identified in this study, mainly due to temperature differences at the end of crop growth which affected the harvest index of the crop. Delay in planting also decreased the potential yield of the crop by 259 kg ha^{-1} day^{-1}; this effect was also associated with a reduction in the harvest index.

The potential yield in this area is close to the potential yield estimated for other highly productive areas of the world, such as Washington, USA and The Netherlands. The gap between actual and potential yield is larger in the area under study than in those areas in the northern hemisphere, probably due to the use of seed of improper physiological age, limitations in water and nutrient management and less efficient control of foliage diseases, i.e. *Phytophthora infestans* and *Alternaria solani.*

2.3.1. Introduction

In Argentina, about 100,000 ha of potatoes are grown in different regions and growing seasons (Huarte & Inchausti, 1994; Caldiz & Inchausti, 1996). The four possible growing seasons are defined as early (June-October), medium-early (July-November), medium-late (October-March) and late (February-June). They have recently been characterized according to weather, soil and crop type, yield level and yield determining, yield limiting and yield reducing factors by Caldiz & Struik (1999).

At a global level, Stol et al. (1991) performed an agro-ecological zoning and estimated the potential yield of the potato crop with the aim of establishing the possibilities of expanding the crop to other areas and to replace, in part, long, tedious and laborious experiments that should be carried out to achieve the same results. For Argentina, Caldiz et al. (2000b) also performed an agro-ecological zoning and estimated the potential yield of the crop for the whole country. In their study the latter authors estimated, for the southeast of the province of Buenos Aires, where more than 40% of the crop is grown, a potential yield ranging from 17.5-20 t ha^{-1} (dry matter). However, there is no detailed information available regarding spatio-temporal variations in potential yield at regional scale. Knowing the possibilities of expanding spatio-temporal crop frontiers allows to: (a) design a policy for strategic development of the crop at regional levels; (b) analyze gaps between actual and potential yields and design specific projects to reduce these gaps; (c) establish a framework for discussions between breeders, ecophysiologists and agronomists for developing ideotypes; (d) design a proper net of field trials at national or regional levels to test new cultivars; and (e) analyze possible areas where high yields can be achieved and where it should be important to increase future investments.

Therefore, a research and development project was developed to identify by means of a Geographic Information System (GIS) and a simulation model, different agro-ecological zones and possible spatio-temporal variations in the potential yield of the crop for the southeast of the province of Buenos Aires.

2.3.2. Materials and methods

Agro-ecological zoning

Agro-ecological zoning was based on the approach of Stol et al. (1991) and van Keulen & Stol (1995) and was carried out without using knowledge on current cultivation. A digitized Atlas de Suelo de la República Argentina (Fundación ArgenINTA et al., 1995) based on the Soil Survey Staff (1992) classification, was used. The Atlas contains soil classification at the level of Orders, Sub-Orders and Great Groups. We used the level of Great Groups. Based on the detailed description given for each Great Group of soils in the Atlas de Suelos (Fundación ArgenINTA et al., 1995), we considered unsuitable for potato cultivation those mentioned in the Atlas with any or a combination of any of the following characteristics related to a specific Great Group of soils: low water permeability, water saturated, very low drainage, high Na content, hardpan, hardpan in sub-superficial profile, highly saturated in bases, destructed profile/s, saline soils, highly erosionated, too sandy soils, insoluble minerals (quartz, zirconium), mobile sands, no water retention, salts in top layer, high water table, limited top layer, very high Ca in the profile, high Ca in the top layer, very low pH, high Fe, high clay content, hydromorfism, rocky soils, superficial soils laying on rocks, soils in development, fragipan and high mountain soils. Hence, Greats Groups of soils with any or a combination of any of these characteristics were excluded from the soil data-base created for this particular work.

Long-term weather data (10-30 years) were available from FAO (1990) and Servicio Meteorológico Nacional (1992). These data were organized in a data-base containing the following variables as monthly averages: radiation (kJ m^{-2} day^{-1}), minimum and maximum temperature (°C), wind velocity (m s^{-1}) and rainfall (mm $month^{-1}$). When the data of global radiation were not available it was calculated based on the Ångstrom formula (Black et al., 1954) and in this case sunshine values were obtained from the Smithsonian Institute (1951) and the Servicio Meteorológico Nacional (1992). Stations from which weather data were used are listed in Table 2.3.1. The Great Groups of suitable soils and the weather stations were localized using the GIS ArcView 1.0 provided with the Atlas de Suelos de la República Argentina (Fundación ArgenINTA, 1995), and the GIS IDRISI V. 4.0 (Eastman, 1993), respectively. Then by means of tesselation, a map with different agro-ecological characteristics was defined, using as a central point for each region the geographical location of the weather stations already mentioned in Table 2.3.1. Pixel size is equivalent to 33.64 (5.8 x 5.8) km^2. For each region suitable soils were identified.

Table 2.3.1. List of weather stations used in the agro-ecological zoning and precise geographical location and altitude.

Weather station	Latitude (S)	Longitude (W)	Altitude (m above sea level)
Azul	36° 44'	59° 59'	132
Bahía Blanca	38° 44'	62° 11'	83
Balcarce	37° 51'	58° 15'	113
Coronel Suárez	37° 26'	61° 53'	231
Mar del Plata	38° 08'	57° 33'	14
Tres Arroyos	38° 19'	60° 15'	120

Estimate of the variation in potential yield for different agro-ecological zones

To establish potential yield of the crop in terms of dry matter, the LINTUL-POTATO model (Kooman, 1995; Kooman & Haverkort, 1995) was used. Simulation is based on: (a) incident Photosyntheticaly Active Radiation (PAR, 400-700 nm); (b) fraction of PAR intercepted by the crop; and (c) radiation use efficiency (RUE) to convert light into dry matter. In the model, accumulated temperatures determine phenological crop development, while development stage determines dry matter partitioning and through haulm growth the pattern of intercepted radiation is defined. The model has been calibrated and validated for different crop situations in the world (Kooman, 1995) while for Argentina calibration and validation were carried out with data from crops grown at the Chacra Experimental de Miramar during 1994/95 and 1995/96 (Caldiz et al., 1996a).

The model simulates the interception of radiation since the moment of 50% emergence until senescence. We assumed that 50% emergence occurred 15 days after planting. Intercepted radiation in relation to dry matter accumulation over time allows to estimate RUE for total and tuber dry matter production. The model estimates potential yield when water and nutrient supplies are not limiting and when no reducing factors such as weeds, pests and diseases occur. If these stresses do occur the crop suffers a reduction in growth, and dry matter distribution is affected as well. These conditions were not considered in this work, where only the potential yield of the crop was estimated.

To run the model certain weather data are required: daily global radiation, minimum and maximum temperatures. This information was obtained from the data base created for the agro-ecological study (FAO, 1990; Servicio Meteorológico Nacional, 1992). The model calculates potential yield for a certain period of time, assuming that crop growth does not take place when minimum temperatures are below 5 °C and maximum temperatures are above 30 °C. This range is different from the 2-28 °C used in global studies (Stol et al., 1991; Kooman, 1995; Kooman & Haverkort, 1995), but was selected because in the area under study, in the period September-March, the crop is normally grown with temperatures above 30 °C. The model allows to modify several physiological variables such as the maximum harvest index of the crop and radiation use efficiency. Values of both variables were defined based on the work of Echeverría et al. (1992) and Saluzzo (1994), maximum harvest index: 0.90 and radiation use efficiency: 2.8 g MJ^{-1}. Temporal variations in potential yield were assessed by considering three possible planting dates: 15 September, 15 October and 15 November and 50% crop emergence was set at 15 days after planting. Two different crop cycles of 120 and 140 days were considered. For the 120 days crop cycle 5.3 pl m^{-2} and for the 140 days crop cycle 4.2 pl m^{-2} were used, as normally done in the area under study.

As a result of the combination of possible planting dates and planting densities for each of the six locations used in the study six different estimations of the potential yield were obtained. Dry matter percentage in the tuber was set at 20%; thus fresh yield can be assessed by multiplying dry matter yield by 5.

2.3.3. Results and discussion

Agro-ecological zoning

Soils suitable for potato growing in the southeast region of the province of Buenos are shown in Figure 2.3.1. Argiudol, Hapludol and Argiustol great groups occupy the largest area in the region. Argialbol and Udipsament occupy a smaller area while Haplustol is only slightly represented in the southwestern part of the region.

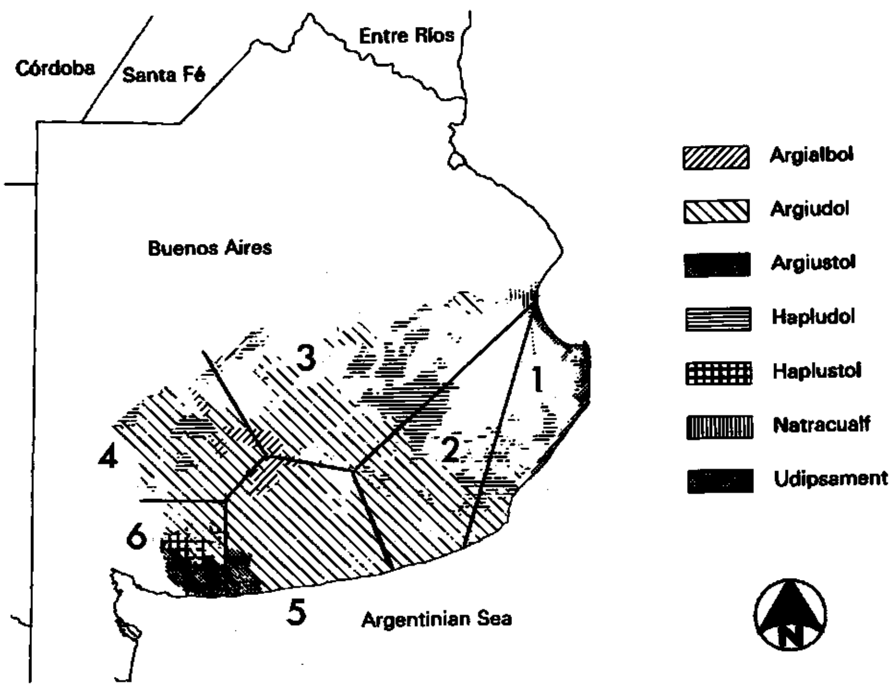

Figure 2.3.1. Agro-ecological zones and suitable soils for potato production in the southeast of the province of Buenos Aires, Argentina.

References: (1) Mar del Plata; (2) Balcarce; (3) Azul; (4) Coronel Suárez; (5) Tres Arroyos and (6) Bahía Blanca.

These soils do not show any of the limitations rendering soils unsuitable, such as: poor texture, poor structure, salinity-alkalinity, flooding, presence of impermeable layers, improper soil development stage (developing soils or undeveloped soils were not considered as suitable), inadequate pH or too many rocks. The results of these soil distributions are consistent with the recent survey carried out by Caldiz & Struik (1999) in the same region.

As a result of the zonation study, six agro-ecological zones were defined in the region. In each of these zones suitable soil types and suitable weather characteristics were combined, as presented in Figures 2.3.1. In these 24 combinations, the largest area is represented by Argiudol T Arroyos, Argiudol Balcarce and Argiudol C. Suárez while Argiudol Azul, Hapludol Azul, Hapludol Balcarce and Udipsament T. Arroyos occupy a smaller area.

Spatio-temporal variation in potential yield for different agro-ecological zones

Cantos de Ruiz (1988) showed that the potential yield of cv. Huinkul grown in Balcarce was 88 ton (fresh yield). This value is close to the one found by Stol et al. (1991) for the same area, but they set the dry matter concentration in tubers at 23%; it is also close to the mean potential yield of 89.18 ton.ha^{-1} estimated in the present study for the different zones, planting dates and plant densities. Maximum estimated values, corresponding to the September planting and the 140 days crop cycle, were above 100 t ha^{-1}. In decreasing order, the values were 130, 128.5, 128.1, 126.1, 124.5 and 107.1 t ha^{-1} for the weather stations of C. Suárez, Azul, T. Arroyos, Balcarce, Mar del Plata and Bahía Blanca, respectively (Figure 2.3.2a). These values are close to the maximum of 140 t ha^{-1} estimated by Kunkel & Campbell (1987) for Washington State, USA and similar to those calculated for northwestern Europe by Stol et al. (1991) and van Keulen & Stol (1995). On the other hand, it was recently mentioned by Huarte & Cacace (1998) that for the southeast region 100 t ha^{-1} have already been obtained in experimental plots. In contrast, the mean actual yield for the region is 30 t ha^{-1} (Caldiz & Struik, 1999).

Probably, differences between actual and attainable yield can be attributed to water and fertilizer use and to the detrimental effect of foliage diseases, i.e. *Phytophthora infestans* and *Alternaria solani* which reduce intercepted radiation. On the other hand, the gap between attainable and potential yield could partly be attributed to the use of seed of improper physiological age, because, in general, seed management for different cultivars is similar even if they are planted on different dates or in different growing seasons. The model does not account for the effect of seed age on crop growth although this is partially compensated for by fixing the length of crop cycle. Nevertheless, it is considered that physiological age is an important limiting factor and seed management should be improved in the future: seed tubers are grown in different areas with different soils and environmental conditions which result in a wide range of physiological age of the seed (van der Zaag & van Loon, 1987; Caldiz, 1991; Caldiz & Fernández, 1995, 1996) with some losts being too young and some others too old. Differences between maximum and mean values of potential yield were due, obviously, to the negative effect of late plantings on potential yield. The lower potential yield values were obtained for the November planting and the 120 days cycle: 46, 30 and 46 t ha^{-1} for Azul, Bahía Blanca and Coronel Suárez, respectively (Figure 2.3.2b).

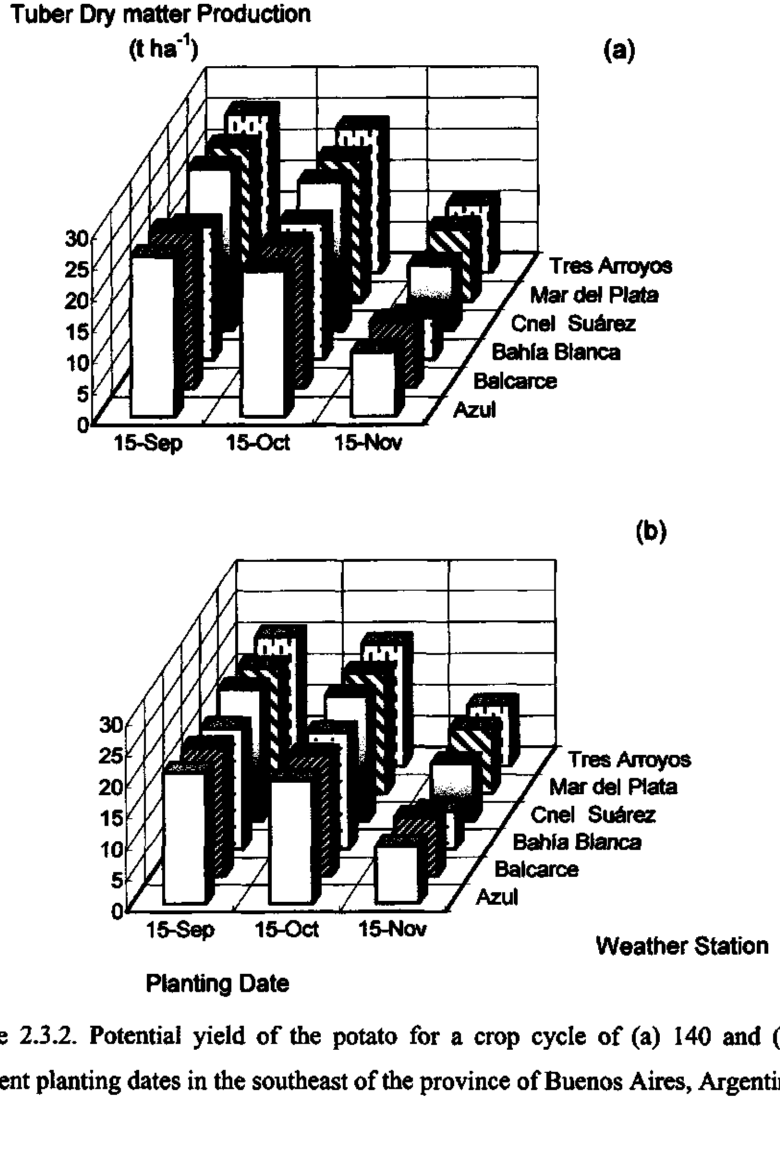

Figure 2.3.2. Potential yield of the potato for a crop cycle of (a) 140 and (b) 120 days at different planting dates in the southeast of the province of Buenos Aires, Argentina.

For each planting season the mean potential yields were 113, 106 and 47 t ha^{-1} for the September, October and November plantings, respectively. This shows the negative effect on yields of late planting. Similar results, but considering the actual yield, were found by Panelo et al. (1982) in experiments carried out in the same area with cvs. Ballenera, Huinkul and Kennebec.

The simulation study showed that for the 120 days cycle in the period September-October the delay in planting caused yield reductions of 21-41 kg ha^{-1} day^{-1}. These values ranged between 164-221 and 337-421 kg ha^{-1} day^{-1} for the period September-November and October-November, respectively. The same analysis performed for the 140 days cycle showed that these values ranged between 65-77, 221-259 and 377-508 kg ha^{-1} day^{-1} for the periods September-October, September-November and October-November, respectively. Lower simulation values were obtained for the Bahía Blanca weather station, probably due to higher minimum and maximum temperatures that occurred in this area (FAO, 1990; Servicio Meteorológico Nacional, 1992).

When planting is delayed, crop growth takes place under high radiation but also higher temperatures. High temperatures (>25 °C) modify crop growth by: (a) extending canopy growth by stimulating sympodial growth, allowing the extension of the crop cycle (Marinus & Bodlaender, 1975); and (b) hastening senescence (Menzel, 1985) and hence, shortening the crop cycle. Moreover, high temperatures decrease the ratio of dry matter partitioned to the tubers (Midmore, 1990, van Dam et al., 1995). Values obtained in this simulation study showed that the latter effect was very clear in the November planting, where important reductions in the harvest index were registered. Harvest index ranged between 0.79-0.82, 0.60-0.72 and 0.20-0.35 for the September, October and November plantings, respectively. The decrease in harvest index in the November planting is explained because, in the model, the harvest index is related to the mean temperature experienced during tuber growth, decreasing significantly when temperature is >20 °C (Stol et al., 1991). This situation of high average temperatures takes place in the southeast region by the end of the crop cycle, for both the 120 and the 140 days crop cycle. Besides, as expected, an important difference was associated with variation in the length of the crop cycle. For the 120 days cycle average potential yields were 102, 97 and 45 t ha^{-1} for the September, October and November plantings, respectively. For the same planting dates, for the 140 days cycle, the potential yields were 124, 115 and 51 t ha^{-1}, respectively. For the various planting dates, these values represented a difference of 21, 18 and 13% in favour of the 140 days cycle. Although these differences are important, it is suggested to analyze, in the future, these differences in terms of: (a) extra costs due to maintainance of the crop for a longer period (fungicides, water and nutrients) and (b) problems associated with harvest delay (rainfall and low temperatures) that could probably result in reductions in quantities of harvestable tubers and loss of quality (Caldiz & Gaspari, 1997).

Based on the results obtained in this study it is concluded that: (a) important yield differences exist between the different agro-ecological zones identified in this study; (b) yield differences between zones are due to temperature effects on crop functioning and not to differences in intercepted radiation; (c) delay in planting, mainly since October onwards, decreases potential yield of the crop by 259 kg ha^{-1} day^{-1}; (d) decrease in potential yield due to delay in planting is a consequence of an important reduction in the harvest index, induced by higher temperatures at the end of the growing season; (e) potential yield in the southeast region and in each of the agro-ecological zones is close to the potential yield estimated for other highly-productive areas of the world, Washington State, USA and The Netherlands; and (f) in the southeast region the gap between actual and potential yield is larger than the one found for the regions already mentioned under (e), hence it is still possible to increase tuber yield in the different agro-ecological zones defined in this study.

In the following Section of this thesis two different simulation models will be used to predict yield (SUBSTOR-POTATO) and for a detailed yield gap analysis between actual and potential yields (LINTUL-POTATO), in order to contribute to further identification of yield defining, yield limiting and yield reducing factors.

SECTION 3

YIELD PREDICTION AND YIELD GAP ANALYSIS

CHAPTER 3.1

YIELD PREDICTION USING THE SUBSTOR-POTATO MODEL

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3.1. YIELD PREDICTION USING THE SUBSTOR-POTATO MODEL

Summary

The performance of the SUBSTOR-POTATO model under Argentinian conditions was evaluated. The model was calibrated and validated using experimental results from different sites and years. Cultivar-specific coefficients were obtained during calibration. Validation based on several independent sets of field data, including cvs Huinkul, Kennebec, Mailén and Spunta showed good agreement ($R^2 = 0.915$; n= 24) between observed and simulated values in normal ranges of tuber yields. However, when the input parameter maturity date was not taken into account, tuber yields were overvalued due to an overestimation of LAI values during maturation. To solve this problem, a genetic coefficient for the duration of tuber filling needs to be included in the model.

3.1.1. Introduction

Environmental conditions in different regions of Argentina are favourable for potato growing, but management practices such as choice of cultivars, fertilization, irrigation, chemical control of pests and diseases and storage are not always optimal (Caldiz, 1989; Caldiz et al., 1989; Rodríguez Quijano, 1989; Escande, 1990). Yield forecasting on a regional basis is also needed by potato growers and organizations involved in marketing decisions. Potato growth and development models have been available since the 1980s and most are useful to predict potential growth (Spiertz et al., 1984; van der Zaag, 1984; MacKerron & Waister, 1985) but, when actual yield is the main interest, simulation of crop growth and development as affected by water stress, nutrient stress, pests and diseases is needed. Several models differing in complexity were developed in which the effects of water or nitrogen supply were included (Ng & Loomis, 1984; Fishman et al., 1985; Spitters, 1987; Kooman & Haverkort, 1995). In Argentina factors limiting yield were analysed within the framework of potential crop yield (Cantos de Ruiz et al., 1989). The SUBSTOR-POTATO model has been tested under a wide range of environmental conditions (Griffin et al., 1992). This model includes the same water and nitrogen balances used in CERES models (IBSNAT, 1989); the effects of soil water and plant nitrogen deficit are simulated and used to modify rates of growth and phenological development on a daily basis. Inputs required are: information on soil, climate, cultural practices and cultivar. To use the model as a tool for farmers' management decisions and yield forecasting, SUBSTOR-POTATO needs to be calibrated and validated for Argentinian conditions. The objective of this paper is to do this for a wide range of growing conditions and cultivars.

3.1.2. Materials and methods

SUBSTOR-POTATO v. 2.1 (Griffin et al., 1992) is a functional model that simulates on a daily basis the development and growth of the potato crop using inputs related to climate, soil, management and cultivar. Four main submodels simulate phenological development, crop growth and tuber yield and water and nitrogen balances. Cultivar-specific coefficients affecting tuber initiation, leaf area development and tuber growth rate are required; photoperiod and temperature sensitiveness are represented by the unitless coefficients P2 and TC; G2 ($cm^2\ m^{-2}\ d^{-1}$) is the leaf area development rate and G3 ($g\ m^{-2}\ d^{-1}$) the tuber growth rate. A further coefficient (PD) describes to what extent the cultivar is determinate or not.

To calibrate these cultivar-specific coefficients for cvs Huinkul MAG, Mailén INTA and Spunta, detailed information on crop growth and development obtained at Balcarce (37° 45' SL, 58°18' WL), was used. Planting took place on 25 October 1991 at 5.3 plants m^{-2} and, to maintain optimal growing conditions, sprinkler irrigation (113 mm during crop cycle) and nitrogen (120 kg N ha^{-1} at planting) were applied. Weeds, pests and diseases were controlled. LAI was derived from green leaf area values. Tuber initiation was determined by weekly observations of the field plots and total and tuber biomass was derived from the dry weight of corresponding samples. Physiological maturity date was defined as the time when tuber dry weight remained constant (Saluzzo, 1994).

A further set of data was used to validate the model. Table 3.1.1 summarizes the experiments used including different sites, years, cultivars and management practices. All crops received phosphate and nitrogen fertilizer and were grown under good phytosanitary conditions. Daily values for maximum and minimum temperature, global solar radiation and precipitation were obtained for each experimental site and years, as indicated in Table 3.1.1.

Model performance was evaluated according to Willmott (1982) calculating the following statistical variables: mean, bias, mean absolute error (MAE), maximum absolute error (MXAE), minimum absolute error (MNAE), root mean square error (RMSE) and the regression coefficients (R^2, a and b).

3.1.3. Results and discussion

Calibration

In SUBSTOR-potato cultivar differences are taken into account using coefficients describing phenology and growth of cultivars. Tuber initiation is affected by photoperiod (P2) and temperature (TC) related coefficients.

Table 3.1.1. List of experiments used to validate SUBSTOR-POTATO.

Reference	Site	Year	Cultivars	Crop Husbandry
Panelo et al. (1982)	Miramar	1979/82	Kennebec	Planting dates
	38° 20' SL		Spunta	Rainfed
	58° 20' WL			
Caldiz (1991)	La Plata	1982/83	Spunta	Storage systems
	34° 54' SL			Irrigated
	57° 90' WL			
Chacra Experimental	Miramar	1987/91	Huinkul	Rainfed
de Miramar (1987/91)	38° 20' SL		Kennebec	Irrigated[1]
	58° 20' WL		Spunta	
Saluzzo (1994)	Balcarce	1991	Huinkul	Irrigated
	37° 45 SL		Mailén	N rates
	58° 18' WL		Spunta	

(1) rainfed or irrigated in different years.

Leaf area development and tuber growth rate are driven by their respective coefficients (G2 and G3). As cultivars currently used in Argentina are mainly of local origin, it was necessary to obtain the appropriate coefficients (Table 3.1.2). This was done by successive runnings using as inputs the experimental data obtained under optimal growing conditions for the cvs Huinkul, Mailén and Spunta. The coefficients related to phenological development, P2 and TC, were set in first order by comparison between simulated and observed tuber initiation dates until differences between them were minimal. The coefficients G2 and G3 were then set after comparing maximal LAI values and tuber dry yields. Although Griffin et al. (1992) used a common G2 value of 2000 cm^2 m^{-2} day^{-1} for all cultivars, our results indicate that it is necessary to adjust G2 for each cultivar to obtain correct maximal LAI values.

To improve the current results, the unitless mineralization rate factor (DMOD) used as a soil input was set to (4) instead of the default value (1) as suggested by the authors. This is commonly done using CERES models with soils containing high organic matter (T. Hodges, personal communication, 1992).

Table 3.1.2. Genetic coefficients for cvs Huinkul, Kennebec, Mailén and Spunta.

Cultivar	Photoperiod (P2)	Temperature (TC)	Leaf area development (G2)	Tuber growth (G3)	Cultivar type[1] (PD)
Huinkul	0.2	17	1,500	24	1
Kennebec	0.8	17	1,500	20	1
Mailén	0.1	19	2,000	27	1
Spunta	0.1	19	1,800	24	1

(1) 0: indeterminate; 1: determinate

Validation

To validate the model, we used the coefficients obtained during calibration for cvs Huinkul, Mailén and Spunta and the coefficients obtained by T. Hodges (personal communication, 1992) for Kennebec. The data set used to validate the model (Table 3.1.1) was obtained from several experiments carried out in different sites, including different years and cultivars, planting dates, rainfed or irrigation conditions, nitrogen rates and different soil types (n= 24). Observed and simulated tuber dry matter yields showed good agreement: R^2= 0.915 (Figure 3.1.1), and the estimation errors were acceptable (Table 3.1.3). The mean absolute error (MAE) of estimation was 11% while the root mean square error (RMSE) was 14.7% for observed yields ranging between 4,000 and 15,000 kg dry matter ha^{-1}. Testing SUBSTOR-potato for tuber yields ranging between 2,000 and 20,000 kg dry matter ha^{-1}, Griffin et al. (1992) obtained a R^2 = 0.81 when working with data sets of contrasting origin (n= 51). However, some problems were detected when using SUBSTOR-potato under Argentinian cropping systems, because this model was developed for the Northern Hemisphere conditions where the maturity date is fixed by the environment (frosts) or industry demand (haulm killing). The present results showed that when the input parameter Maturity Date (MD) was not taken into account in the corresponding file and using the same data set mentioned earlier, yields were overestimated by as much as twice the observed values, mainly with high yielding crops grown under ample water and nitrogen supply (Figure 3.1.2).

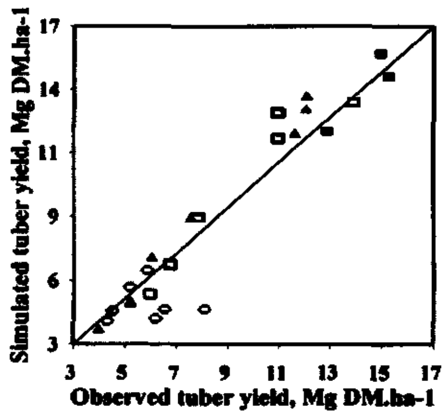

Figure 3.1.1. Comparison between observed and simulated tuber yields (Mg dry matter ha^{-1}) for cultivars: Mailén (■), Huinkul (□), Spunta (Δ) and Kennebec (○).

Table 3.1.3. Main statistics for the comparison between observed and predicted tuber yields (kg dry matter ha^{-1}).

Obs.[1]	Pred.[2]	Bias[3]	MAE[4]	MXAE[5]	MNAE[6]	RMSE[7]	R^2	a	b	n
8484	8485	1	940	3540	63	1259	0.915	-917.2	1.109	24

(1) observed; (2) predicted; (3) predicted observed mean (4) mean absolute error; (5) maximum absolute error; (6) minimum absolute error; (7) root mean square error; R^2, a and b: regression coefficients.

Mean simulated increased to 14848 kg dry matter ha^{-1} instead of 8485 kg dry matter ha^{-1}. Maturity was estimated to occur late and we obtained a maximum absolut error of 100% for maturity date estimates. If the maturity date is unknown the model assumes that crops reach maturity when LAI has decreased to 10% of its maximal value. Our results suggest that LAI is not well simulated because the final values were always greater, leading to an overestimation of tuber yields because the model continues to simulate tuber growth until the minimum value of LAI is reached. In the model this always takes place later than in the field. Under experimental conditions, when water and nitrogen are not limiting yield, tuber bulking may end at LAI values higher than 10% of the maximum value. Data from Radley et al. (1961) and Ivins & Bremmer (1964) showed that tuber bulking ends at a LAI value of about 50% of its maximum; similarly studies carried out in Argentina with cv. Huinkul under ample water and nitrogen supply showed final LAI values to be up to 40% of their maximum at the end of tuber growth (Echeverría et al., 1992).

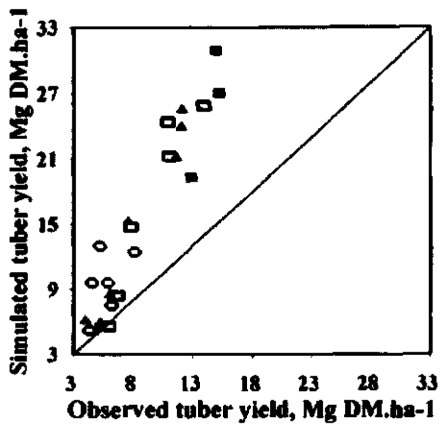

Figure 3.1.2. Comparison between observed and simulated tuber yield (Mg dry matter ha^{-1}) for cultivars Mailén (■), Huinkul (□), Spunta (Δ) and Kennebec (O) assuming physiological maturity date as unknown.

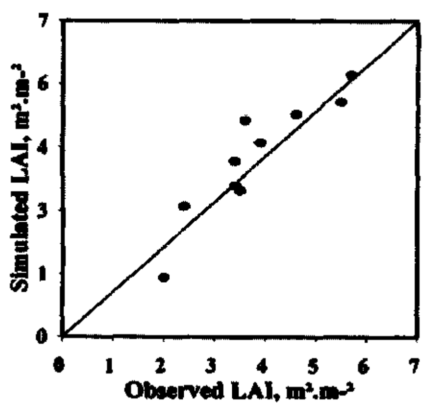

Figure 3.1.3. Comparison between observed and simulated maximal leaf area index (LAI).

Agreement between observed and simulated maximal LAI values (Figure 3.1.3) suggests that at least during early phases of development the model estimates leaf area well but the decrease in leaf area up to maturity is less well estimated. This may present a constraint to the use of the model in Argentina, because harvest time is not always as predictable as in the Northern Hemisphere. Some of the IBSNAT models include genetic coefficients to simulate maturity date. They are generally based on accumulated thermal time (i.e., CERES-wheat, CERES-maize, Soygro; IBSNAT, 1989), but this is not taken into account in SUBSTOR-potato. For Argentinian conditions it would be desirable to include a coefficient for maturity which would be cultivar-specific and which could be related to the accumulated thermal time between the beginning and the end of tuber growth. In some of the experiments used for validation, the values of accumulated thermal time during this period varied between 900 and 1500 °C for late and early planting dates respectively. Maturity date depends not only on planting date and cultivar characteristics, but is also influenced by crop management (Beukema & van der Zaag, 1990). Therefore it should be considered to modify the scheme used to end tuber bulking in the model based not only in a LAI value of 10% of the maximum. In the phenology subroutine, the end of crop growth is defined with the following FORTRAN sentence:

- IF (LAI .LT. 0.1*MAXLAI .OR. JDATE .EQ. MATJD) THEN
  CALL CALDAT (MONTH, ND)

To avoid yield overestimations when maturity date is unknown, it would be necessary to add a statement such as:

- IF (LAI .GT. 0.1*MAXLAI .AND. CTT .GT. MAT) THEN
  JDATE .EQ. MATJD[1]

[1]**List of acronyms:** MAXLAI: maximal LAI; CTT: accumulated thermal time; JDATE, Julian date; MAT: maturity, MATJD: maturity Julian day; CALDAT: calendar date.

This would solve the problem when final LAI values are greater than 10% of their maximal values, so limiting the duration of tuber bulking by the cultivar specific coefficient related to thermal time. These results suggest that information on crop phenology for different cultivars in a wide range of planting dates, management and environmental conditions is needed to improve SUBSTOR-potato performance for Argentinian conditions.

CHAPTER 3.2

YIELD GAP ANALYSIS FOR DIFFERENT AGRO-ECOLOGICAL ZONES WITH THE LINTUL-POTATO MODEL

submitted as:

Caldiz, D.O., P.C. Struik & L.V. Fernández, 2000f. Yield gap analysis for different agro-ecological potato growing zones in Argentina with the LINTUL-POTATO model.

3.2. YIELD GAP ANALYSIS FOR DIFFERENT AGRO-ECOLOGICAL ZONES WITH THE LINTUL-POTATO MODEL

Summary

A study with data for five agro-ecologically different potato growing zones in Argentina was carried out and potential yield data from the LINTUL-POTATO simulation model were compared with the actual and attainable yields in order to perform a yield gap analysis and to make further suggestions for yield improvement. The actual average yield of 30 t ha^{-1} achieved in the southeast of the province of Buenos Aires, the main potato growing zone in the country, is far below the 126 t ha^{-1} potential calculated in this study with the LINTUL-POTATO model. Differences between actual and potential yield could be mainly attributed to suboptimal light interception by the foliage. Improved water and fertilizer management could reduce the gap between actual and potential yield, as shown by attainable yields of 100 t ha^{-1} achieved in the zone already mentioned. For other areas, physiological age of seed tubers and water and fertilizer management were identified as main yield limiting factors, while the phytosanitary state of the seed tubers (virus) and crops (blights) were identified as main yield reducing factors.

3.2.1. Introduction

In Argentina potato production is practised in large fields in different areas and seasons (Table 1.1) as recently surveyed by Caldiz & Struik (1999). Differences in agro-ecological conditions, levels of technology of the farms and input utilization are responsible for the large yield and quality differences both in seed and ware production (Table 1.1 and Caldiz & Struik, 1999). There is not a comprehensive report on the influence of these and other factors on yield and/or quality in Argentina, although several authors described crop production for seed (Caldiz et al., 1999) and ware (Huarte, 1996), while Huarte & Inchausti (1994) described commercialization within the MERCOSUR (MERcado Común del SUR). Potatoes are grown under rainfed conditions, with furrow, sprinkler or pivot irrigation and on farms of different sizes, depending on the area of production and technology level of the farm. Based on actual average yields from a recent survey (Caldiz & Stuik, 1999) and potential yield estimates of the LINTUL-POTATO simulation model (Kooman, 1995) for different agro-ecological zones an attempt is made to perform a yield gap analysis with data from five different agro-ecological zones in which the crop is grown in different seasons and with different irrigation systems. The yield gap analysis results in suggestions for yield improvement based on the weighing of the effects of different yield defining (YDF), yield limiting (YLF) and yield reducing factors (YRF).

3.2.2. Materials and methods

Data on actual and attainable yields for the different agro-ecological zones were based on the recent survey of Caldiz & Struik (1999). Potential yield was estimated with the LINTUL-POTATO simulation model (Kooman, 1995) using daily global radiation, minimum and maximum temperature from FAO (1990) and Servicio Meteorológico Nacional (1992) data bases. The model establishes potential yield of a certain cultivar for a pre-determined growing period and plant density, assuming that there are no yield limiting factors (YLFs) or yield reducing factors (YRFs) present and that crop growth does not take place when minimum temperatures are below 5 °C or maximum temperatures are above 30 °C. Model simulation was based on: (a) incident Photosynthetic Active Radiation (PAR, 400-700 nm); (b) fraction of PAR intercepted by the crop; and (c) radiation use efficiency (RUE) to convert light into dry matter. Phenological crop development is driven by accumulated temperature, while development stage determines dry matter partitioning, and through haulm growth the pattern of intercepted PAR is defined. The model simulates the interception of radiation since the moment of 50% emergence through senescence. Radiation use efficiency (RUE) was set at a constant value of 2.8 g MJ^{-1} based on the results of Echeverría et al. (1992) and Saluzzo (1994) for Argentinian conditions. Tuber yields equal the product of total biomass produced and the harvest index. The harvest index was derived from the average temperature during tuber growth. In potato more dry matter is allocated to the haulm with increasing temperatures (Midmore, 1990; van Dam et al., 1995): thus up to 15 °C the harvest index remains constant at 0.8 and decreases at higher temperatures to reach 0 at 28 °C (Stol et al., 1991).

A yield gap analysis was performed by comparing actual and attainable yields with potential yield estimates from the LINTUL-POTATO in terms of the different yield defining, yield limiting and yield reducting factors that could affect the crop (Caldiz & Gaspari, 1997). Characteristics of the different agro-ecological zones considered in this study can be found elsewhere (Caldiz & Struik, 1999).

3.2.3. Results and discussion

Actual, attainable and potential yields and their corresponding ratios for each of the areas studied are presented in Table 3.2.1, potentials yields are generally in agreement with the approximate estimates of van Keulen & Stol (1995) for the region under study.

Table 3.2.1. Actual, attainable and potential yield ($t.ha^{-1}$) of ware potato crops for different agro-ecological zones in Argentina.

Location	South latitude	Actual (A)	Attainable (B)	Potential (C)	A:B	B:C	A:C
Tucumán, early crop	26° 48′	18	51[1]	68[7]	0.35	0.75	0.26
Villa Dolores, medium-early crop	31° 57′	25	48[2]	55[7]	0.52	0.87	0.45
Villa Dolores, late crop	31° 57′	18	41[3]	47[7]	0.43	0.87	0.38
Mendoza, medium-late crop	33° 50′	20	35[4]	65[7]	0.57	0.53	0.30
Rosario, late crop	35° 00′	13	25[4]	55[7]	0.52	0.45	0.23
Balcarce, medium-late crop	37° 51′	30	100[5]	126[7]	0.30	0.79	0.23
Río Negro, medium-late crop	40° 00′	25	44[6]	125[8]	0.56	0.35	0.20

(1) from Caldiz et al. (2000d); (2) from Caldiz & Fernández, 1999 (unpublished); (3) from Caldiz et al. (1997); (4) estimated by the authors; (5) from Huarte & Cacace (1998); (6) from Caldiz et al. (2000e); (7) based on LINTUL-POTATO and (8) from Caldiz et al. (2000a).

In Tucumán, a first approach with the LINTUL-POTATO model established a potential yield of 68 t ha^{-1} for the early crop, while the actual average yield is only 18 t ha^{-1}, due to the poor physiological status of the seed used (N. Zamudio, personal communication, 1996). However, attainable yields of 51-55 t ha^{-1} are achieved when seed of suitable age is used and crops are well fertilized and irrigated (Caldiz et al., 2000d). The ratio actual:attainable is moderately low (0.35) when compared with other zones (Table 3.2.1) but the ratio attainable:potential is rather high (0.75). Under this situation the ratio actual:potential yield is low (0.26), but it could be significantly improved by using seed of suitable age and proper water and nutrient management.

In Villa Dolores potential yields are 55 and 47 t ha^{-1} for the spring and autumn crops, respectively, while the actual average yields for these seasons are 25 and 18 t ha^{-1}, respectively. In this area a much larger proportion of the potential is realized. Ratios actual:attainable yield are 0.52 and 0.43 for the medium-early and the late crop while the ratio attainable:potential yield is very high, 0.87, for both growing seasons. The role of different YDFs and YLFs for each of these crops were discussed previously and recently, Caldiz & Haverkort (1994) discussed different alternatives to improve yields in this double cropping system even further. The latter authors concluded that for the spring crop improvements in fertilization rate should be achieved, while for the autumn crop improvement of the physiological age of seed tubers is needed. In this regard, recently, an attainable yield of 51 t ha^{-1} was achieved (Caldiz, 2000) which means an attainable:potential ratio of 0.92, a result higher than in this analysis. However, in this double cropping zone the presence of the perennial weed *Sorghum halepense* (Caldiz & Struik, 1999) can cause yield reductions up to 50% (Beltrano & Caldiz, 1993).

For Mendoza with crops growing in the period October-February the potential yield based on LINTUL-POTATO was 65 t ha^{-1}, while the actual average is 20 t ha^{-1} (Table 3.2.1). Probably, in this case, the use of seed of unsuitable age and inadequate crop management (J. Ortego, personal communication, 2000) are both partially responsible for the yield gap, which resulted in a low actual:potential ratio (0.23). The values for ratio actual:attainable and attainable:potential were 0.57 and 0.53, respectively, which suggests that also in this zone much can be done to reduce the effect of yield limiting factors. However, the dry, hot and persistent *zonda* wind that reduces the relative humidity to less than 15-20% is an important YDF (J. Ortego, 1994, personal communication).

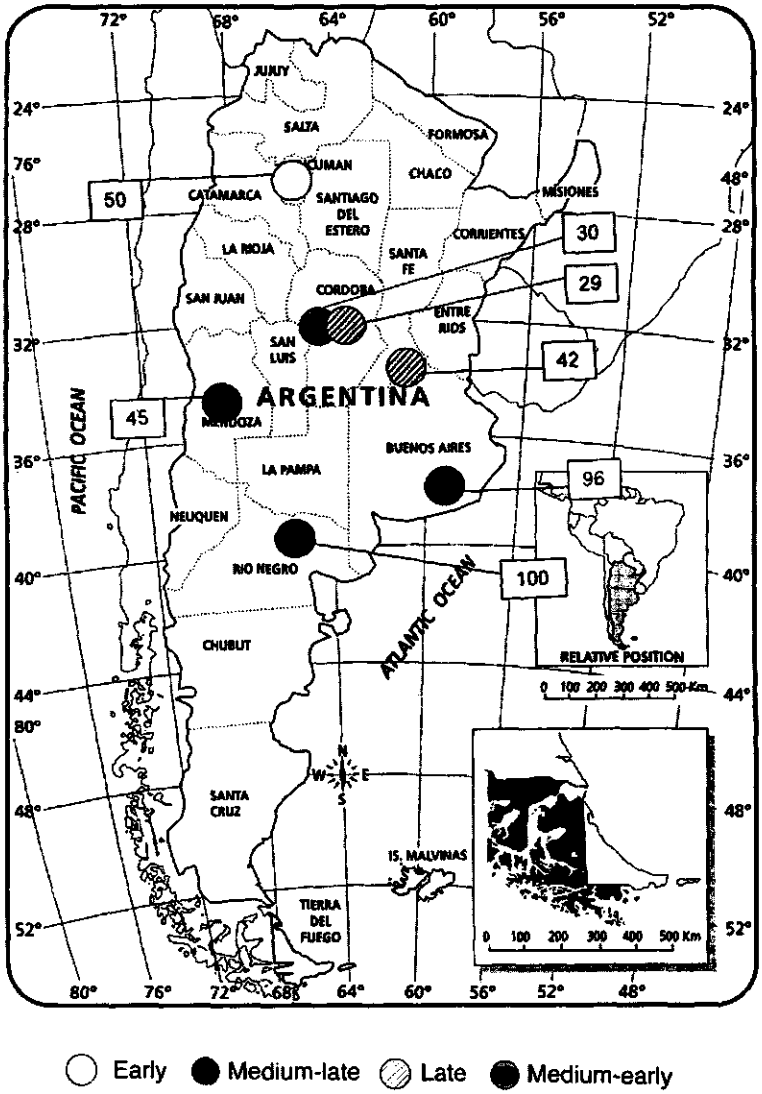

Figure 3.2.1. Yield gaps (in t ha^{-1}) between actual and potential yields for the current potato growing zones in Argentina.

In Rosario, the late crop has a potential yield of 55 t ha^{-1}, but the actual yields of 13 t ha^{-1} are less than 25% of the potential. This is caused by a combination of factors, including poor seed management, inadequate physiological age of the seed, and suboptimal supply of water and fertilizer. The ratios actual:attainable and attainable:potential are high, 0.52 and 0.45, respectively. However, in this zone production dramatically decreased in the period 1980-1994 (Caldiz & Struik, 1999) due to the spread of *Ralstonia solanacearum*, an important YRF favoured by the double cropping systems and by high temperatures (A. Escande, personal communication, 1981). Hence to improve the ratio actual:potential yield management of YLF's and YRF's should be improved.

In the most important potato production area, Balcarce, in the southeast of the province of Buenos Aires, the actual average yield of 30 t ha^{-1} is far below the 88 t ha^{-1} of potential yield calculated by Cantos de Ruiz (1988) based on van der Zaag & Burton (1978) or the 126 t ha^{-1} potential calculated in this study with the LINTUL-POTATO model. Nevertheless, best farmers have obtained more than 50 t ha^{-1} in the 1994/95 season, mainly due to improved water and fertilizer management and an efficient control of early (*Alternaria solani*) and late (*Phytophthora infestans*) blight (Huarte, 1996). These practices probably enhance ground cover duration, by faster canopy development and a delay of leaf senescence, giving larger and longer light interception. Recently, Huarte & Cacace (1998) also presented data on attainable yields of 100 t ha^{-1}, in experimental plots.

For Río Negro a potential yield of 125 t ha^{-1} was established for a medium-late crop while the attainable yields and the average actual yields are 44 and 25 t ha^{-1}, respectively. Differences between actual and attainable yield were already attributed to the yield limiting effect of nutrient and water supply (Caldiz et al., 2000a), while the difference between attainable and potential yield could be attributed to the limiting effect of strong and persistent winds which enhance evapotranspiration and high temperatures at the end of crop growth which reduce the harvest index, as mentioned by Caldiz et al. (2000a). However this is a new zone for commercial potato production, either for seed or ware, and possibilities to reduce the gap between actual and potential yields are enormous, considering the favourable conditions (long day, high solar radiation and ample daily thermal amplitude) during the potential growing period. A more detailed analysis of this area is presented elsewhere (Caldiz et al., 2000a).

In Figure 3.2.1, the yield gap between actual and potential yields for the different regions is shown. The ratio of actual:potential yield ranged from 0.20-0.48 for Río Negro and Villa Dolores, respectively. Similar values were also found by van der Zaag (1984) for different selected areas of the world, also differing in agro-ecological conditions and technological level.

However, in other situations, such as the tropical highlands the ratio actual:potential could be very low (up to 0.12; Haverkort, 1986).

Table 3.2.2. Yield defining, yield limiting and yield reducing factors and their relative importance for different agro-ecological zones in which currently the potato is grown.

Factors	Agro-ecological zones					
	Tucumán	V. Dolores	Mendoza	Rosario	Balcarce	R. Negro
Yield defining factors						
Temperature	1[a]	3	2	3	2	3
Daylentgh	0	0	0	0	0	0
Solar radiation	3	3	3	3	3	3
Yield limiting factors						
Water	2	3	2	2	2	3
Nutrients	2	2	2	2	2	3
Physiological age	3	3	2	3	2	2
Wind	0	0	3	0	0	3
Yield reducing factors						
Diseases						
Virus diseases	2	2	1	2	2	1
A. solani	2	2	1	2	2	1
P. infestans	3	2	2	2	2	1
R. solani	1	1	1	1	1	1
Pests						
Aphids	1	1	1	1	1	1
Leaf miners	1	2	1	1	2	1
Soil worms	1	1	1	1	2	1
Meloidogyne spp.	2	2	2	1	1	1
Nacobbus spp.	1	0	0	0	0	0
Weeds						
S. halepense	0	2	0	1	0	0
C. rotundus	2	2	0	1	0	0

(a) relative importance: (0), none; (1), low; (2), medium and (3), high

In this paper several YDFs, YLFs and YRFs have been discussed regarding their effect on tuber yield in different agro-ecological zones. To show their incidence and relevance in each of these zones and in the whole system, they were ranked according to their relative importance (Table 3.2.2). Among the YDFs temperature appeared as the most important for three different areas, regarding its negative effects on crop growth. Daylength, although a determining yield factor is not a major one for these zones, while solar radiation is highly important in any area.

Among the YLFs, all of them have the same overall relative importance; however, physiological age proved more important for the early crops in Tucumán and for the double cropping systems in Rosario and Villa Dolores, than for the rest of the zones (Table 3.2.2). Strong and persistents winds are important in Río Negro, but proper windscreens can reduce its negative effects

In general, YRFs have a medium or low relevance. However, *Phytophthora infestans* has a relatively high importance for the early crops in Tucumán, where weather conditions at the end of the growing season favour the outbreak of late blight. It is also interesting to note that two of the worst weeds in the world are of medium relative importance for the double cropping areas. This could be due to lack of suitable weed control and lack of suitable crop rotations due to the double cropping, which enhance weed populations and persistence. In these zones also volunteer potatoes are a problem, because they reduce seed quality (cultivar type, presence of virus) or future crop yield (increased infestations of soil with soil-borne pathogens and pests). No other pest and/or diseases showed a high relative importance for the rest of these agro-ecological zones.

The present approach for a yield gap analysis clearly assists in identifying YDFs, YLFs and YRFs and their relative importance for each agro-ecological zones. Moreover, these results will be helpful to improve, seed lot and crop management for each agro-ecological zone.

SECTION 4

PHYSIOLOGICAL AGE OF SEED TUBERS

CHAPTER 4.1

PHYSIOLOGICAL AGE INDEX: A NEW, SIMPLE AND RELIABLE INDEX TO ASSESS THE PHYSIOLOGICAL AGE OF SEED TUBERS

submitted as:

Caldiz, D.O., L.V. Fernández & P. C. Struik, 2000c. Physiological age index: a new, simple and reliable index to assess the physiological age of seed potato tubers (*Solanum tuberosum* L.) based on haulm killing date and length of the incubation period.

4.1. PHYSIOLOGICAL AGE INDEX: A NEW, SIMPLE AND RELIABLE INDEX TO ASSESS THE PHYSIOLOGICAL AGE OF SEED TUBERS

Summary

Chronological and physiological age of seed tubers have major impacts on yields. This paper presents a new, simple and reliable physiological age index (PAI) that considers and reconciles the effects of chronological and physiological age. PAI calculation is based on different key-data of the life cycle of a seed tuber, which are easy to assess, i.e. the haulm killing date of the seed crop (T_0) and the end of the incubation period of seed tubers, measured under standard conditions. The PAI formula is: T_1/T_2, where T_1 is the time from haulm killing date (T_0) to possible planting date and T_2 the time from T_0 to the end of the incubation period. The PAI expresses physiological ageing of seed potato tubers within a range from 0 (for physiologically young) to 1 (old) tubers. To test the PAI existing data were re-evaluated and re-elaborated and specific experiments regarding seed origin and storage conditions for different cultivars were performed during 1994-1999. The PAI proved useful to assess differences caused by differences in growing conditions, cultivar, seed origin and storage system, haulm killing and pre-planting treatments. The PAI is easy to measure, objective, reproducible and reliable and could be used for modelling purposes to describe performance of seed tubers.

4.1.1. Introduction

The term physiological age was first used in a wide biological sense by Krenke (1940) to explain leaf age. Other botanists used similar terms to explain different stages of plant development. In this sense, physiological age (Robbins, 1957; Schaffalitzky de Muckadell, 1959), is synonym to stadial age (Uranov, 1975) and ontogenetical age (Passecker, 1977). Gatzuk et al. (1980) have also shown that living organisms undergo a sequence of phases characterized by their chronological age and by anatomical, morphological, physiological and biochemical changes.

The physiological age of a potato seed tuber is partly a characteristic of the tuber and (after the dormancy ends) also partly a characteristic of the sprout (Struik & Wiersema, 1999). Kakawami (1936) called physiological degeneration the reduction in yield caused by the use of aged tubers and later he used the term physiological age to explain crop productivity in terms of the chronological and physiological age of the seed tubers (Kawakami, 1952; 1962; 1963). However, it is more appropriate to use the term degeneration for those yield reducing effects caused by virus (Sívori, 1951) and the term declination for those caused by environmental factors (Tizio et al., 1954; Claver et al., 1957; Went, 1959). Nowadays it is accepted that the physiological age of a tuber is a consequence of a physiological evolution that proceeds within its storage tissues according to a well-defined sequence and which expresses itself by the influence that it exerts throughout the process of growth and tuberization (Perennec & Madec, 1980). The European Association for Potato Research (EAPR) agreed on the following definition: the physiological age of a seed tuber is the physiological stage of the tuber which influences its productive capacity (Reust, 1986). But it should probably say: *the physiological stage of the tuber and sprout(s)*, because it was demonstrated by several authors that both tuber and sprout age affect the physiological age (Krijthe, 1962; van Ittersum, 1992). Until breaking of dormancy physiological age is fully reflected by the mother tuber. After the onset of sprouting the behaviour of the sprout is influenced by the age of the mother tuber, but this effect may be modified by additional effects of conditions and treatments that directly interfere with the functioning of the sprouts (e.g. diffuse light or de-sprouting). Perennec & Madec (1980) stated that the physiological age of a tuber at any given time also depends on its chronological age, measured from the date of tuber formation in the field. Although it is also recognized that the chronological age and environmental conditions affect the seed tuber since it is initiated from the mother plant (Reust, 1986; van Ittersum, 1992), from a practical point of view it is difficult to precisely measure tuber initiation under field conditions. However, tubers with the same chronological age could have, at a certain moment, different physiological ages due to the effect of different environmental and management conditions during growth (van der Zaag & van Loon, 1987) and storage (Hartmans & van Loon, 1987).

The ageing process progresses even when there are no visible symptoms (i.e. sprouting). There is not always a statement, indication or measurement of the relationship between chronological and physiological age (van der Zaag & van Loon, 1987). The physiological age of a seed tuber changes with time and with environmental conditions and management during seed production (Scaramella Petri, 1959; Claver et al., 1957; Went, 1959; Sawyer & Cetas, 1962; Goodwin et al., 1966; Bodlaender, 1973; van der Zaag, 1973; Claver, 1973; 1975; Susnoschi, 1981; Caldiz et al., 1985; Panelo & Caldiz, 1989; Caldiz, 1991; van Ittersum & Scholte, 1993; van Ittersum et al., 1993; Caldiz & Fernández, 1996; Caldiz et al., 1998a), storage (Madec, 1956; Krijthe, 1958; Iritani, 1968b, Wurr, 1980; Iritani et al., 1983; Escande et al., 1985, 1986; Hartmans & van Loon, 1987; Caldiz, 1991; van Ittersum, 1992; van Ittersum & Scholte, 1993, van Ittersum et al., 1993;), pre-planting treatments (Timm & Schweers, 1965; Iritani, 1968a; Bus & Schepers, 1978; Marinus, 1993) and presence of diseases (Bhatia & Young, 1985).

The physiological age of the seed tubers affect future crop performance, i.e: emergence rate, percentage of emergence, number of emerged stems per mother tuber, time to tuber initiation, crop growth and vigour, tuber yield and dry matter distribution (Went, 1959; O'Brien & Allen, 1975; Wurr, 1979; O'Brien et al., 1983; Vakis, 1986; van Loon, 1987; Caldiz, 1991; Moll, 1994). Physiological age is a well-known limiting factor in potato production (Caldiz & Gaspari, 1997) and its causes and effects upon crop growth, development and yield have been intensively studied since the 1950s (Kawakami, 1952; Tizio et al., 1954; Madec & Perennec, 1955; Claver et al., 1957; Krijthe, 1958; Scaramella Petri, 1959; Went, 1959). These effects also differ between cultivars (Bodlaender & Marinus, 1987; van der Zaag & van Loon, 1987; van Ittersum, 1992; Caldiz, 1994; Struik & Wiersema, 1999) and are very important because seed tubers are planted in different zones of the same country (Caldiz et al., 1998a) or are shipped to overseas areas with double or triple cropping resulting in different age requirements (Claver et al., 1971; Fahem & Haverkort, 1988, Caldiz & Haverkort, 1994; Struik & Wiersema, 1999).

Seed age can be modified by crop and storage management to make it suitable for different conditions (Bus & Schepers, 1978; van Ittersum, 1993; van Ittersum & Scholte, 1993; van Ittersum et al., 1993). There is general agreement that rather young seed produces high yields in long growing seasons, while rather old seed is suitable to obtain high yields early in the season or in short cycle seasons (Madec & Perennec, 1955; O'Brien & Allen, 1975; Wurr, 1979).

Many attempts have been made to develop an indicator of the physiological age of seed tubers. Physiological indicators like sprout type (Krijthe, 1958), sprouting capacity (Krijthe, 1962), length of the longest sprout (O'Brien & Allen, 1981) and the length of the incubation period (Claver, 1953; Madec & Perennec, 1956; Reust & Münster, 1975; Caldiz, 1991) have been and are being used to establish physiological age. Biochemical indicators were also developed, based on the tuber or sprout contents of sugars (van Es & Hartmans, 1984; Caldiz et al., 1986), enzyme activity (Sacher & Iritani, 1982; van Es & Hartmans, 1987, Caldiz et al., 1996b), organic acid content (Reust & Aerny, 1985), polyamines content (Apelbaum, 1984), ATP, ADP and bound phosphate levels (Biotto & Siegenthaler, 1991) and electrolyte leakage (de Weerd et al., 1995). Also bio-physical indicators based on accumulated day-degrees from dormancy break (O'Brien & Allen, 1981; O'Brien et al., 1983), storage T sum (Scholte, 1986) - who actually warned against the use of storage temperature sum, (K. Scholte, personal communication, 1999; Struik & Wiersema, 1999)- and relative growth vigour indices (Bodlaender et al., 1987; van Ittersum, 1992) have been developed. Indicators are needed in order to quantify and explain cultivar differences in rate of ageing (such as the interaction between cultivar and storage conditions) and the effect of seed age on crop growth and yield. Moreover, the effect of chemicals applied to the haulm of the seed crop, on seed age has not been accurately quantified until know. However, comparisons using existing indicators and their relationships with tuber yield are not always clear; often the effect of the chronological age of the seed tuber is not considered. In many cases, similar figures for the same indicator do not exactly reflect the same physiological age (Caldiz et al., 1985; van der Zaag & van Loon, 1987) or differences are masked by other factors (Sacher & Iritani, 1982; W. Iritani, personal communication, 1989). Hence, a quantitative and comparable indicator of the physiological age is lacking. The physiological age index presented in this paper should overcome these difficulties. An index should: (a) be easy to measure, objective, reproducible and reliable; (b) be able to account for effects of environment, cultivars and their interaction; (c) be able to account for seed treatments; (d) be able to account for differences among seed lots of different origins or with different storage histories; and (e) at the end it should be able to reconcile chronological with physiological age.

4.1.2. Materials and methods

To develop and assess the physiological age index (PAI) existing data were re-evaluated and re-elaborated and specific experiments regarding seed origin and storage conditions for different cultivars were performed during the period 1994/1999. Experiments were selected that could quantitatively illustrate specific trends in PAI caused by agronomically relevant factors.

Development of PAI values over time

Certified seed crops of cv. Kennebec grown in the area of Tres Arroyos (38° 19' SL, 120 m above sea level) by two different growers (Grower A and Grower B) were haulm killed on 14 and 16 February 1998, respectively. Seed tubers were harvested 9 and 7 days later and stored in a cold store at 4 °C until planting, on 21 October 1998 and 19 February 1999, in the medium-late crop at Otamendi (38° SL, 100 m above sea level) and the late crop in Villa Dolores (31° 57' SL, 569 m above sea level), respectively. The PAI was evaluated immediately after harvest (February 1998), in August, September and October 1998 and February 1999.

Development of PAI under different growing conditions

Data from Claver (1973), for tubers of cv. Katahdin grown at different temperatures during 1972 in a study in which the incubation period was used as an indicator of physiological age were re-elaborated to test the PAI.

Development of PAI for different cultivars

A field trial to study differences in the PAI among cultivars was carried out during 1997/98 in the Balcarce area (37° 51' SL, 113 m above sea level), with cultivars Frital INTA, Huinkul MAG, Keluné INTA, Kennebec, Russet Burbank, Shepody and Spunta. Certified seed tubers previously stored in a cold store were planted by mid-October 1997. Crops were sprinkler irrigated, fertilized and pests and diseases controlled as normally done in the area. For each cultivar, haulm senescence occurred between 30 January and 28 February 1998, and it was assessed by a visual scale from 0 (complete senescence) to 10 (all green). After harvest, the seed tubers were stored in a cold store at 4 °C and the PAI was measured about two weeks after haulm killing (February/March 1998), September and October 1998 and February 1999.

Development of PAI for different cultivars under different storage systems

Data from a study by Escande et al. (1985) on effects of cultivar and storage system in which the incubation period was used as an indicator of physiological age, were recalculated to test the PAI.

Development of the PAI after different haulm killing dates of the seed crop

To test the effect of different haulm killing dates on the PAI, data from Panelo & Caldiz (1989) and Caldiz et al. (1994) in which the incubation period was used as an indicator of physiological age, were recalculated. These experiments were carried out at Miramar (38° 20′ SL, 100 m above sea level) during the period 1983/84–1988/89 in order to test the effect of different haulm killing date and pre-planting treatments on physiological age and tuber yield.

Development of the PAI after different pre-planting treatments

Certified seed crops of cv. Kennebec grown in the area of Tres Arroyos by two different growers (Grower A and Grower B) were haulm killed on 14 and 16 February 1998, respectively. Seed tubers were harvested 9 and 7 days later and stored in a cold store at 4 °C until one month before planting, 28 September, 1998. At that time part of the tubers (a) remained in the cold store at 4 °C, part (b) was stored under natural diffuse light at ambient temperature; and part (c) was stored in darkness at 17 °C. The PAI was tested before and after pre-planting treatments. Planting was carried out with a 4-row planting machine on 21 October 1998. Crops were sprinkler irrigated and pests and diseases controlled as common in the area.

Results of the experiments especially conducted to develop the PAI were compared by Tukey′s test ($P < 0.05$) using the Statgraphics program V. 2.0.

4.1.3. Results and discussion

Calculation of the physiological age index

The calculation of the dimensionless physiological age index (PAI) is based on different key-data for the life cycle of a seed tuber, which are easy to assess. The first key-date is the haulm killing date of the seed crop (T_0). At that time seed tubers start their independent life. The other key-date is, of course, the sampling or possible planting date when physiological age is relevant for crop performance. At that time, samples of 30-50 tubers for each lot (10 tubers x 3-5 replications for each origin, cultivar, storage system, etc.) were exposed to standard conditions (darkness, 17 °C, 90-95% relative humidity) to measure the length of the incubation period, that is the time elapsed from sprouting until new tuber formation on the sprouts (Claver, 1951; 1953), as accepted by the EAPR (Reust, 1986). At sprouting time two measurements were taken, the date when 80% of the tubers bear sprouts longer than 5 mm and the sprouting date for each individual tuber of each replication. At least two weeks difference appeared to exist between sprouting time considered as the moment when 80% of the tubers bear sprouts >5 mm (Reust, 1986) and sprouting time based on the average sprouting date (sprouts >5 mm) resulting from measurements of each individual tuber within each replication. As this last assessment was considered more accurate for establishing the length of the incubation period, because it considers the sprouting date of each tuber, it was used, whenever possible, both for the re-elaboration of the data and the calculation of the PAI. The end of the incubation period is the average value resulting from recording twice or three times a week which individual tubers had formed tubers on their sprouts; this is the other key-date needed to calculate the index.

The index is calculated as PAI= T_1/T_2, where T_1 is days from T_0 to possible planting date and T_2 is days from haulm killing (T_0) to the end of the incubation period. This index ranges from 0 for young seed tubers to 1 for old seed tubers. Its meaning and use can be easily illustrated as follows, based on a seed crop grown in the southeast area of the Buenos Aires province, Argentina (38° 20' SL, 60° 15' WL), considering haulm killing date 3 March (Julian day 62) and next possible planting dates 15 May (Julian day 136) for an early crop in the north of the country (Tucumán, 26° 48' SL, 481 m above sea level) and 30 October (Julian day 304) for the southeast area in Balcarce (37° 51' SL, 113 m above sea level). PAI by 15 May: T_1 (74)/T_2 (242) = 0.36 and PAI by 30 October: T_1 (242)/T_2 (261)= 0.93.

Development of PAI values over time

At the first sampling, carried out 13 days after T_0, the PAI was close to 0, as shown in Table 4.1.1. This was due to the short time elapsed from T_0 to the sampling date and the long time elapsed from T_0 to the end of the incubation period (13/255: 0.05 PAI for Grower A). This shows that tuber ageing can also take place even in the absence of sprouts, as shown by Krijthe (1962) and van Ittersum (1992), but denied by O'Brien & Allen (1981). As time proceeded, the PAI values also increased, as shown for both seed growers (Table 4.1.1). These results showed (a) that the incubation period was longer in physiologically young tubers (see also Claver, 1951, 1953, 1973, 1975; Madec & Perennec, 1956; Caldiz et al., 1985; Hartmans & van Loon, 1987; Panelo & Caldiz, 1989; Caldiz, 1991; Caldiz & Fernández, 1995), a fact rejected by Tizio & Tizio (1981), and (b) that even small physiological age differences, like those due to seed origin, can be measured with the PAI (Table 4.1.1). Moreover, when seed tubers from one of these origins were stored until February 1999 for planting in the late season crop, the resulting incubation period at that time was even shorter while the PAI was very high (0.86).

Table 4.1.1. Physiological age index over time for cv. Kennebec grown in the Tres Arroyos area by different seed growers and stored in a cold store at 4 °C, 1998/99.

Treatment	T_0[1]	T_0 to sampling[2] (A)	Incubation date[1]	Incubation period[2]	T_0 to end of incubation[2] (B)	PAI A/B
February 1998						
Grower A	45	13	300	154	255	0.05 a
Grower B	47	11	322	176	275	0.04 b
September 1998						
Grower A	45	226	371	155	326	0.69 a
Grower B	47	224	391	112	344	0.65 b
October 1998						
Grower A	45	254	388	85	343	0.74 a
Grower B	47	252	391	88	344	0.73 a
February 1999						
Grower A	45	370	475	59	429	0.86

(1) Julian days; (2) number of days. For each date averages followed by the same letter do not differ significantly ($P < 0.05$).

Development of PAI due to different growing conditions

The re-elaborated data from Claver (1973) show that the PAI can be applied to assess the effect of different growing conditions on the physiological status of the seed tubers (Table 4.1.2). These results confirm data for the development of the PAI over time (Table 4.1.1).

Table 4.1.2. Physiological age index for tubers of cv. Katahdin grown at different temperatures.

	T_0[1]	Sampling date[1]	T_0 to sampling[2] (A)	Incubation day[1]	Incubation period[2]	T_0 to end of incubation[2] (B)	PAI A/B
20 °C	114	235	121	375	140	261	0.46
27 °C	114	235	121	349	114	235	0.51

(1) In Julian days; (2) number of days. Data re-elaborated from Claver (1973).

Development of the PAI for different cultivars.

Cultivar evaluation (Table 4.1.3) by the PAI confirmed data of Table 4.1.1. By May, about 50-60 days from T_0, the PAI was closer to 0, because seed tubers were young. By this time, higher values were registered in cvs. Shepody and Spunta; the latter cultivar is well known for its sensitivity to physiological ageing (Escande et al., 1985; 1986; Caldiz, 1991). Shepody, Kennebec and Huinkul followed, while Frital, Keluné and R. Burbank showed a lower PAI. At the following planting date, after seed tubers had been stored at 4 °C, the PAI was higher in all cases (Table 4.1.3) and cv. Spunta achieved the highest value. Differences between cultivars were consistent thanks to the use of the PAI and it was possible to establish differences between cultivars (Table 4.1.3).

The incubation period was already used by several authors to study cultivar sensitivity to ageing (Reust & Münster, 1975; Reust, 1982; Caldiz et al., 1988). However, growing conditions vary from year to year, hence modifying the resulting incubation period and the PAI. Although the length of the incubation period can be used as an indicator of the physiological age, its values, expressed in days (Claver, 1973; 1975; Reust & Münster, 1975; Caldiz et al., 1985; van der Zaag & van Loon, 1987; Caldiz, 1991, 1994) or in degree-days (Reust, 1982), may be counter-intuitive because a large figure means that the tubers are younger. This is not the case with the PAI values.

Table 4.1.3. Physiological age index for different cultivars grown in Balcarce, 1997/98.

	T_0[1]	Sampling date[1]	T_0 to sampling[2] (A)	Incubation day[1]	T_0 to end of incubation[2] (B)	PAI A/B
30 May 1998						
Frital	43	150	107	317	274	0.39 c
Keluné	49	150	101	308	259	0.39 c
Huinkul	53	150	97	296	243	0.40 bc
Kennebec	43	150	107	294	251	0.43 b
R. Burbank	57	150	93	294	237	0.39 c
Shepody	43	171	128	294	251	0.51 a
Spunta	43	150	107	283	240	0.45 b
21 October 1998						
Frital	43	294	251	367	324	0.78 c
Keluné	49	294	245	362	313	0.78 c
Huinkul	53	294	241	353	300	0.81 b
Kennebec	43	294	251	357	314	0.80 b
R. Burbank	57	294	237	350	293	0.81 b
Shepody	43	294	251	364	321	0.79 bc
Spunta	43	294	251	334	291	0.85 ab

(1) Julian days; (2) number of days. For each date averages followed by the same letter do not differ significantly ($P < 0.05$).

Development of the PAI for one cultivar stored in different systems

These experiments were part of a more ambitious project to evaluate the effect of crop and storage management on seed age of cv. Spunta for the late cropping season in the Villa Dolores area. As previously shown in this paper inmediately after haulm killing the PAI was close to 0. At planting time, no differences were found for tubers stored under similar conditions (cold and forced ventilated store at 4 °C and cold store at 4 °C) while those stored in heaps in the field had a higher PAI at planting (Table 4.1.4). The PAI of seed stored in a barn under natural diffuse light was intermediate at planting. These results also confirmed cultivar behaviour under similar storage conditions as previously reported by Escande et al. (1986) and Caldiz (1991).

Table 4.1.4. Physiological age index for cv. Spunta stored under different conditions, Villa Dolores 1997/98.

	T_0[1]	Sampling date[1]	T_0 to sampling[2] (A)	Incubation period[2]	T_0 to end of incubation[2] (B)	PAI A/B
At harvest	315	321	6	178	240	0.025
At planting[3]						
Heaps in the field	315	423	108	85	193	0.56 a
Natural diffuse ligth	315	423	108	93	206	0.52 b
Cold Store	315	423	108	103	217	0.50 c
Cold + Ventilated	315	423	108	109	220	0.49 c

(1) Julian days; (2) number of days; (3) at planting, after being stored in different storage systems. At planting, averages followed by the same letters do not differ significantly ($P < 0.05$).

Development of the PAI for different cultivars stored under different conditions

Data regarding physiological age measurements by the length of the incubation period for different cultivars stored in different systems (Escande et al., 1985) were recalculated using the PAI formula as shown in Table 4.1.5. These recalculations showed that differences between cultivars and storage systems can be perfectly assessed with the PAI. For example, for both years and cultivars seed tubers stored in heaps in the field showed the shorter incubation period and this was also reflected in a higher PAI at planting (0.86-0.90). On the other hand, when tubers of both cultivars were stored under controlled conditions (silo, heaps-silo and cold store) they had a lower PAI (0.79-0.85) at planting as shown in Table 4.1.5. Moreover, these recalculated results are in agreement with cultivar behaviour as mentioned in the original work (Escande et al., 1985).

Development of the PAI after different haulm killing dates

Haulm killing date is recognized as a key-date during the life cycle of a seed tuber and its effects on physiological age, growth and yield were already studied (Hutchinson, 1978; O'Brien & Allen, 1975; Panelo & Caldiz, 1989; Caldiz et al., 1994). When data from different haulm killing date trials (Panelo & Caldiz, 1989) were re-elaborated, similar results were found as those already mentioned.

Table 4.1.5. PAI for seed from different cultivars stored in different systems.

Treatment	T_0[1] (A)	T_0 to planting[2]	Incubation period[2]	T_0 to end of incubation[2] (B)	PAI A/B
Year 1980					
cv. S. Volcán					
Silo	71	273	69	342	0.80
Heaps-Silo	71	273	70	343	0.79
Heaps	71	273	31	304	0.90
Cold store	71	273	61	334	0.82
cv. Spunta					
Silo	71	273	52	325	0.84
Heaps-Silo	71	273	54	327	0.83
Cold store	71	273	61	334	0.82
Heaps	71	273	44	317	0.86
Year 1981					
cv. S. Volcán					
Silo	71	253	43	296	0.85
Heaps-Silo	71	253	49	302	0.84
Heaps	71	253	27	280	0.90
Cold store	71	253	50	303	0.83
cv. Spunta					
Silo	71	253	60	313	0.81
Heaps-Silo	71	253	57	310	0.82
Heaps	71	253	39	292	0.87
Cold Store	71	253	55	308	0.82

(1) Julian days; (2) number of days. Data recalculated from Escande et al. (1985).

Differences in the length of the incubation period are better expressed and better assessed when the PAI was used, which means that (a) the length of the incubation period is related to seed age (Claver, 1953; Caldiz, 1991) and (b) that the PAI can really explain differences in physiological age. Re-elaborated data for 1986/87 in cv. Ballenera clearly showed the effects of a warm and dry growing season on seed age, resulting in a high PAI value of 0.64 and 0.59 for the early killing and natural death treatments, respectively (Table 4.1.6), compared with the 0.43-0.48 values for the same treatments in 1984/85 and 1985/86.

Table 4.1.6. Results of applying the PAI to incubation measurements used to express physiological age for seed of cv. Bonaerense La Ballenera from different haulm killing dates.

Treatment	T_0[1]	T_o to sampling[2] (A)	Incubation period[2]	T_0 to end of incubation[2] (B)	PAI A/B
1984/85					
Early killing	61	123	133	256	0.48
Natural death	65	119	135	254	0.47
1985/86					
Early killing	60	136	157	293	0.46
Natural death	80	116	152	268	0.43
1986/87					
Early killing	80	123	67	190	0.65
Natural death	107	96	67	163	0.59

(1) Julian days; (2) number of days. Data recalculated from Panelo & Caldiz (1989).

Effect of pre-planting treatments on development of PAI

Different pre-planting treatments can be carried out to enhance crop emergence and growth, such as high temperature treatments (van Ittersum, 1992), gibberelic acid application (Marinus & Bodlaender, 1978) and pre-sprouting (Headford, 1962). In this work the effect of different pre-planting treatments, such as pre-sprouting and storage temperature, were tested during one month before planting in order to study their effects on the PAI. Pre-sprouting and storage at 17 °C for 4 weeks before planting resulted in higher PAI values than for seed tubers stored at 4 °C for the same pre-planting period (Table 4.1.8).

Table 4.1.7. Results of applying the PAI to incubation measurements used to express physiological age for seed of cv. Bonaerense La Ballenera from different pre-sprouting and haulm killing dates.

Treatment	T_0 [1]	T_0 to sampling[2] (A)	Incubation period[2]	T_0 to end of incubation[2] (B)	PAI A/B
1987/88					
P-S Nat Death[3]	56	110	81	191	0.58
P-S EHK[4]	20	146	95	241	0.61
H Nat Death[5]	77	99	77	176	0.56
H EHK[6]	85	146	85	231	0.63
1988/89					
P-S Nat Death[3]	56	110	116	226	0.49
P-S EHK[4]	38	128	114	242	0.53
H Nat Death[5]	71	95	101	196	0.48
H EHK[6]	38	128	123	251	0.51

(1) Julian days; (2) number of days; (3) P-S Nat Death: pre-sprouted seed and natural foliage death; (4) P-S EHK: pre-sprouted seed and early haulm killing; (5) H Nat Death and (6) H EHK, seed stored in heaps without pre-sprouting with natural foliage death and and early haulm killing, respectively. Data recalculated from Panelo & Caldiz (1989).

Differences in PAI can explain the effect of chronological age since T_0 for different cultivars. Similar results were obtained by Hartmans & van Loon (1987) and van der Zaag & van Loon (1987) when they tried to correlate chronological age with the length of the incubation period. However, in these cases, the length of the incubation period can only give an idea of the seed age, but does not allow physiological age comparisons. The PAI reconciles chronological and physiological age and can also explain differences in physiological age due to seed origin, haulm killing date, storage conditions and pre-planting treatments and allow in all cases comparisons between cultivars, crop and storage management and pre-planting conditions. The PAI is simple to measure, non-invasive and required investment is low. However, a disadvantage for the PAI is the long time needed to obtain the final result which limits its predictive value for future plantings and for grower's use. Further work is in progress to use the PAI as input of a simulation model to predict tuber yield based on seed age.

Table 4.1.8. Physiological age index over time for cv. Kennebec grown in Tres Arroyos area by different seed growers, and with different pre-planting treatments, 1998/99.

Treatment	T_0[1]	T_0 to sampling (A)[2]	Incubation end[1]	Incubation period[2]	T_0 to end of incubation[2]	PAI A/B
Grower A						
Cold	45	254	388	343	85	0.74 c
Darkness	45	241	353	308	67	0.75 bc
Pre-sprout NDL[3]	45	254	367	322	68	0.79 a
Grower B						
Cold	47	252	391	344	88	0.74 bc
Darkness	47	239	353	306	67	0.75 bc
Pre-sprout NDL[3]	47	252	376	329	77	0.77 ab

(1) In Julian days; (2) number of days; (3) Pre-sprout NDL, pre-sprouted in natural diffuse light. Averages followed by the same letter do not differ significantly ($P < 0.05$).

CHAPTER 4.2

SEED SUPPLY, SEED ORIGIN, SEED FLOW AND PHYSIOLOGICAL AGE OF SEED POTATOES AND THEIR EFFECTS ON CROP GROWTH AND YIELD IN DIFFERENT SEASONS

submitted as:

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4.2. SEED SUPPLY, SEED ORIGIN, SEED FLOW AND PHYSIOLOGICAL AGE OF SEED POTATOES AND THEIR EFFECTS ON CROP GROWTH AND YIELD IN DIFFERENT SEASONS

Summary

In Argentina seed potatoes are produced during the medium-late (summer) crop in different areas located at sea level or in mountain valleys. From these areas the seed flows to the late (autumm), early (winter) and medium-early (spring) crops in different agro-ecological areas. In this paper seed supply, seed origin, and seed flow were analyzed, in terms of their effects on the physiological age of the seed, crop growth and tuber yield. Seed supply is based on production of pre-basic seed under controlled conditions and production of basic seed in isolated areas for several generations. Seed tubers from these areas are suitable to establish a specific seed supply for different ware and processing producing areas in order to achieve higher yields. In crops from seed tubers with a low physiological age index initial ground cover is also low, while the opposite occurred in crops from seed tubers with a high physiological age index. A close relationship was found between the physiological age index of the seed and the proportion of potential yield achieved by the crop. These effects should be improved to optimize utilization of different resources (water, nutrients) depending on agro-ecological conditions.

4.2.1. Introduction

In Argentina, potatoes are grown the whole year for seed, ware or processing in different areas and seasons, as already shown in Figure 2.1.3. Early (winter) crops are grown in the northern provinces of Tucumán, Salta, Jujuy Chaco and Formosa (22-28° SL) during June-November for ware production. Medium-early (spring) crops are mainly grown in the mediterranean province of Córdoba for ware production and for seed production for the late (autumm) crop in the same province, and that in the north of Buenos Aires province, Mendoza, Tucumán and Santa Fé (28-34° SL) grown for ware and processing potatoes. Medium-late (summer) crops are grown at sea level in Buenos Aires, Río Negro, Chubut, Santa Cruz and Tierra del Fuego and in mountain valleys in Tucumán, Catamarca, Córdoba and Mendoza, either for ware, processing or seed production in the case of isolated areas at sea level or in the mountains (Caldiz & Struik, 1999; Haverkort & Caldiz, 1994). Late (autumm) crops are mainly grown in Córdoba and in the provinces of Tucumán, Santa Fe and Buenos Aires for ware and processing. For further information the reader is referred to Caldiz et al. (1999) who recently discussed the seed potato production system in Argentina.

At present, seed of almost 50 different cultivars (Dirección Nacional de Cultivares SAGPyA, personal communication, 1999) is being grown in about 5,000 ha, in the medium-late seed crop under different yield determining, limiting and reducing factors (Caldiz & Gaspari, 1997), producing above 120,000 t $year^{-1}$ with an average yield of 22 t ha^{-1} (Caldiz & Struik, 1999). This seed flows towards the other cropping seasons, to grow crops in different regions with a differential need for seed supply. Cv. Spunta occupies 85-90% of the area cropped with potato (Fernández et al., 1999) and the seed required for this cultivar should be stored for different periods and under different conditions to supply the early, medium-early, medium late crops and the export market for different purposes. However, in this complex situation seed stocks do not always have the required physiological age for each specific case regarding planting season, length of the growing season, potential yield of the crop and market requirements.

The physiological age of a seed tuber changes with time and with environmental conditions and management during seed production (van der Zaag, 1973; Caldiz et al., 1985; Caldiz, 1991; van Ittersum & Scholte, 1993; van Ittersum et al., 1993), storage (Hartmans & Van Loon, 1987; van Ittersum, 1993), pre-planting treatments (Marinus, 1993) and presence of diseases (Bhatia & Young, 1985).

The purpose of this paper is: (a) to survey the seed requirement for different areas; and (b) to analyze the effect of different seed origin and storage systems on seed supply, seed flow and productivity of the following crop in terms of physiological age evolution until following planting dates in different areas and seasons and their effects on crop growth and tuber yield.

4.2.2. Materials and methods

Seed supply and seed requirement

The seed supply systems were analyzed based on previous work of Escarra (1989) and Huarte & Inchausti (1994). Based on evidences regarding the production of healthy seed in different areas the seed supply system was analyzed in terms of seed availability for the different growing seasons and crop purposes (seed, ware or processing). Seed requirements were established based on the hectareage cropped in each of the ware areas according to data from Caldiz & Struik (1999) and Caldiz et al. (1999).

Seed origin and storage and their effects upon physiological age

During the period 1993/94 (Table 4.2.1) and 1994/95 seed tubers of cv. Spunta produced during the medium-late (October-January) and late (February-July) crops (summer and autumm, respectively, for the Southern Hemisphere) in different regions of Argentina (Villa Dolores, Malargüe, Tupungato, Tierra del Fuego and Tafí del Valle).

Table 4.2.1. Data on seed origins cv. Spunta (1993/94).

Seed origin	Planting date[1]	T_0[1]	Harvest date[1]	T_0 to sampling	Incubation period[2]	T_0 to end of incubation[2]
Río Grande (53° 48' SL)	29 Oct 1993	55	109	124	115	249
Cabo San Pablo (54° 20' SL)	27 Oct 1993	61	103	118	116	244
Ushuaia (54° 48' SL)	1 Nov 1993	84	98	95	107	222
Tafí del Valle (26° 56' SL)	10 Nov 1993	46	105	161	78	253
Tupungato (33° 45' SL)	15 Dec 1993	88	120	101	136	257
Malargüe (35° 30'SL)	12 Jan 1994	96	115	93	169	282
Villa Dolores (31° 57'SL)	5 Mar 1994	174	191	26	126	207

(1) Julian days; (2) number of days. Data recalculated from Caldiz & Fernández (1995).

The tubers were harvested between 2-8 weeks after haulm killing and stored for different periods either in a cold store at 4 °C or in heaps in the field until the following possible planting date. Immediately after haulm killing and at each possible planting date the physiological age of the seed tubers was assessed by means of the physiological age index (PAI) as proposed by Caldiz et al. (2000c). PAI is based on the length of the incubation period (Claver, 1953) and two different key-dates for the life cycle of a seed tuber, which are easy to assess, i.e. the haulm killing date of the seed crop (T_0) and the sampling or possible planting date of the seed. PAI: T_1/T_2, where T_1 *is the time from haulm killing date* (T_0) *to possible planting date and* T_2 *the time* from T_0 to the end of the incubation period. The PAI ranges from 0 for physiologically young to 1 for physiologically old tubers, respectively (Caldiz et al., 2000c).

Seed origin and storage and their effects on physiological age, crop growth and tuber yield

During 1995/96 about 450-500 kg of seed tubers of cv. Spunta produced during the medium-late crop in different regions of Argentina (Tafí del Valle, 26° 56' SL, 2000 m above sea level; Malargüe, 35° 30' SL, 1400 m above sea level and Balcarce, 37° 51' SL, 113 m above sea level) were harvested 2-3 weeks after haulm killing and stored in a cold store at 4 °C until the new planting in the early, medium-early and medium-late crops grown in Tucumán (26° 48' SL, 481 m above sea level), Villa Dolores (31° 57' SL, 600-900 m above sea level) and Balcarce, respectively. Immediately after haulm killing and at each possible planting date the physiological age of the seed tubers was assessed by means of the physiological age index (PAI) as already mentioned. In these locations planting was done by hand in plots of 10 m by 4 rows, 0.80 m apart, with four replicates per origin at a density equivalent to 50,000 pl ha^{-1}. N-P-K (18-46-0) at 300 kg ha^{-1} was applied and in all locations irrigation (sprinkler in Tucumán and Balcarce and furrow irrigation in Villa Dolores) was applied to maintain the soil close to field capacity. In all cases pests and diseases were controlled as normally done in each area. Emergence date was assessed when more than 80% of the plants in the plot appeared 0.05 m above soil level. For Tucumán and Balcarce plantings, ground cover was periodically measured (5 observations per replicate) following the procedure described by Centro Internacional de la Papa (1986). In all locations crops were allowed to die naturally and at harvest, which was performed over 5 furrow sections of 2 m length per replicate, tuber weight was recorded. Results are presented as t ha^{-1}.

In all cases the statgraphics v. 2.0 computer program was used to perform an analysis of variance and averages were compared by Tukey's test ($P < 0.05$).

4.2.3. Results and discussion

Seed supply and seed requirement

Since 1984-85 Argentina is self sufficient regarding basic seed production (Mendiburu, 1986). This achievement was due to the adoptation of in vitro techniques, the wide use of ELISA test and the production of basic seed in isolated areas (Escarrá, 1989). Government and private organizations are involved in the production of pre-basic seed under controlled conditions: in vitro material, plantlets or microtubers (Pre Initial 0), minitubers (Pre Initial I), minitubers (Pre Initial II); basic seed produced under field conditions in isolated areas (Caldiz et al., 1999): (Initial I), (Initial II), (Initial III) and Foundation; and certified seed: registered, certified A and B (Normative 245 from INASE, A.M. Escarrá, personal communication, 2000). About 50% of the seed required for the ware and processing crops is certified, i.e: about 5,000 ha from the total area required for these crops (Fernández et al., 1999). These figures are in agreement with the total seed requirement, according to data presented in Table 4.2.2. The total seed requirement of 254,500 tonnes (about 5,090,000 bags of 50 kg, as commercialized in Argentina) means, for an average yield of 22 t ha^{-1} as quoted by Caldiz & Struik (1999), that no less than 10,000-12,000 ha of seed potatoes from different categories must be grown each year.

Table 4.2.2. Area of production and annual required amount of seed[1].

Crop Type	Cultivated area (ha)	Seed requirement (tonnes)
Early	5,700	14,250
Medium-early	28,000	70,000
Medium-late	47,100	117,750
Late	21,000	52,500
Total	101,800	254,500

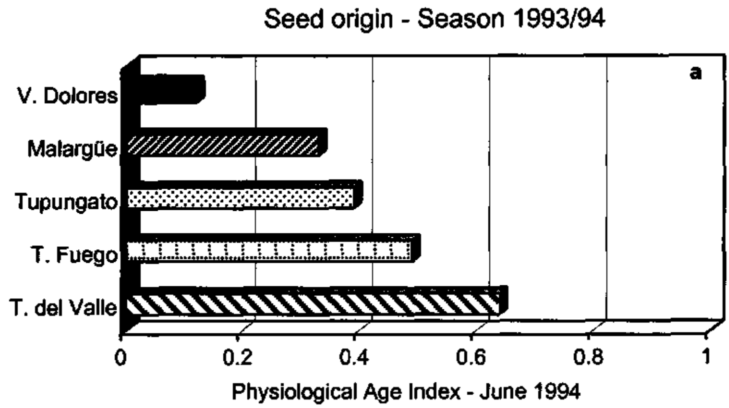
(1) Based on Caldiz & Struik (1999).

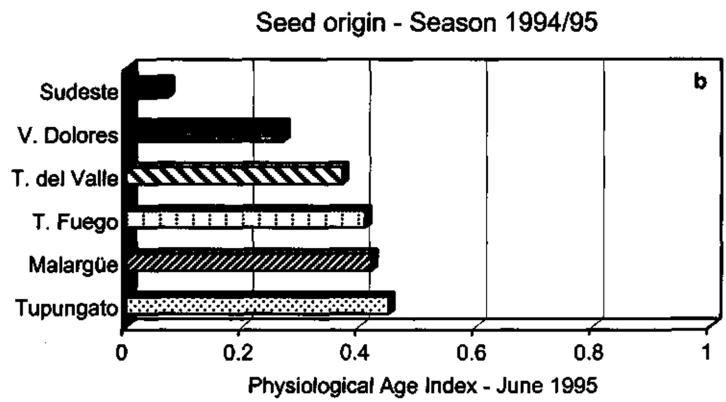
Seed origin and storage and their effects upon physiological age

During 1993/94 the effect of five different seed origins on the physiological age and its possible effects on seed supply were evaluated. Between T_0 and harvest date, tubers remained in the soil, while between harvest date and sampling date they were stored, for each location, in a barn at ambient temperature or in the field for different periods. Hence, PAI values were affected by both the effect of growing and post-harvest conditions until sampling date. At a certain possible planting date (mid-June), corresponding to an early crop, lower PAI values were obtained for those seed tubers grown in Malargüe and Tupungato as a result of a late planting during the previous medium-late season (January and December as shown in Figure 4.2.1a).

Seed tubers from the southern province of Tierra del Fuego (Río Grande, San Pablo and Ushuaia) - although grown under low temperatures (Caldiz et al., 1999) - had a higher PAI than those from Malargüe and Tupungato, due to an early planting (end of October, beginning of November). Similar results, for different cultivars, were found by Caldiz et al. (1985).

Seed tubers from Tafí del Valle, although grown under favourable growing conditions, had a higher PAI as a consequence of the time elapsed from T_0 to harvest and storage conditions from harvest onwards.





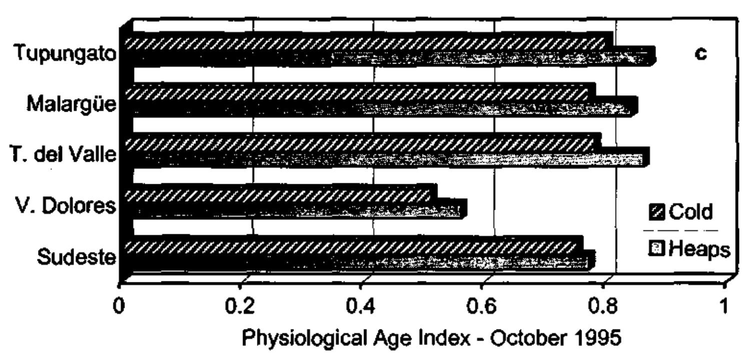


Figure 4.2.1. Effect of seed origin and storage on the physiological age index (1993/94 and 1994/95).

However, the most interesting case is the seed grown in the late crop at Villa Dolores. Even when the length of the incubation period was similar to that of seed grown in Tierra del Fuego (Río Grande and Cabo San Pablo) or Tupungato, the PAI was absolutely different due to the shorter time elapsed from T_0 to the sampling date. When seed tubers of the same origins were analyzed during 1994/95 some differences appeared when PAI was evaluated in June (Figure 4.2.1b). Seed from Balcarce was younger than that of other origins. Seed from Tupungato appeared older than in 1993/94, while seed from Tierra del Fuego and Malargüe appeared younge than in that season. However, an interesting case is that of the seed from Tafí del Valle. This seed origin appeared as the older one in 1993/94 but it was much younger in 1994/95. The crucial factor was the significant shortening in the period elapsed between haulm killing and harvest and from harvest until storage (see Materials and methods for more details). By October 1995, the PAI was higher for all origins as a consequence of the time elapsed since haulm killing.

Within each origin, seed stored in heaps in the field resulted has a higher PAI than that stored in a cold store (Figure 4.2.1c). These results demonstrated that seed lots from different origins show different physiological age at planting due to the effects of either crop, post-harvest and/or storage conditions.

Seed origin and storage and their effects upon physiological age, crop growth and tuber yield

After haulm killing the PAI differed between origins, the seed from Balcarce being younger than that from Malargüe and Tafí (Table 4.2.3). However, post-harvest conditions in Tafí (a barn at ambient temperature) resulted in a higher PAI for seed from that origin.

Normally, in Argentina, after haulm killing, potatoes remain in the soil for long periods (Escande et al., 1985, 1986) which means that tubers are subject to different and uncontrolled environmental conditions. This period should be shortened or seed should be stored in cold stores if the purpose is to obtain seed with a low PAI. However, during the year, the PAI increased with the delay in planting time, independently of seed origin. Even in a cold store, an important increase in PAI occurred between haulm killing (March) and the first planting in Tucumán (mid-July), probably as a consequence of post-harvest conditions, as already mentioned. The PAI was higher at planting in Villa Dolores (mid-August) and Balcarce, with differences between origins (Table 4.2.3) as a consequence of the thime elapsed from haulm killing.

Table 4.2.3. Physiological age index (PAI), tuber yield and proportion of the potential yield achieved at different planting time by seed from different origins.

Seed origin		Early planting (Tucumán)			Medium-early planting (Villa Dolores)			Medium-late planting (Balcarce)		
	PAI at HK[1]	PAI	Yield[2]	A/P yield[3]	PAI	Yield[2]	A/P yield[3]	PAI	Yield[2]	A/P yield[3]
Tafí	0.31b	0.56b	51a	0.75	0.67a	35a	0.63	0.82a	38a	0.30
Malargüe	0.33a	0.59a	51a	0.75	0.65ab	32a	0.58	0.81ab	42a	0.33
Balcarce	0.26c	0.55b	55a	0.80	0.62b	34a	0.61	0.80b	39a	0.30

(1) HK, haulm killing; (2) tuber yield in t ha^{-1}. Within each column means followed by the same letter do not differ significantly ($P < 0.05$); (3) ratio actual: potential yield, based on actual yields of Table 2.1.3 and potential yields of Table 3.2.1.

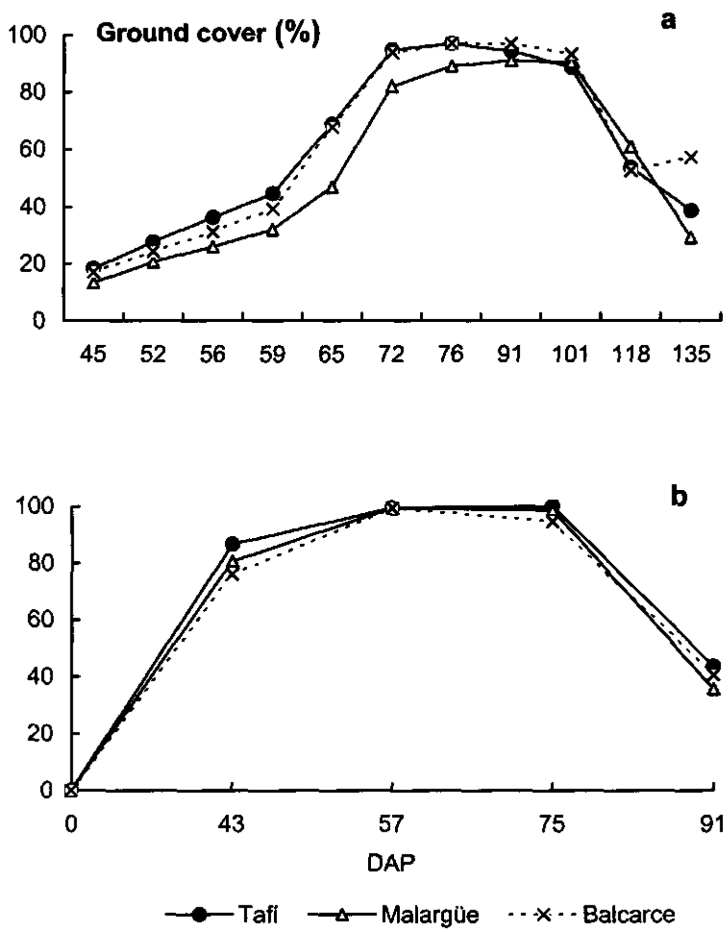


Figure 4.2.2. Ground cover for crops from different origins grown at (a) Tucumán and (b) Balcarce, 1996/97. DAP: days after planting

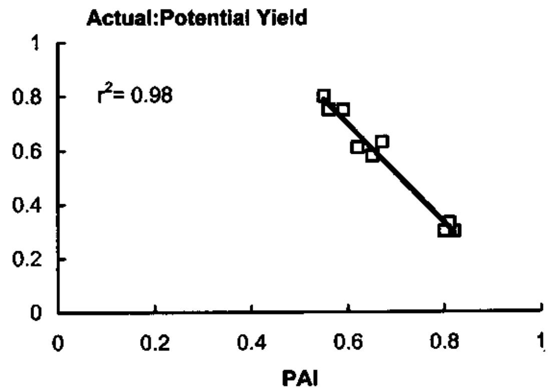


Figure 4.2.3. Relationship between physiological age index (PAI) and actual/potential yield ratio for seed from different origins planted in different seasons.

Significant differences in PAI appeared between origins at the same planting time, but they were not reflected in tuber yield. When differences in PAI were larger, for example when PAI for the different planting seasons is considered, these differences were clearly reflected in tuber yield (Table 4.2.3). These differences in PAI were also reflected in the initial ground cover of the crop, as shown in Figure 4.2.3. At the early planting in Tucumán, when the PAI was low, initial ground cover development was also low but no differences between seed origins were found. More than 70 days passed before the crop achieved a 100% of ground cover (Figure 4.2.2a). However, at the time of planting the medium-late crop in Balcarce, the PAI was high and also the initial ground cover was high. A 100% ground cover was achieved after 57 days after planting. Moreover, crop cycles in both locations differ significantly: 135 days for Tucumán and 91 days for Balcarce. Consequently, with the delay in planting and the increased PAI values the tuber yields decreased from 55 t ha^{-1} when the PAI was close to 0.50 for the crops in Tucumán to 42 t ha^{-1} for the crops in Balcarce when the PAI was close to 0.80 (Table 4.2.3). These results also reflect the effect of storage period on PAI and consequently their effects on ground cover and tuber yield, as found earlier by Caldiz (1991). When PAI for the different seed origins was plotted against the proportion of the potential yield achieved in each planting season a close relationship between PAI and yield appeared (Figure 4.2.3) for the upper range of PAI. Even when differences in PAI are small they have an important effect on potential tuber yield; as the storage period increased the PAI also increased for all seed origins (Table 4.2.3).

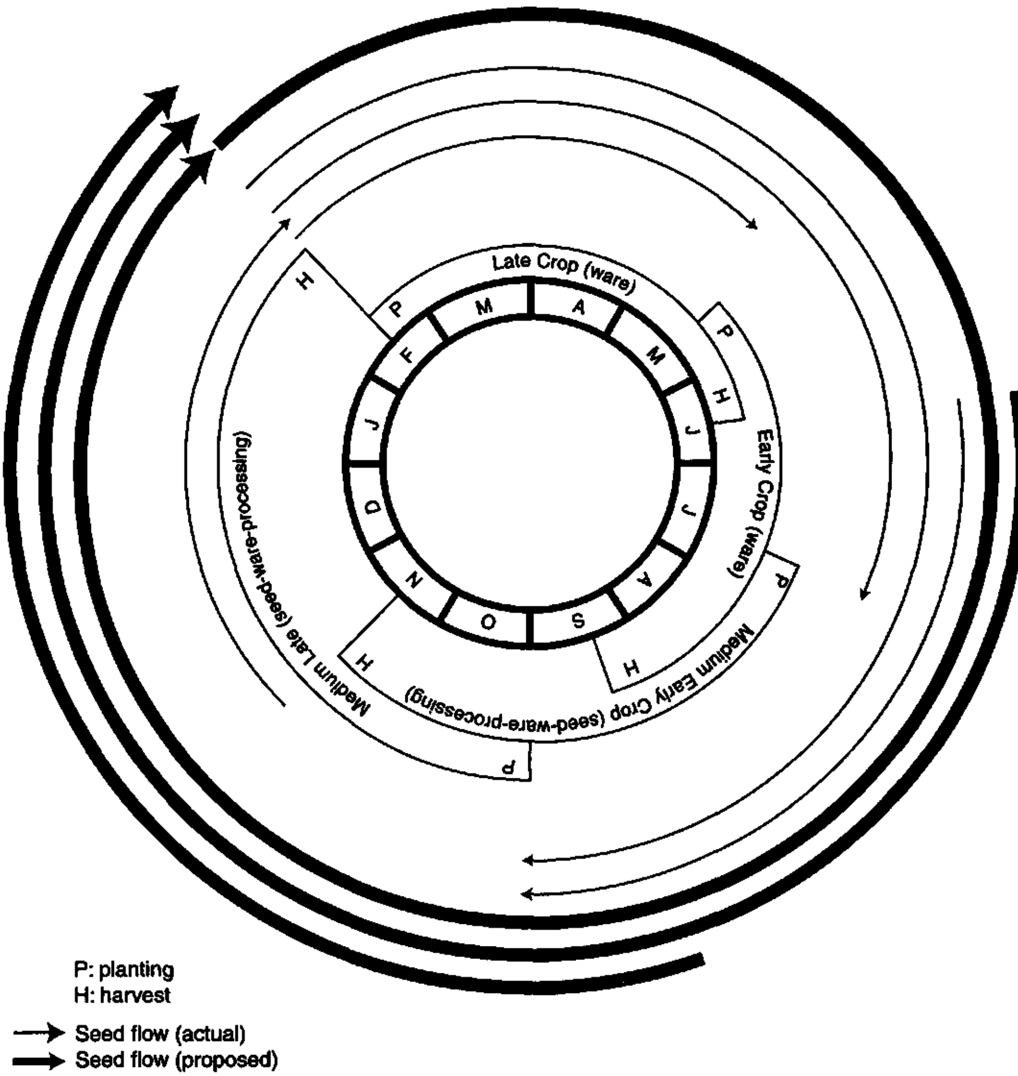


Figure 4.2.1. Actual and proposed seed flows in Argentina

Note: Early and late crops are grown for ware production but could be used for seed production if proper phytosanitary conditions are created.

A similar relationship between physiological age and yield was found by Caldiz et al. (1985). In the lower ranges of PAI, its effects on proportion of the potential yield attained will be quite. In any case the site-specific period between haulm killing and planting is a major factor in determining the PAI.

Seed lots from different cultivars differ in their PAI due to differences in growing, post-harvest and storage conditions. These differences also have consequences for tuber yield depending on the planting season. Hence, to improve resource utilization, seed potatoes in Argentina must be grown and stored according to their use in future seasons. A proper crop, post harvest and storage management will contribute to higher yields.

The basic and registered seeds are produced in several isolated or restricted areas as described elsewhere (Caldiz et al., 1999) and flows from those areas to the ware and processing areas as presented in Figure 4.2.4. Based on the results of this paper, it is clear that actual seed flows do not provide seed with suitable age for all growing seasons (Caldiz, 1991; Caldiz et al., 1998a). Then, options should be considered

(a) to develop new seed flows in different growing seasons, as proposed in Figure 4.2.4; taken into account that proper phytosanitary measures must be taken. Areas in late and early seasons could be developed for this purpose (Figure 4.2.4). According to a recent work from Caldiz et al. (2000b) expansion of the area cropped with potatoes is possible;
(b) to improve crop management, regarding planting and harvesting time;
(c) shortening the period between haulm killing to harvest, which has a major impact on the physiological age of the seed tubers, as will be show later in this paper;
(d) to improve storage facilities and storage management.

SECTION 5

STRATEGIES TO IMPROVE SEED QUALITY AND YIELD

CHAPTER 5.1

STRATEGIES TO REDUCE PHYSIOLOGICAL CONSTRAINTS

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5.1. STRATEGIES TO REDUCE PHYSIOLOGICAL CONSTRAINTS

Summary

The modifying effects of applying the plant growth regulators (PGRs) benzylaminopurine (BAP), gibberellic acid (GA_3) and BAP + GA_3 on physiological age were studied. Two experiments with two cultivars, differing in rate of physiological ageing (the medium-late Huinkul and the medium-early Pampeana) and two storage systems were performed during 1988/89 and 1989/90 in two different potato areas of Argentina.

In both seasons seed tubers stored in heaps reached an advanced physiological age at planting, compared to tubers from the cold store. Seed tubers of Pampeana were older than those of Huinkul. Crops sprayed with BAP maintained ground cover and photosynthesis longer and crops sprayed with GA_3 shorter than control crops. Consequently tuber yield was decreased by GA_3 in 1988/89, but in 1989/90 all crops treated with PGRs outyielded the control. BAP could overcome effects of advanced physiological age on crop senescence and tuber yield.

5.1.1. Introduction

Health status, size and especially physiological age of seed tubers are crucial in modern potato production (van der Zaag, 1986). During the last 25 years much attention was paid to the effects of seed crop and storage environment on the physiological age of seed tubers (van der Zaag, 1973; Claver, 1975; Perennec & Madec, 1980; Caldiz et al., 1985, van der Zaag & van Loon, 1987; Caldiz, 1991). It was demonstrated by O' Brien et al. (1983) that early-potato growers could maximize their yield by planting physiologically old seed for the earliest harvest and progressively younger seed for later harvests. Many efforts have been carried out to provide potato growers with seed of suitable age according to cropping purpose. Seed age can be manipulated by production in special areas and seasons, by crop husbandry, storage management and also by applying plant growth regulators (PGRs) either to the seed crop or the seeds (Bodlaender & van de Waart, 1989; Caldiz et al., 1989; van Ittersum et al., 1993).

PGRs are mainly used to break dormancy for rapid virus testing or "in vitro" production, but they are not commonly used in field crops (Bruinsma, 1982). However, CCC, GA, 2-4 D, B9, Alar and other PGRs have proved to be effective for different purposes in seed potato production (Marinus & Bodlaender, 1978; Bodlaender & van de Waart, 1989, van Ittersum et al., 1993; Mikitzel, 1995; Caldiz, 1996; Caldiz et al., 1996), while Iritani (1983) stated that the use of PGRs could be an important tool in potato production.

In the southeast area of the province of Buenos Aires, Argentina, seed potatoes from cultivars with a long absolute dormant period are stored in *heaps in the field* from harvesting to new planting. Hence, the physiological state of the tubers at planting depends on the environmental conditions experienced during the storage period which are not always suitable and tubers may reach the new planting season with inadequate physiological age (Caldiz et al., 1984; Escande et al., 1985; Escande et al., 1986). In other cases cold storage facilities are not available for all the seed that is being produced and cultivars sensitive to physiological ageing also reach the new planting season with a too much advanced physiological age; hence crops develop rapidly and yields are relatively low, given the long available growing period (Caldiz, 1991).

Therefore two experiments with two cultivars, differing in their rate of physiological ageing, and two storage systems were performed. The possibilities of modifying the effects of physiological age of the seed on the crop grown from it, by PGRs applications were studied. Analysis focussed on ground cover, photosynthetic rate and tuber yield.

5.1.2. Materials and methods

Field experiments were carried out during 1988/89 at Lobería (38° 10' S) and 1989/90 at La Plata (34° 54' S) both in the Province of Buenos Aires, Argentina, using certified seed tubers of cultivars Huinkul MAG (medium-late) and Pampeana INTA (medium-early).

In both growing seasons seed tubers were harvested in the southeast of the Province of Buenos Aires during April-May and stored in: (a) a cold store at 2-4 °C (C) and (b) heaps in the field (H), till 4 weeks before planting. At that moment seed tubers from both storage systems were pre-sprouted under natural diffuse day-light. In 1988/89 planting was done 21st October 1988, at distances of 0.75 m between rows and 0.25 m between plants within the row, with a four-row planting machine. In 1989/90 planting was done 4th October 1989 by hand, at the same plant arrangement. In both growing seasons, at planting time, a sample of 50 tubers per treatment (2 cultivars x 2 storage systems) was taken to determine physiological age by assessing the length of the incubation period, following procedures described by Caldíz et al. (1984).

Each growing season, at time of tuber initiation, foliar applications of: (a) BAP, 50 $mg.l^{-1}$; (b) GA_3, 50 $mg.l^{-1}$ and (c) BAP+GA_3, 50 $mg.l^{-1}$ each, and (d) control, were performed with four replications, on rows of 6.25 m length of each treatment, in a factorial design (2 cultivars x 2 storage systems x 4 chemical treatments). PGRs were applied with an ultra low volume spraying machine. The total water volume applied to each plot was equivalent to 35 $l.ha^{-1}$. Tween 80, 0.5% was added and the control treatment was sprayed with water.

For each plot ground cover was periodically measured (5 observations per replicate) with a rectangular frame described by CIP (1986) and the photosynthetic rate (Phrate) of the 5th leaf from the top was assessed, in 5 plants per replication, using an infrared gas analyzer (Licor LI 6200, Lincoln, Nebraska, USA), as described by Caldiz & Beltrano (1992). Pests and diseases were controlled as normally done in the area and in both years 350 mm water were applied by sprinkler irrigation. In Figure 5.1.1 the meterological data for each year are shown. Two weeks after natural haulm death each plot was harvested, discarding 0.5 m from each border, and tuber number and fresh yield in the fractions: <80 g; 80-400 g and >400 g were determined. The statgraphics v. 2.0 computer program was used to perform an analysis of variance and averages were compared by Tukey's test (P <0.05).

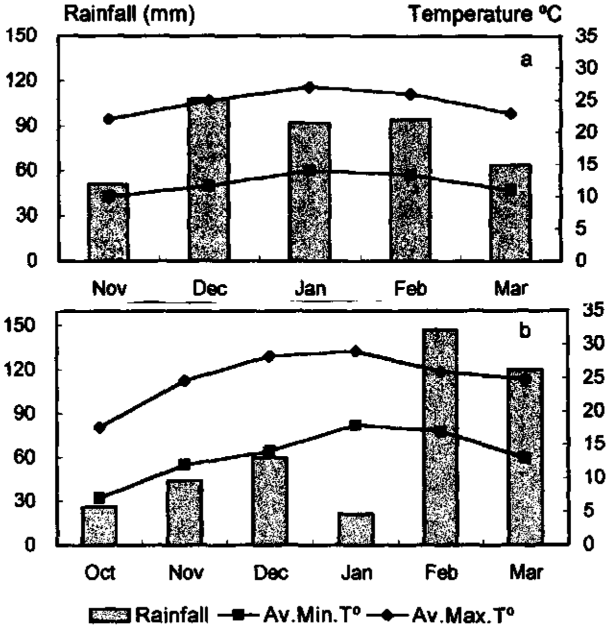

Figure 5.1.1. Meteorological data for both locations (a) Lobería, and (b) La Plata.

5.1.3. Results and Discussion

Physiological age at planting

In both seasons, seed tubers of both cultivars stored in heaps in the field were older than those tubers stored in the cold store. Seed tubers of Pampeana INTA, a cultivar ageing more rapidly than Huinkul (Caldiz, 1994), were older (had a shorter incubation period) than those of Huinkul, either stored in heaps or in the cold store (Table 5.1.1).

Table 5.1.1. Physiological age of seed tubers (days) of two cultivars at planting in 1988/89 and 1989/90.

Storage treatments	Pampeana INTA	Huinkul MAG
1988/89		
Heaps in the field	50 b	65 b
Cold store	65 a	86 a
1989/90		
Heaps in the field	41 b	62 b
Cold store	61 a	82 a

Within each cultivar and year averages followed by the same letter do no differ ($P < 0.05$)

Ground cover

Experiment in 1988/89

At the time of PGRs application (47 days after planting, DAP) ground cover was highest in Pampeana (H) treatments (Table 5.1.2). This is in agreement with the advanced physiological age of these seed tubers at planting and agrees with the well-known behaviour that physiologically advanced seed promotes early canopy development (Perennec & Madec, 1980; O'Brien et al., 1983; Caldiz, 1991). Following this pattern, 47 DAP, Huinkul (C) was the treatment with the lowest ground cover (Table 5.1.2). For both cultivars, from 62 DAP onwards, neither BAP or GA_3 alone or combined increased ground cover, compared to the control. The results obtained with GA_3 application are in contrast with Bodlaender & van de Waart (1989) and its application caused a temporary yellow discolouration of the leaves. As expected, in the medium-late cultivar Huinkul, natural haulm death occurred later than in Pampeana and no effect was observed on ground cover (Table 5.1.2).

Experiment in 1989/90

In Pampeana (H) and (C) and Huinkul (H) and (C) BAP maintained a larger ground cover at the end of crop growth, from 83 to 97 DAP (Table 5.1.3), while in Huinkul (H) and (C) and Pampeana (C) BAP+GA_3 did not modify ground cover between 75-97 DAP (Table 5.1.3). In both cultivars the pattern of ground cover normal for physiologically old seed was modified by foliar applications of BAP, resulting in larger ground cover than in the control at the end of the season (Table 5.1.3).

Table 5.1.2. Ground cover (%) of crops from seed tubers of two cultivars previously stored in heaps in the field (H) and a cold store (C) after foliar applications of BAP, GA_3 and BAP+GA_3 in 1988/89.

Treatments	Days after planting					
	47[#]	54	62	73	87	103
Pampeana H						
Control	44 a	52 a	63 a	63 a	63 a	--
BAP		50 a	58 a	61 ab	64 a	--
GA_3		49 a	58 a	56 b	63 a	--
BAP+GA_3		47 a	54 b	55 b	59 a	
Pampeana C						
Control	39 a	55 a	59 a	59 a	65 a	--
BAP		53 a	58 a	61 a	60 a	--
GA_3		51 ab	63 a	61 b	61 a	--
BAP+GA_3		48 a	58 b	57 b	56 a	
Huinkul H						
Control	36 b	43 b	55 a	54 a	55 a	12 a
BAP		42 b	55 a	56 a	59 a	13 a
GA_3		47 a	60 a	57 a	56 a	13 a
BAP+GA_3		43 b	54 a	53 a	56 a	8 a
Huinkul C						
Control	30 c	39 a	46 a	51 a	58 a	10 a
BAP		40 a	44 a	47 ab	51 a	11 a
GA_3		40 a	45 a	48 a	51 ab	11 a
BAP+GA_3		37 a	45 a	46 a	53 ab	8 a

Within each cultivar, storage system and column, averages followed by the same letter do no differ ($P < 0.05$). (#) At day 47, averages followed by the same letter do not differ ($P < 0.05$).

Table 5.1.3. Ground cover (%) of crops from seed tubers of two cultivars previously stored in heaps in the field (H) and a cold store (C) after foliar applications of BAP, GA_3 and BAP+GA_3 in 1989/90.

Treatments	Days after planting									
	33	40	47	54	61	68	75	83	87	97
Pampeana H										
Control	21 a	33 a	47 a	73 a	82 a	92 a	92 a	75 b	69 b	26 b
BAP	18 a	35 a	47 a	71 a	82 a	96 a	94 a	84 a	79 a	35 a
GA_3	16 a	31 a	45 a	64 b	81 a	91 a	95 a	79 ab	73 ab	29 a
BAP+GA_3	17 a	33 a	44 a	73 a	79 a	93 a	95 a	79 ab	73 ab	28 a
Pampeana C										
Control	18 a	31 a	47 a	77 a	82 a	98 a	90 a	73 c	66 b	32 b
BAP	17 a	33 a	48 a	76 ab	82 a	96 a	94 a	83 a	77 a	38 a
GA_3	13 a	30 a	45 a	68 c	78 a	95 a	93 a	78 ab	71 ab	30 b
BAP+GA_3	20 b	33 a	49 a	72 bc	81 a	96 a	91 a	75 bc	68 b	28 b
Huinkul H										
Control	6 a	17 ab	26 a	54 a	77 a	95 a	87 a	71 b	64 c	35 b
BAP	6 a	18 a	27 a	53 ab	77 a	96 a	87 a	87 a	81 a	45 a
GA_3	4 a	15 b	23 a	47 b	71 a	91 a	88 a	78 b	72 b	35 b
BAP+GA_3	7 a	18 a	26 a	55 a	72 a	96 a	90 a	76 b	70 bc	36 b
Huinkul C										
Control	8 ab	21 ab	33 ab	60 a	83 a	96 a	91 a	77 b	71 b	36 b
BAP	11 a	23 ab	36 a	59 a	81 a	96 a	94 a	88 a	82 a	47 a
GA_3	6 b	20 b	32 a	60 a	76 a	97 a	93 a	81 b	76 b	36 b
BAP+GA_3	8 ab	24 a	35 ab	65 a	83 a	97 a	93 a	80 b	73 b	42 ab

Within each cultivar, storage system and column, averages followed by the same letter do not differ ($P < 0.05$).

Photosynthetic rate

Experiment in 1988/89

Average Phrate was similar to previous values obtained by Caldiz and Beltrano (1992) with the same cultivars. At PGRs application the Phrate was higher in Pampeana (C) than in other treatments. After PGRs application and till the end of crop growth, BAP increased Phrate in Pampeana (H) and (C) (Table 5.1.4). In Huinkul (H), 62 DAP an increase in Phrate was observed after BAP application, while in Huinkul (H) and (C) BAP also increased the Phrate 103 DAP.

Table 5.1.4. Photosynthetic rate (μmol $CO_2.m^{-2}.s^{-1}$) of crops from seed tubers of two cultivars previously stored in heaps in the field (H) and a cold store (C) after foliar applications of BAP, GA_3 and BAP+GA_3 in 1988/89.

Treatments	Days after planting				
	47#	62	73	87	103
Pampeana H					
Control	17 b	15 b	11 b	11 c	--
BAP		23 a	15 a	16 a	--
GA_3		12 b	12 a	15 ab	--
BAP+GA_3		15 b	13 b	14 b	--
Pampeana C					
Control	23 a	20 b	17 b	15 b	--
BAP		29 a	22 a	17 a	--
GA_3		24 b	18 b	13 bc	--
BAP+GA_3		22 b	20 ab	12 c	--
Huinkul H					
Control	17 b	14 c	23 a	17 ab	4 b
BAP		24 a	22 ab	18 a	9 a
GA_3		19 b	21 ab	16 b	7 ab
BAP+GA_3		20 b	17 b	11 c	9 a
Huinkul C					
Control	18 b	23 a	19 a	15 ab	4 c
BAP		21 a	19 a	19 a	13 a
GA_3		14 c	19 a	16 ab	8 b
BAP+GA_3		17 bc	17 a	14 b	0.3 d

Within each cultivar, storage system and colum, averages followed by the same letter do no differ ($P < 0.05$). (#) For day 47, averages followed by the same letter do not differ ($P < 0.05$).

Table 5.1.5. Photosynthetic rate (μmol $CO_2.m^{-2}.s^{-1}$) of crops from seed tubers of two cultivars previously stored in heaps in the field (H) and a cold store (C) after foliar applications of BAP, GA_3 and BAP+GA_3 in 1989/90.

Treatments	Days after planting						
	57#	71	78	85	92	99	106
Pampeana H							
Control	25 c	20 a	12 d	17 b	10 b	---	---
BAP		22 a	17 b	24 a	14 a	9 a	---
GA_3		14 c	15 c	15 c	7 b	5 b	---
BAP+GA_3		18 b	20 a	15 c	8 b	6 b	---
Pampeana C							
Control	29 ab	19 b	18 b	12 c	9 b	4 c	---
BAP		24 a	21 a	20 a	10 a	9 a	---
GA_3		17 b	15 c	7 d	8 c	6 b	---
BAP+GA_3		18 b	17 b	14 b	9 b	7 b	---
Huinkul H							
Control	30 a	20 a	15 b	17 b	12 b	8 b	---
BAP		20 a	20 a	19 a	16 a	10 a	4 a
GA_3		16 c	13 c	14 c	11 b	11 a	---
BAP+GA_3		18 b	13 c	15 c	9 c	10 a	2 b
Huinkul C							
Control	28 b	19 a	16 b	17 c	11 b	6 c	---
BAP		20 a	19 a	19 a	14 a	11 a	4 a
GA_3		19 a	11 d	14 d	9 c	7 b	---
BAP+GA_3		16 b	13 c	16 b	12 b	6 c	1 b

Within each cultivar, storage system and colum, averages followed by the same letter do no differ ($P < 0.05$). (#) For day 57, averages followed by the same letter do not differ ($P < 0.05$).

Experiment in 1989/90

During this season BAP application on both cultivars increased Phrate (Table 5.1.5), since 78 to 99 DAP for Pampeana (H) and (C), while in Huinkul (H) and (C) it was maintained at a higher level till 106 DAP. No major differences were registered between other treatments, except for

GA_3 applied on Pampeana (C) and Huinkul (C), which decreased Phrate during the period 78-92 DAP. This could be associated with temporary yellowing of the leaves, as already mentioned.

BAP promoted an increase in ground cover and Phrate in both seasons and cultivars. In Pampeana this effect was noticed along crop growth in both seasons, while in Huinkul this was true in 1989/90 and at the end of the season in 1988/89. This behaviour modified the normal pattern of physiological ageing for these parameters.

Tuber number and tuber yield

Experiment in 1988/89

BAP+GA_3 increased total tuber number in Pampeana (H), Huinkul (H) and (C), while BAP and GA_3 only increased it in Huinkul (C). GA_3 effects are in agreement with those reported by Bodlaender & van de Waart (1989), Struik et al. (1989) and Caldiz (1996), but BAP treatments did not increase tuber number as effectively as shown by Caldiz (1996) in other cultivars. As a consequence of these increments in the number of tubers in the fraction < 80 g the number of tubers and yield of the fraction 80-400 g was decreased when GA_3 or BAP+GA_3 was applied in Pampeana (H) and (C). In Huinkul (H) BAP+GA_3 also increased the fraction < 80 g (Table 5.1.6).

Regarding tuber yield, as observed by Struik et al. (1989), foliarly applied GA_3 decreased total tuber yield in Pampeana (H) and (C) and Huinkul (H). However, when applied in combination with BAP total tuber yield was similar to the control in Huinkul (H) and (C). BAP only increased total tuber yield in Huinkul (H) as shown in Table 5.1.6.

Experiment in 1989/90

In this season PGRs application increased tuber number in the fraction < 80 g in all treatments (Table 5.1.7). However, when the crops were originated from seed tubers stored in (C) no effects of PGRs were registered in the fraction 80-400 g. Regarding total tuber number and total yield, PGRs application outyielded the control in all cases (Table 5.1.7).

Total tuber yields differed between years but PGRs application increased it significantly in five of eight cases when BAP was applied. Probably the beneficial effects of BAP on ground cover and Phrate were responsible for the increments in tuber yield. However, Dwelle & Hurley (1984) did not find beneficial effects of cytokinins on yield when applied to cv. Russet Burbank.

Although there were not always consistent effects for both years, it is shown that BAP can reverse the effects of an advanced physiological age on crop growth, senescence and yield; in the latter in more than 60% of the cases (Table 5.1.6 and 5.1.7). It could be possible to obtain larger effects if differences in physiological age are not so small (Caldiz et al., 1985; van der Zaag & van Loon, 1987). Nevertheless, other basic improvements in crop and storage management should be matched before deciding on the use of PGRs in field crops.

Table 5.1.6. Tuber number and tuber yield of crops from seed tubers of two cultivars previously stored in heaps in the field (H) and a cold store (C) after foliar applications of BAP, GA_3 and BAP+GA_3 in 1988/89.

Treatments	Tuber number.m^{-2}			Tuber yield ($t.ha^{-1}$)		
	<80 g	80-400 g	Total	<80 g	80-400 g	Total
Pampeana H						
Control	28.40 c	28.48 a	56.48 b	14.30 ab	38.00 a	52.30 a
BAP	26.23 c	26.48 a	53.07 b	11.00 b	38.80 a	49.80 ab
GA_3	39.48 b	21.13 c	60.61 ab	12.30 ab	24.00 b	36.30 c
BAP+GA_3	47.36 a	23.81 b	71.17 a	16.60 a	23.30 b	39.90 bc
Pampeana C						
Control	30.56 b	25.06 b	55.62 a	14.00 b	31.30 b	45.30 a
BAP	31.49 b	28.31 a	59.80 a	13.00 b	37.30 a	50.30 a
GA_3	41.90 a	20.10 c	62.00 a	15.30 b	24.80 c	40.10 b
BAP+GA_3	43.98 a	16.75 d	60.73 a	20.70 a	18.70 d	39.40 b
Huinkul H						
Control	11.60 c	22.60 a	34.20 b	7.00 b	26.60 bc	33.00 b
BAP	20.74 a	16.71 b	37.45 ab	7.20 b	31.20 a	38.40 a
GA_3	15.24 b	21.80 a	37.04 ab	5.50 c	23.70 c	29.20 c
BAP+GA_3	21.88 a	23.20 a	45.08 a	7.80 a	30.30 ab	38.10 ab
Huinkul C						
Control	15.12 b	17.40 a	32.52 b	5.30 b	21.00 c	26.30 a
BAP	20.71 ab	21.36 a	42.0 a	9.60 a	25.60 a	35.20 a
GA_3	21.49 a	20.77 a	42.26 a	9.00 a	24.10 a	33.10 a
BAP+GA_3	24.61 a	18.63 a	43.24 a	8.70 a	20.30 a	29.00 a

Within each cultivar, storage system and colum, averages followed by the same letter do no differ ($P < 0.05$).

Table 5.1.7. Tuber number and tuber yield of crops from seed tubers of two cultivars previously stored in heaps in the field (H) and a cold store (C) after foliar applications of BAP, GA_3 and BAP+GA_3 in 1989/90.

Treatments	Tuber number.m^{-2}			Tuber yield ($t.ha^{-1}$)		
	<80 g	80-400 g	Total	<80 g	80-400 g	Total
Pampeana H						
Control	45.90 b	13.03 a	58.93 b	18.60 b	6.30 a	24.90 b
BAP	67.30 a	2.86 b	70.16 a	29.50 a	6.10 a	35.60 a
GA_3	64.40 a	2.44 b	66.84 a	27.20 a	3..60 b	30.80 a
BAP+GA_3	67.10 a	4.12 b	71.12 a	28.00 ab	4.00 ab	32.00 a
Pampeana C						
Control	43.83 c	1.75 a	45.58 c	25.90 b	2.90 b	28.80 b
BAP	62.10 b	3.77 a	65.87 b	31.70 ab	6.70 a	38.40 a
GA_3	67.94 b	3.13 a	71.07 b	31.70 ab	5.90 a	37.60 a
BAP+GA_3	80.38 a	3.14 a	83.52 a	36.80 a	2.60 b	39.40 b
Huinkul H						
Control	16.68 c	5.37 b	22.05 b	17.50 c	9.40 b	26.90 c
BAP	33.02 b	6.10 a	39.12 a	21.90 b	13.00 a	34.90 a
GA_3	37.36 ab	4.87 c	42.23 a	20.40 bc	8.30 c	28.70 c
BAP+GA_3	42.08 a	4.26 a	46.34 a	25.80 a	8.10 c	33.90 a
Huinkul C						
Control	24.15 b	5.42 a	30.21 b	12.00 c	5.40 b	17.60 c
BAP	39.25 b	6.34 a	45..59 a	22.50 b	10.70 a	33.20 b
GA_3	59.65 a	6.40 a	66.05 a	29.10 a	12.70 a	41.80 a
BAP+GA_3	45.40 b	7.28 a	52.68 b	27.30 ab	10.90 a	38.20 a

Within each cultivar, storage system and colum, averages followed by the same letter do no differ ($P < 0.05$).

CHAPTER 5.2

STRATEGIES TO REDUCE PHYTOSANITARY CONSTRAINTS

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5.2. STRATEGIES TO REDUCE PHYTOSANITARY CONSTRAINTS

Summary

In Argentina, different areas are suitable for seed potato production; however, each of them has particular problems, mainly related to different pest and diseases. Tierra del Fuego island is well isolated from traditional potato growing areas. Therefore, it was tested for its potential for seed production. The cultivars Achatt, Mailén INTA, Pampeana INTA and Spunta were grown in Río Grande, San Pablo and Ushuaia from 1991-1994. Presence of nematodes was assessed and aphid population dynamics were recorded. Average tuber yield ranged from 20.1-37.6 t ha^{-1} and after three years the PVY and PLRV percentage remained low (0-1% for different cultivars and locations), due to low aphid densities during crop growth. Moreover, seed tubers obtained were physiologically young. Long days, early frosts and strong winds may limit tuber yield in some years but quality of the seed potatoes obtained was excellent. The island can be considered as an ecological *safe haven* and is very suitable to obtain healthy and physiologically adequate seed potatoes.

5.2.1. Introduction

According to Mendiburu (1986), the history of the production of seed potatoes in Argentina can be divided into four periods: (1) beginning of crop production-1936, local seed production with local and foreign cultivars; (2) 1937-1955, seed imports only; (3) 1955-1984/85, use of both local and imported seeds; (4) 1984/85-till now, self-sufficiency. Seed imports in period (1) were putatively needed because of *seed degeneration* of local cultivars Chaqueña and Blanca, associated with the incidence of virus diseases (Sívori, 1951), and also because of lack of interest of commercial growers (Anonymous, 1954). During period (2) mainly White Rose and Kathadin, imported from Canada, were used, while in period (3) both local (such as Huinkul MAG, Ballenera MAA, Sierra Volcán and Sierra Bachicha) and imported cultivars (such as Kennebec, Spunta and Jaerla) were used. Period (4) started as a result of the adoption of in vitro techniques, wide use of the ELISA test and production of basic seed in isolated areas (Escarrá, 1989).

Traditionally more than 50% of the potatoes of the country (seed, ware and industry) are grown in the southeast area of the province of Buenos Aires (Figure 5.2.1a, site 5), while potato seed tubers are also produced in several other areas as shown in Fig. 5.2.1a, such as Tafí del Valle (1), Las Estancias (2), Malargüe (3) and Pampa de los Gigantes (4).

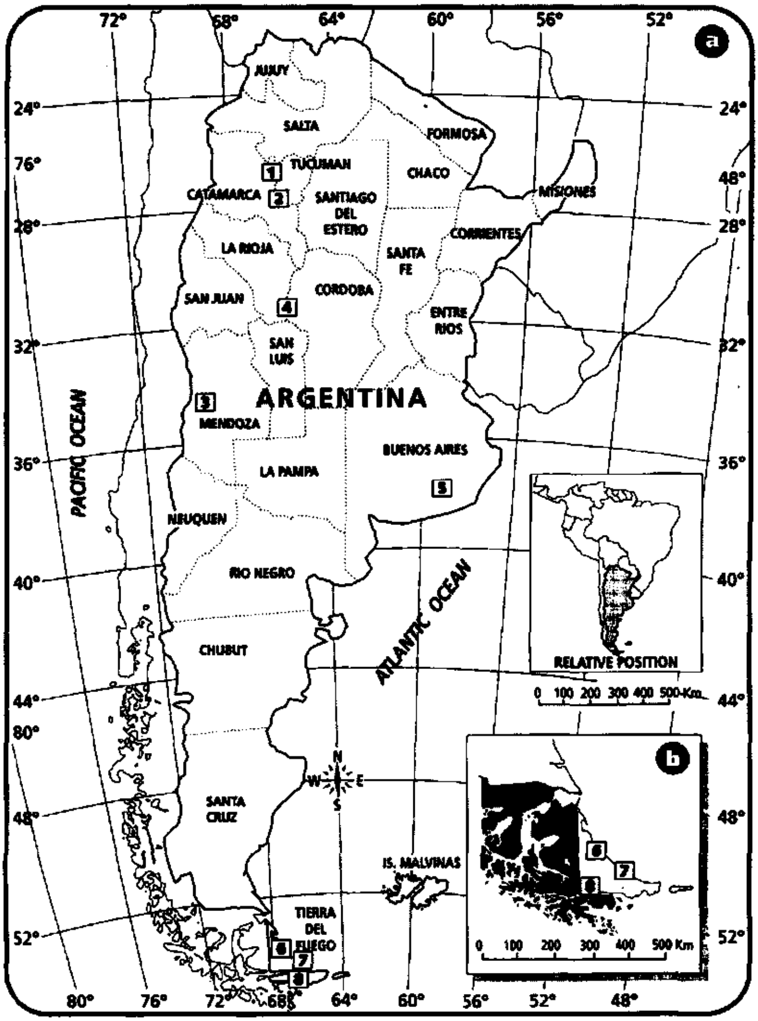

Figure 5.2.1. Seed potato production zones in Argentina (a) and areas studied in Tierra del Fuego Island (b). References: (1) Tafí del Valle, Tucumán; (2) Las Estancias, Catamarca; (3) Malargue, Mendoza; (4) Pampa de los Gigantes, Córdoba; (5) Southeast of Buenos Aires Province. In Tierra del Fuego: (6) Río Grande; (7) San Pablo and (8) Ushuaia.

Certain fields in these areas have particular problems, such as soil erosion (Orell, 1990) and presence of *Nacobbus aberrans* in Tafí del Valle (Costilla et al., 1978); presence of *Meloidogyne* spp. (Chaves, 1989) and aphids in the southeast of Buenos Aires; high levels of potato virus Y (PVY^N) in Malargüe (Ferreyra, 1990; J. Ortego, personal communication, 1995) and difficult accessibility at Las Estancias (A. Santángelo, personal communication, 1989), which could also be an advantage regarding isolation.

In all these areas, seed is produced during October-March (spring-summer period in the southern hemisphere), either on the mountains or in coastal areas (Haverkort & Caldiz, 1994) and is delivered to be planted in the ware potato areas in February-March (late), May-June (early), July-August (medium-early) and October-November (medium-late) crops, respectively. The combination of seed origin, environmental conditions and planting time makes that in many cases the seed is too young or too old to achieve high yields. Detailed information about seed and ware potato in Argentina can be found in Caldiz & Struik (1999). This situation requires the identification of new appropiate growing areas to preserve the self sufficiency in the production of basic seed and to improve yields of ware crops.

Tierra del Fuego is an island located in the most southern part of Argentina (52° 30' to 55' SL) and has only very limited means of access. This limited access can contribute to an efficient control of seed flows. Following introductions from Europe or Chile, potatoes have been multiplied on the island for more than 30 years, in small family plots without being seriously infected with virus diseases. A report from Huarte & Butzonich (1984) recognized the potential of the island for seed and ware production, but since then no attempts were made to develop a project for that purpose. Several factors, however, may determine, limit or reduce tuber yield there, such as long days during crop growth delaying tuber initiation, the occurrence of late and early frosts and the constant presence of strong winds in the northern part of the island.

In order to test the importance of these factors a series of field trials was carried out at three locations of the island during 1991-94. Trials included four cultivars, records of nematode presence, aphid population, incidence of virus diseases and assessments of tuber yield and physiological age of the seed produced. It is also proposed to consider this work as a case study to be applied for similar situations elsewhere in the world.

5.2.2. Materials and methods

Agro-ecological conditions in Tierra del Fuego Island

Tierra del Fuego Island has a characteristic oceanic cold climate and the temperature is controlled by cold oceanic currents and the ice masses from Antarctica. Mean temperatures of the coldest month are 0 to -2 °C whereas the mean temperatures for the warmest month are 8-10 °C. Occidental winds are predominant and rainfall ranges from 300 mm in the northern part of the island to more than 1000 mm in the area of Cordillera de los Andes, running from northwest to southeast. The experiments were carried out at three different locations during the summer season of 1991/92, 1992/93 and 1993/94. These three locations, Río Grande (6), Cabo San Pablo (7) and Ushuaia (8) have different agro-ecological conditions (Figure 5.2.1b).

Río Grande. This location (referred to as RG), belongs to the Magallanic Steppe. It is an arid area with rainfall between 200-400 mm and strong occidental winds. The soils are Pachic crioborolls with loam texture, 4-6% organic matter and low pH (Soil Survey Staff, 1992).

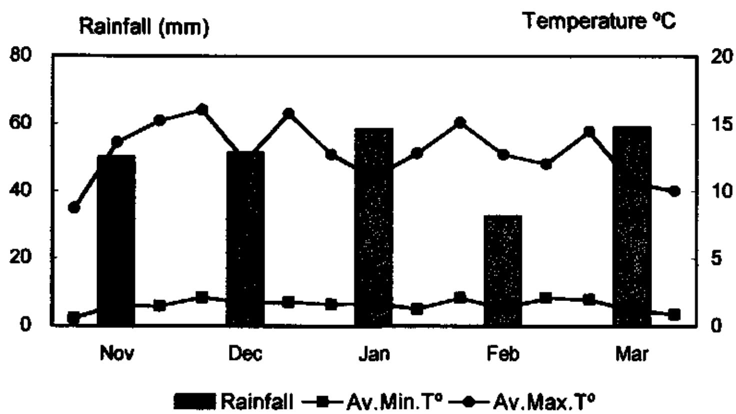

Figure 5.2.2. Meteorological data for Ushuaia 1992/93.

Cabo San Pablo and Ushuaia. Both locations belong to the Magallanic Deciduous Forest. This natural formation occupies the central and eastern part of the island and can be divided into two sub-areas. The northern part occupies the northwest of Cordillera de los Andes, with prevalence of the native tree *Nothofagus antarctica*, that spreads towards the steppe, in a natural park. Soils are Typic crioborolls, loamy, with up to 12% organic matter (Soil Survey Staff, 1992). *Estancia Inés*, in Cabo San Pablo Cape belongs to this environment (San Pablo, SP). The other sub-area is a typical forestry area, well represented in *Estancia Río Pipo*, Ushuaia (USH). Soils are Typic criumbrepts with high clay content (Soil Survey Staff, 1992). As an indication for the climate of the region data from Ushuaia 1992/93 are shown (Figure 5.2.2).

Experiments in Río Grande and Ushuaia, 1991/92. Certified seed tubers produced during the season 1990/91 in the Balcarce area (Figure 5.2.1a, site 5) of the medium early cultivars Achatt, Mailén INTA, Pampeana INTA and Spunta were pre-sprouted in diffuse light for one month before planting, at a temperature of 20-25 °C in a laboratory and at 10-15 °C in a farm barn, for Ushuaia and Río Grande trials, respectively, in order to obtain 2-4 short (<20 mm) sprouts per tuber. Planting was done by hand on November 16 (Ushuaia) and 18 (Río Grande), 1991. Rows were 0.70 m apart and plant distance within the row was 0.30 m. Plot size was 2.8 x 12 m and experiments were laid down in a complete randomized block design with four replicates.

Experiments in Río Grande, San Pablo and Ushuaia in 1992/93. In this season the material produced in the island during 1991/92 was used. These tubers were stored at 2 °C in Ushuaia till one month before planting. Planting was carried out at three sites, Río Grande, San Pablo and Ushuaia with tubers pre-sprouted in diffuse light in farm barns at each of the three places, in similar plots to those used in 1991/92 with 6 rows. Seed lots were moved within the island to test possible cultivar x site interaction; henceforward, seed origin (year before or both years before) is shown within brackets after each cultivar name. The potatoes were planted at Río Grande, San Pablo and Ushuaia on November 2, 4 and 6, respectively.

Experiments in Río Grande, San Pablo and Ushuaia in 1993/94. Planting was carried out with pre-sprouted tubers in plots of 6 rows, 20 m long. The potatoes were planted at Río Grande, San Pablo and Ushuaia on October 27, 29 and November 1, respectively.

Crop management and assessments

Cultivation, ground cover and tuber yield. All experiments were carried out in different fields of the same farms without irrigation. N-P-K (18-46-0), 150 kg ha^{-1}, was applied each year. N dose was kept low to reduce haulm growth, already enhanced by the long days. Weeds were controlled mechanically and/or chemically with metribuzin (1 l ha^{-1}; pre and post-emergence) and with pirifenop (4 l ha^{-1}; post-emergence). No other chemicals were applied. Between 45 and 50 days after planting the ridges were earthened up. Ground cover (GC) of the crop was regularly measured following the procedure proposed by Centro Internacional de la Papa (1986). These measurements were used to calculate ground cover duration (GCD) by applying the formula proposed by Watson (1952) for leaf area duration, as presented in Hunt (1982):

$$GCD_{1\text{-}2} = (GC_1 + GC_2)\,(T_2\text{-}T_1)\,/\,2$$

where: GC is ground cover and T time. GCD provides an estimate of the fraction of the incident radiation intercepted by the canopy (Burstall & Harris, 1983).

Roguing was carried out twice during crop growth in each trial to eliminate virus infected plants. The two central rows of each plot were harvested to determine tuber yield and values were converted into t ha^{-1}. In each year harvests were carried out in late March and tubers were stored in underground structures or in a wooden barn till the following planting season. For each location and year, an analysis of variance was carried out and means were separated by Tukey's test ($P < 0.05$).

Nematodes and virus detection. One month before planting, soil samples (2-3 kg, 40 subsamples each) were taken in each year and for each field trial and location to determine the presence of nematodes. Samples were analyzed by two different government approved laboratories. Each sample was analyzed for the presence of filiform and globe-shaped nematodes following the flotation-centrifugation technique and the Fenwick technique modified by Oostenbrink (1960) as described by Doucet (1980).

After each harvest a sample of 100 tubers per cultivar and location was sent to the laboratories already mentioned in 1991/92 and 1993/94 and to the Institute of Plant Physiology and Pathology from Instituto Nacional de Tecnología Agropecuaria at Córdoba (1992/93) to determine the presence of PVY and PLRV in seed tubers by the ELISA test.

Aphid population. To study aphid population in each field trial, for each location and year, a Moericke trap (Hille Ris Lambers, 1980) was set up in the middle of each field. Due to the low temperature the material in the traps was kept in good condition for two weeks, which allowed to check the traps with that frequency instead of every 3-7 days, as recommended normally. In the field, the trap content was filtered, collected and kept in alcohol 80% for identification. Aphid species were identified by the laboratories mentioned earlier and INTA Malargüe. In the respective figures only the population of *Myzus persicae* Sulzer is shown, while other aphids not frequently found in the traps are mentioned in the text.

Assessment of physiological age. After harvest of the 1992/93 and 1993/94 crops, the physiological age of the seed tubers at that time was measured. The length of the incubation period, time elapsed from sprouting till new tuber formation on the sprouts, was used as an indicator of physiological age (Claver, 1953). When using this value it must be noticed that a longer incubation period means a physiologically younger seed tuber. The incubation period was measured in a dark growth room at 17 ± 1 °C and 90% relative humidity, following procedures described by Caldiz (1991). After harvest, a sample of 40 tubers was put in trays of

0.25 x 0.50 x 0.10 m filled with vermiculite, under the conditions already mentioned. A randomized design with four replications of 10 tubers for each cultivar and origin was used. An analysis of variance was carried out and means were separated by Tukey's test ($P < 0.05$).

5.2.3. Results and discussion

Ground cover, ground cover duration and tuber yield. Due to the use of pre-sprouted seed tubers, crop emergence was always good, 95-98%, for all cultivars, years and locations. Pre-sprouted seed promotes early growth of roots and sprouts, enhancing crop establishment (Headford, 1962); pre-sprouting is an important management factor because of the short growing season available. In some cases, Spunta lots of different origins differed in initial development, probably due to differences in physiological age at planting. These differences also affected early GC and tuber yield (Figure 5.2.3 and Table 5.2.1).

In 1991/92, GC was higher in Spunta than in other cultivars, either grown in Río Grande or Ushuaia (Figures 5.2.3a and b). No differences were found between other cultivars; only for Río Grande, Pampeana reached, on 75 days after planting, the GC of Spunta (Figure 5.2.3a). In Ushuaia early frosts in mid January killed the foliage.

In 1992/93 for Río Grande and Ushuaia, Pampeana had a higher GC than Mailén and Spunta or Mailén, respectively (Figures 5.2.3c and e). In San Pablo, both Spunta (RG) and Spunta (USH) had a higher GC than Achatt (USH), that only reached 40% of ground cover (Figure 5.2.3d). In this season frosts were delayed until the end of February resulting in a long growing season at all locations (Figures 5.2.3c and d).

In 1993/94 for Rio Grande, the maximum GC was 42, 37 and 30% for Mailén (RG, RG), Pampeana (RG, RG) and Spunta (RG, RG) (data not shown). For San Pablo maximum values were 42 and 30% for Pampeana (RG, RG) and Pampeana (USH, USH), 33 and 27% for Mailén (RG, RG) and Mailén (USH, USH) and 32% for Spunta (RG, SP), respectively. In Ushuaia (Figure 5.2.3f) an important difference in GC occurred between Spunta (RG, RG) and Spunta (USH, SP) that could be responsible for the considerable differences in tuber yield between these seed lots (Table 5.2.1).

In potatoes, as in other crops, the production of dry matter under different environments is determined by the amount of intercepted radiation (Allen & Scott, 1980; Haverkort & Harris, 1986; Manrique et al., 1991). On the island, radiation during crop growing ranges between 13.56-18.00 MJ m^{-2} at mid day, but these low values are partially compensated for by the long days, more than 18 hours of light during summer.

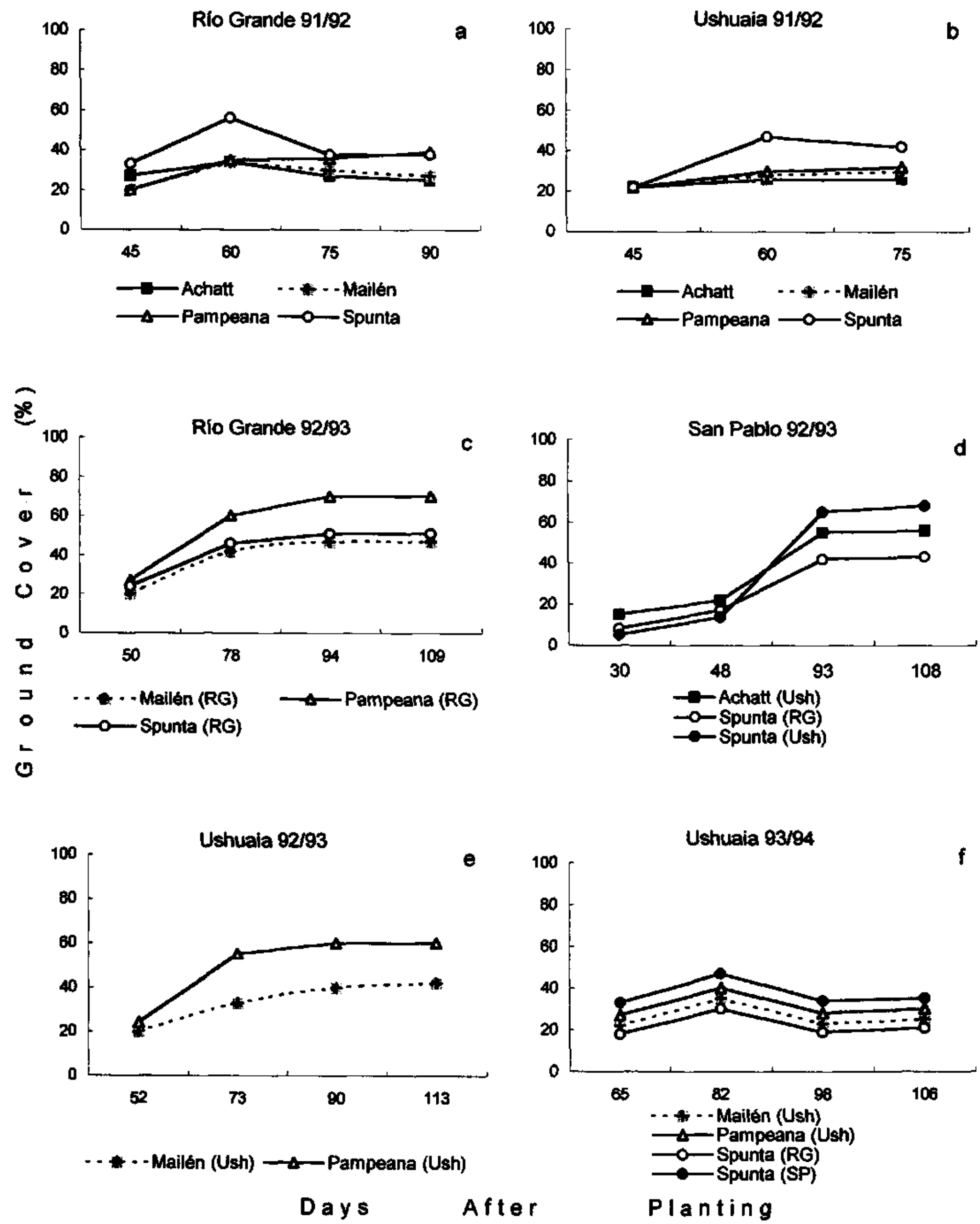

Figure 5.2.3. Ground cover for all years, sites and cultivars.

Within brackets the production site in the previous year is shown. In Figure 5.2.3f the origins are: Mailén (USH USH); Pampeana (USH USH); Spunta (RG RG) and Spunta (USH SP).

GCD differed between cultivars and years (Figure 5.2.4). GCD values were lower than those obtained for the same cultivars under temperate conditions (D.O. Caldiz & L.V. Fernández, unpublished). Low GCD values were due to low temperatures and early frosts that reduced and shortened leaf growth, respectively. However, tuber yield was closely related to GCD (R^2= 0.74, Figure 5.2.4). Tuber yield during 1991/92 was the lowest one (Table 5.2.1), mainly due to the early frosts in February which abruptly interrupted foliage growth, reducing GC, GCD and shortened tuber growth period by 25 or 35 days for Ushuaia and Rio Grande, respectively (Figures 5.2.3a and b and 5.2.4).

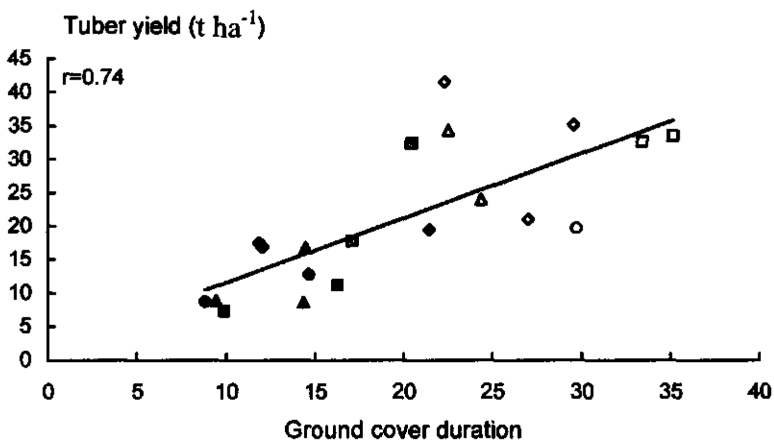

Figure 5.2.4. Relationship between GCD and tuber yield for different cultivars and seasons in the period 1991-1994.

References: (● O) Achatt (only 1991/92 and 1992/93), (▲ Δ Δ) Mailén, (■ ▢ ▢)Pampeana and (◆ ◆ ◆) Spunta, for 1991/92, 1992/93 and 1993/94, respectively.

For the 1991/92 season at both sites, Spunta gave the highest yields, 17.6 and 19.5 t ha^{-1} for Ushuaia and Río Grande, respectively; whereas the other cultivars showed no differences. Tuber yields were much higher in the 1992/93 season, mainly due to higher temperatures, both in Ushuaia and Río Grande which allowed a greater GCD (Figure 5.2.2).

Table 5.2.1. Tuber yield of different cultivars in each year and site in Tierra del Fuego Island, 1991-1994.

1991/92	Tuber yield ($t\,ha^{-1}$)	1992/93	Tuber yield ($t\,ha^{-1}$)	1993/94	Tuber yield ($t\,ha^{-1}$)
Río Grande		*Río Grande*		*Río Grande*	
Achatt	12.77 b	Mailén (RG)	24.00 b	Mailén (RG, RG)	40.21 a
Mailén	8.60 b	Pampeana (RG)	33.42 a	Pampeana (RG, RG)	29.23 b
Pampeana	11.19 b	Spunta (RG)	21.00 b	Spunta (RG, RG)	19.67 c
Spunta	19.49a				
Ushuaia		*Ushuaia*		*Ushuaia*	
Achatt	8.71 b	Mailén (USH)	34.28 a	Mailén (USH)	16.80 b
Mailén	8.84 b	Pampeana (USH)	32.57 a	Pampeana (USH, USH)	17.79 b
Pampeana	7.35 b			Spunta (RG, RG)	16.95 b
Spunta	17.56a			Spunta (USH, SP)	32.40 a
		San Pablo		*San Pablo*	
		Achatt (USH)	19.71 c	Mailén (RG, RG)	22.80 b
		Spunta (RG)	41.57 a	Mailén (USH, USH)	15.42 c
		Spunta (USH)	35.14 b	Pampeana (RG, RG)	23.60 b
				Pampeana (USH, USH)	17.10 c
				Spunta (RG, SP)	36.00 a

Means followed by the same letter within each year and site do not differ significantly ($P < 0.05$). Between brackets the origin of the seed in the previous crop (RG): Río Grande; (SP): San Pablo, and (USH): Ushuaia.

Moreover the early planting, 15-20 days earlier than in 1991/92 season, contributed to an early GC. In Río Grande, tuber yield was higher in Pampeana (RG) than in the other cultivars, whereas no differences were found between Mailén (RG) and Spunta (RG). In this last case, the crop was severely affected by strong winds. In San Pablo, Spunta (RG) produced the highest yields, with differences between origins, probably due to the different physiological stage of the seed tubers. Tuber yield in Achatt (USH) was significantly lower than Spunta. In Ushuaia, no differences were observed between cultivars (Table 5.2.1).

Due to the low yields of Achatt in 1991/92 and 1992/93 this cultivar was not planted in the following crop. In 1993/94 for Río Grande, tuber yield was significantly higher in Mailén (RG, RG) followed by Pampeana (RG, RG) and Spunta (RG, RG). As already mentioned for other cases, the GC of the cultivars was an important physiological yield determinant. A similar situation was found in San Pablo, but in this site yields were higher in Spunta (RG, SP), and origin differences were registered between Mailén (RG, RG), Pampeana (RG, RG) and Mailén (USH, USH), Pampeana (USH, USH), respectively. In Ushuaia, no differences were observed between Mailén (USH, USH) and Pampeana (USH, USH) cultivars, while for Spunta (RG, RG) and (USH, SP), important differences between origins were observed which could be attributed to differences in physiological age, due to the different storages systems used for each seed origin, and differences in GCD (Figure 5.2.4).

Nematodes. The soil samples analyzed each year for each site showed no plant pathogenic nematodes. Although the environment and soils where the trials were conducted are representative for those in different areas of the island, it is recommended to take soil samples to detect the presence of nematodes before a new crop is planted.

Aphid population and virus diseases. Aphids play a key role in the epidemics of PVY and PLRV, because aphid transmission is the only relevant way of virus dissemination from plant to plant in the field (Beemster & de Bokx, 1987). In Figure 5.2.5 *Myzus persicae* population for each site and season is presented. The highest number of aphids per trap, 8 and 16, were registered 110 and 91 days after planting in Río Grande 1991/92 and Ushuaia 1993/94, respectively (Figures 5.2.5a and c). In 1992/93 the lowest aphid population for each site was registered and in San Pablo a single aphid was counted late in the season, 140 days after planting when the foliage was already killed by frosts (Figure 5.2.3d). In 1993/94 the highest aphid population was registered for Ushuaia, with more than 5 aphids per trap on five occasions. In Río Grande and San Pablo the population was very low. These values are lower than those recently reported for Tafí del Valle (Figure 5.2.1a, site 1), a seed potato producing region in the Aconquija mountains at 2220 m above sea level. Zamudio et al. (1996) reported for the Tafí region in the growing period September-March 1991/92-1995/96 a minimum and maximum counting of *M. persicae* of 10 (November, 1993) and 130 (February 1995), respectively, with an average value of more than 30 aphids $month^{-1}$.

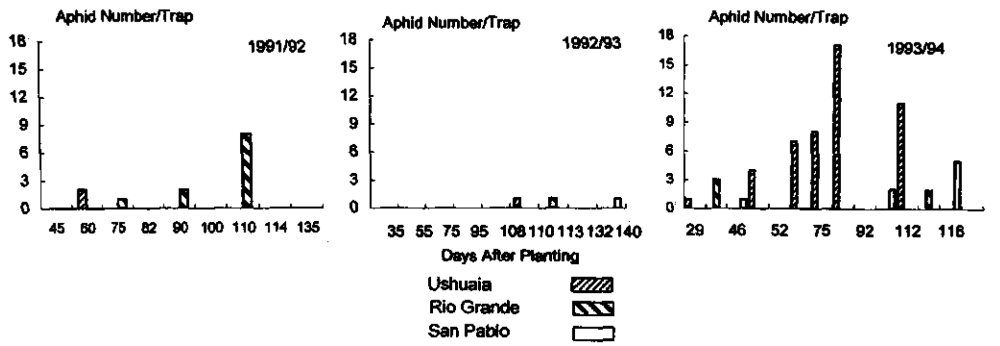

Figure 5.2.5. *Myzus persicae* population dynamics for all years and sites.

Aphid species found during these trials were *Brachycaudus helichrysi, B. rumexicolens, Cavariella aegopdii, Lipaphis erysimi, Macrosiphum euphorbiae, Myzus persicae, Pemphigus sp.* and *Rhopalosiphum ninphae*. From these only *B. rumexicolens* and *R. ninphae* are not clearly involved in potato virus transmission (J. Ortego, personal communication, 1994). *M. persicae* was the most abundant among these species. Like in some seed growing upland districts of Scotland and Wales (Ministry of Agriculture, Fisheries and Food, 1979), the growing season in Tierra del Fuego is too cool and windy for rapid multiplication of aphids or aphid movement, reducing virus transmission to a minimum. This is confirmed by the post-harvest tuber tests on the presence of PVY and PLRV, two of the most common virus diseases transmitted by aphids (Table 5.2.2). Starting with certified seed produced in the traditional seed growing area of the country showed an initial high value of PVY^N in Mailén for Ushuaia and Río Grande, of 11 and 6%, respectively, whereas a 5% PVY^N was registered for Spunta, in Río Grande, after the 1991/92 growing season. Due to roguing carried out in each year in the 1992/93 season these values were reduced to 0%. For the season 1993/94 the values for PVY and PLRV range from 0-1% (Table 5.2.2).

Table 5.2.2. PVY and PLRV percentage for different cultivars for each year and site in Tierra del Fuego Island, 1991- 1994.

1991/92	Virus %	1992/93	Virus %	1993/94	Virus %
Río Grande		*Río Grande*		*Río Grande*	
Achatt	0	Mailén (RG)	0	Mailén (RG, RG)	1 PLRV
Mailén	6 PVY	Pampeana (RG)	0	Pampeana (RG, RG)	0
Pampeana	0	Spunta (RG)	0	Spunta (RG, RG)	0
Spunta	5 PVY				
Ushuaia		*Ushuaia*		*Ushuaia*	
Achatt	0	Mailén (USH)	0	Mailén (USH)	0
Mailén	13[a]	Pampeana (USH)	0	Pampeana (USH, USH)	0
Pampeana	0			Spunta (RG, RG)	1 PVY
Spunta	0			Spunta (USH, SP)	0
		San Pablo		*San Pablo*	
		Achatt (USH)	0	Mailén (RG, RG)	0
		Spunta (RG)	0	Mailén (USH, USH)	0
		Spunta (USH)	0	Pampeana (RG, RG)	1 PLRV
				Pampeana (USH, USH)	0
				Spunta (RG, SP)	0

The virus type, PVY or PLRV, is indicated after each figure. (a), 11% PVY and 2% PLRV

Table 5.2.3. Physiological age of seed tubers, measured by the length of the incubation period, immediately after harvest for different years and sites in Tierra del Fuego Island, 1991-1994.

1992/93	Incubation period (in days)	1993/94	Incubation period (in days)
Río Grande		*Río Grande*	
Mailén (RG)	113 a	Mailén (RG, RG)	112 a
Pampeana (RG)	121 a	Pampeana (RG, RG)	90 b
Spunta (RG)	120 a	Spunta (RG, RG)	115 a
Ushuaia		*Ushuaia*	
Mailén (USH)	106 a	Mailén (USH, USH)	110 a
Pampeana (USH)	115 a	Pampeana (USH, USH)	93 b
		Spunta (RG, RG)	115 a
		Spunta (USH, SP)	116 a
San Pablo		*San Pablo*	
Spunta (RG)	114 a	Mailén (RG, RG)	116 a
Spunta (USH)	122 a	Mailén (USH, USH)	118 a
		Pampeana (RG, RG)	88 b
		Pampeana (USH, USH)	75 c
		Spunta (RG, SP)	116 a

Means followed by the same letter, within each year, do not differ significantly ($P < 0.05$)

Windy and cold weather resulted in low aphid populations and in addition to meteorological effects on aphid flights, these regions tend to have low aphid abundances, presumably because they are avoided by winged migrants (Nemecek, 1993). These results showed that the island has a low degeneration rate and may allow the multiplication of basic seed for several generations without increasing virus incidence.

Physiological age of the seed tubers. After the 1992/93 growing season no large differences in physiological age at harvest were registered between cultivars and sites. As the physiological age was measured only to test the effect of the previous growing conditions, however, and not the effect of storage conditions it is possible that differences in physiological age at planting are responsible for the differences in early GC and tuber yield between Spunta (RG, RG) and Spunta (USH, SP) grown in Ushuaia in 1993/94.

Contrary to 1992/93 in 1993/94 some differences between cultivars and sites were registered. All Pampeana lots had an advanced physiological age when compared with Mailén or Spunta from different origins (Table 5.2.3). The cause of this difference is not clear. Nevertheless, when the physiological age of Spunta seed tubers grown at Tierra del Fuego Island was compared with that from other origins, it resulted in younger seed in two out of three cases, than of seed tubers grown in the southeast of the Buenos Aires Province (Caldiz & Fernández, 1995).

Moreover, when these values were compared with average values of several years from Spunta seed tubers produced in the southeast region (Caldiz, 1994) the tubers produced in the island were physiologically younger (Table 5.2.3). This can be an advantage for use of these tubers in other regions with long growing seasons, to increase the yield potential of the crop.

Seed yields, on average for the three seasons, and for each cultivar, were acceptable [20.1 and 37.6 t ha^{-1}, for Pampeana (USH) and Spunta (SP), respectively], and, as shown, the seed was very healthy, concerning not only virus but also fungal and bacterial diseases. Such conditions, that allow seed multiplication for several generations without enhancing virus transmission make the island a kind of *safe heaven*, suitable for, either, basic seed multiplication or breeding programmes to carry out initial multiplications of new cultivars. In other areas such as the southeast of the Buenos Aires province an average of 5-15% PVY has been found in the basic seed (M. Panelo, personal communication, 1998), while data for Malargüe showed that with an initial level of 5% PVY^N reached 30% after two aphid flights (Ortego, 1995).

Hence, the development of the island as a seed production area will contribute to maintain the self-sufficiency policy started in the country in 1984/85. The local and national authorities should establish strict regulations to preserve this unique situation and should financially support local farmers to improve crop management and technology to increase seed yield.

Moreover, based on the results presented in this paper it is concluded that this is an interesting case study which can be relevant to follow when the potential for seed potato production elsewhere in the world must be analyzed.

SECTION 6

GENERAL DISCUSSION

6. GENERAL DISCUSSION

This study shows how a complex potato production system, with several growing seasons in contrasting agro-ecological zones, can be analyzed by means of the combined used of a field survey, GIS and simulation models. This approach and the resulting yield gap analysis allow for the identification of the main yield defining, yield limiting and yield reducing factors. In a final stage, and based on the information obtained from these previous steps, it is possible to develop specific strategies to counteract the effects of those yield defining, yield limiting or yield reducing factors. Figure 6.1 summarizes the framework and the information flows therein.

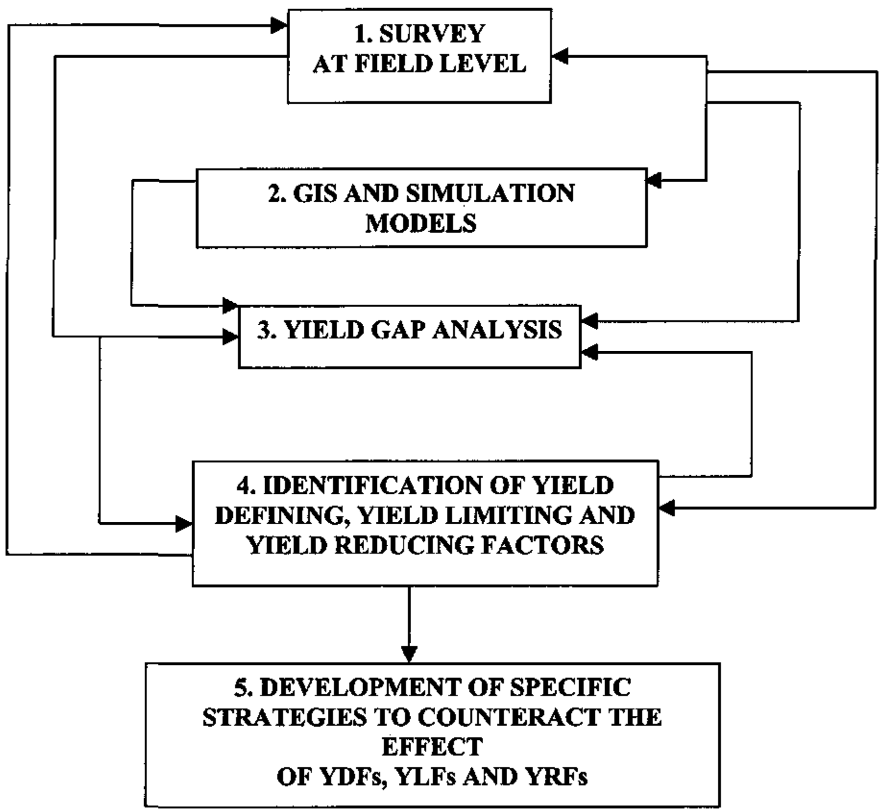

Figure 6.1. Framework and information flow for the analysis of a complex cropping system.

6.1. Survey at field level

The survey (Figure 6.1, Box 1) carried out in this thesis clearly shows the complexity of the Argentinian potato production system (Chapter 2.1). Each of the seed, ware or processing areas has different yield determining, yield limiting and yield reducing factors. Weather and soil vary between and within growing areas and also technology level is variable. This made a complete survey necessary (Chapter 2.1). This survey showed that the area croppped with potatoes has stabilized at 100,000 ha while tuber yields per unit area, for the whole country, are still increasing, due to the use of better seed, new cultivars, and higher input levels (Escarrá, 1989; Caldiz & Beltrano, 1992; Huarte, 1996). The results of this survey, on area, crop type, crop yield and identification of the main yield determining, yield limiting and yield reducing factors are used later to perform a yield gap analysis (Figure 6.1, box 3).

6.2. Geographic Information Systems (GIS) and simulation models

The results of the agro-ecological zoning study and of the estimations of the potential yield of the crop (Figure 6.1, Box 2) suggest it is still possible to:

(a) substantially increase the area cropped with potatoes since there are still favourable environments and suitable soils not used, even in the main potato growing area of the southeast of the province of Buenos Aires (Chapters 2.2 and 2.3), and

(b) achieve further improvements in tuber yield, because the yield gap analysis performed for all different production zones showed that actual yields are still far below attainable and potential yield (Chapter 3.2).

Yield predictions at regional levels were possible with the SUBSTOR-POTATO. It showed good agreements with observed values provided a genetic coefficient for the duration of tuber bulking is included in the model for Argentinian conditions (Section 3, Chapter 3.1). This yield prediction and the use of satellite images (M.I. Travasso, personal communication, 2000) could also greatly contribute to estimate cropped area and production and would provide the information that can help to regulate market prize that differ up to 34% (country average) within the same year (Inchausti, 1989). Moreover, the results of the potential yield study at the national and the regional level are used for the yield gap analysis (Figure 6.1, Box 3) and in the future this information will flow to update the survey data (Figure 6.1, Box 1).

6.3. Yield Gap Analysis

Based on the results of the survey at field level (Figure 6.1, Box 1) on those of the agro-ecological zoning and potential yield estimations (Figure 6.1, Box 2) a yield gap analysis is carried out (Figure 6.1, Box 3). The results of this analysis show, for example, that the ratio actual:potential yield is still low in certain areas, like those in the north (Tucumán) where the early crop is grown, or in new developing zones in the Argentinian patagonia, such as Río Negro (Caldiz & Gaspari, 2000a). This analysis, performed on five different agro-ecological zones, also allows further identification of different yield determining, yield limiting and yield reducing factors for each zone (Figure 6.1, Box 4).

6.4. Identification of yield defining, yield limiting an yield reducing factors

In this thesis several yield defining, yield limiting and yield reducing factors are identified (Figure 6.1, Box 4 and Chapters 2.1, 2.2, 2.3 and 3.2). Further yield improvements are possible by taking the specific and adequate counteracting measures in each case. One of the main yield limiting factors that repeatedly was identified for different zones and seasons is the physiological age of seed tubers. For the particular case of Argentina its effects are very important because seed tubers produced in various areas are planted in different zones of the same country (Caldiz et al., 1998a) even in double cropping systems with different age requirements (Caldiz & Haverkort, 1994). Although several indicators of the physiological age exist (Chapter 4.1), their relationship with tuber yield of the following crop is not always clear (van der Zaag & van Loon, 1987). In order to partially solve this problem a physiological age index (PAI) was developed in this thesis. The PAI reconciles chronological and physiological age, can identify and quantify differences in physiological age due to seed origin, haulm killing date, storage conditions and pre-planting treatments, and allows comparisons between cultivars, crop and storage management and pre-planting conditions. However, a disadvantage of the PAI is the long time needed to obtain the final result which limits its predictive value for future plantings and for grower's use (Chapter 4.1). Nevertheless, the PAI was very useful to explain the effect of seed ageing on the proportion of the potential yield achieved by early, medium-early and medium-late crops planted in one calendar year. Based on these results new seed flows are proposed (Chapter 4.2). These new flows would contribute to improve the physiological status of the seed, mainly of that used in the late ware crop, provided the phytosanitary status of the seed crops is taken into account.

Virus diseases were also identified as a main seed quality and yield reducing factor for different seed and ware areas (Chapters 2.1 and 3.2). In the future, seed quality requirements will probably increase due to the tendency of increasing crop production by increasing tuber yield while the area is maintained. Hence, seed areas should increase their management and control practices in order to maintain high quality of seed and in this regard the control of virus diseases play a crucial role.

Based on the identification of these yield limiting and yield reducing factors the next step in the information flow presented in Figure 6.1 is that related to the development of specific strategies to counteract the effect of different yield defining, yield limiting and yield reducing factors (Figure 6.1, Box 5).

6.5. Development of specific strategies to improve seed quality and yield

Although several yield defining, yield limiting and yield reducing factors were identified by means of the survey, the agro-ecological zoning and the yield gap analysis (Figure 6.1, Box 1, 2 and 3 and information flow to Box 4) performed in this thesis, studies to develop possible strategies to increase yield by reducing the gap between actual:potential yield focussed on overcoming physiological age effects and developing an isolated area for seed production (Figure 6.1, Box 5; Chapters 4.1, 5.1 and 5.2). Results of Section 4 showed that in order to obain seed with a suitable physiological age index for different seasons and purposes, it is necessary to improve crop management, regarding planting time, haulm killing dates, shortening the period between haulm killing and harvest, and shortening the period between harvest and start of storage period. Some of these strategies have been successfully developed during the last three years with a Research and Development project grant by the government and various private companies (Caldiz, 2000). Results of Chapter 5.1 showed that when all other crop factors are well managed the use of plant growth regulators, mainly benzyl aminopurine, could be an interesting strategy to make use of physiologically old seed for long growing seasons. This practice could be of help for ware growers that do not have access to modern storage facilities, a normal situation in Argentina.

At the same time, the development of new isolated areas could be part of a risk-avoiding strategy for the system, in case a disease or pest appeared in the actual areas. In this regard, Tierra del Fuego Island fulfils several requirements to be a seed area: it is isolated, free from aphids during the available growing period, free from pests and diseases and (due to the cold weather) seed produced is very young (Chapter 5.2). In the north part of the island more than 5000 ha of suitable soils could be used for this purpose. This particular island, and of course other isolated places, should be preserved and seed crops must be developed from clean basic seed.

Final Remarks

The progress in potato production in Argentina could be so significant that, if proper political, financial, technological and marketing decisions are taken, Argentina could play an important strategic role in the world potato market in the future. The potential for such a role is present due to suitable soils and environments, the high technological know-how and the scientific support to increase the cropped area and crop yields.

This study may contribute not only to improve potato production in Argentina but may also serve as an example for analysis of different cropping systems in regions with contrasting agro-ecological zones.

REFERENCES

Allen, E.J. & R.K. Scott, 1980. An analysis of growth of the potato crop. *Journal of Agricultural Science, Cambridge* 94: 583-606.

Anonymous, 1954. *La papa en el sudeste de la provincia de Buenos Aires.* Cámara de Productores y Acopiadores de Papa. Balcarce, Argentina, 144 pp.

Anonymous, 1989. Principales regiones productoras de papa de la República Argentina. *Guipap 1989.* Enfoques del Sudeste, Mar del Plata: pp. 21-32.

Anonymous, 1998. La necesidad de exportar a Brasil semilla de papa de calidad superior. *Noticias CyT, Boletín de la Secretaria de Ciencia y Tecnología* Año 2: 6-10.

Apelbaum, A., 1984. Polyamines as possible indicators of physiological age. *Potato Research* 27: 309.

Beemster, A.B.R. & J.A. de Bokx, 1987. Survey of properties and symptoms. In: J.A. de Bokx & J.P.H. van der Want, Eds. *Viruses of potatoes and seed-potato production, 2nd ed.* Pudoc, Wageningen, pp. 84-116.

Beltrano, J. & D.O. Caldiz, 1993. Effects of Johnsongrass densities on potato yield. *Pesquisa Agropecuaria Brasileira* 28: 21-24.

Beukema, H.P. & D.E. van der Zaag, 1990. *Introduction to potato production.* Pudoc, Wageningen, 208 pp.

Bhatia S.K. & R.J. Young, 1985. Reaction of potato tuber slices to *Phytophthora infestans* in relation to physiological age. *American Potato Journal* 62: 471-478.

Biotto, C. & P.A. Siegenthaler, 1991. Study of physiological states of seed potato tubers during their storage. Correlations between morphological and biochemical parameters. *Réunion de la Section Physiologie EAPR*, Le Conquet, France, pp. 39-40.

Black, J.N., C.W. Bonython & G.A. Prescott, 1954. Solar radiation and the duration of sunshine. *Quarterly Journal of the Royal Meteorological Society* 80: 231-235.

Bodlaender, K.B.A., 1973. Influence of temperature during growth of seed tubers on their seed value. *Abstracts of Conference Papers 5th Triennial Conference EAPR*, Norwich, UK, pp. 151.

Bodlaender, K.B.A. & J. Marinus, 1987. Effect of physiological age on growth vigour of seed potatoes of two cultivars. 3. Effect on plant growth under controlled conditions. *Potato Research* 30: 423-440.

Bodlaender, K.B.A. & M. van de Waart, 1989. Influence of gibberellic acid (GA_3) applied to the crop on growth, yield and tuber size distribution of seed potatoes. *Netherlands Journal of Agricultural Science* 37: 185-196

Bodlaender, K.B.A., H.M. Dekhuijzen, J. Marinus, A. van Es, K.J. Hartmans, L.J.P. Kupers, C.D. van Loon & D.E. van der Zaag, 1987. *Effect of physiological age on growth vigour of seed potatoes. A study with seed tubers of two cultivars stored at two different temperatures.* Instituut voor Bewaring en Verwerking van Landbouwprodukten (IBVL), Rapport 555, Wageningen, The Netherlands, 142 pp.

Bouma, J., 1998. Introduction. In: J.J. Stoorvogel, J. Bouma & W.T. Bowen, Eds. *Information Technology as a Tool to Assess Land Use Options in Space and Time. Quantitative Approaches in Systems Analysis N° 16*, AB-DLO and The C.T. de Wit Graduate School for Production Ecology, Wageningen, pp. 1-11.

Bruinsma, J., 1982. Plant Growth Regulators in Field Crops. In: J.S. McLaren, Ed. *Chemical Manipulation of Crop Growth and Development.* Butterworths, London, pp. 3-11.

Burstal, L. & P.M. Harris, 1983. The estimation of percentage light interception from leaf area index and percentage ground cover in potatoes. *Journal of Agricultural Science, Cambridge* 100: 241-244.

Bus, C.B. & A. Schepers, 1978. Influence of pre-treatment and physiological age of seed on growth and yield of potatoes cv. Bintje. *Abstracts of Conference Papers, 7th Triennial Conference EAPR*, Warsaw, Poland, pp. 16-17.

Caldiz, D.O., 1983. Seed potato production in Argentina. *Proceedings 6th Symposium International Society for Tropical Root Crops.* Lima, Perú, 1983, pp. 174.

Caldiz, D.O., 1989. *Fisiología de los tubérculos de papa semilla durante el cultivo y el almacenamiento.* Frigopap S.A., Balcarce, 23 pp.

Caldiz, D.O., 1991. Influence of crop origin and storage system on physiological age, crop growth and tuber yield of seed potato (*Solanum tuberosum* L.). *Indian Journal of Agricultural Sciences* 61: 1-6.

Caldiz, D.O., 1994. Genetic Improvement and Associated Physiological Changes in the Potato. In: G.A. Slafer, Ed. *Genetic Improvement of Field Crops.* Marcel Dekker, New York, pp. 361-411.

Caldiz, D.O., 1996a. Efectos del manejo del cultivo y el almacenamiento sobre la productividad de papa semilla en la Argentina. *Primer Seminario de Refrescamiento del International Potato Course para Alumnos de América Latina y el Caribe.* IAC-Holanda y MINAG-Cuba, La Habana, Cuba, 11 pp.

Caldiz, D.O., 1996b. Physiological basis for yield improvement in the next millenium. *Proceedings 2nd Asian Pacific Conference on Plant Physiology*, Kuala Lumpur, Malaysia. *Unpublished.*

Caldiz, D.O., 1996c. Seed potato (*Solanum tuberosum* L.) yield and tuber number increase after foliar applications of cytokinins and gibberellic acid under field and glasshouse conditions. *Plant Growth Regulation* 20: 185-188.

Caldiz, D.O., 2000. *Análisis del sistema de producción de papa y desarrollo de estrategias de cultivo y almacenamiento para lograr aumentos en el rendimiento y la calidad en la Argentina.* Proyecto de Investigación y Desarrollo, PID 665, 1997-2000. Agencia Nacional de Promoción Científica y Tecnológica, Fondo Nacional de Ciencia y Tecnología, Argentina. Various Reports: 1997-2000. *Available upon request.*

Caldiz, D.O. & J. Beltrano, 1992. Physiology and improvement of potatoes (*Solanum tuberosum* L.). *Transactions of the Malaysian Society of Plant Physiology* 3: 80-83.

Caldiz, D.O. & A.J. Haverkort, 1994. Alternativas para incrementar la producción de papa en el área de Villa Dolores, Córdoba. *Gaceta Agronómica* 14: 186-189.

Caldiz, D.O. & L.V. Fernández, 1995. Edad fisiológica de los tubérculos de papa producidos en la Argentina y sus implicancias para el cultivo posterior. *I Seminario Latinoamericano da Cultura da Batata.* Cámara Latinoamericana do Paraná, Curitiba, Brasil. Unpublished.

Caldiz, D.O. & L.V. Fernández, 1996. Edad fisiológica de los tubérculos de papa producidos en diferentes regiones de la Argentina. *Actas XXI Reunión Argentina de Fisiología Vegetal,* Mendoza, Argentina, pp. 160-161.

Caldiz, D.O. & M.H. Inchausti, 1996. Situación actual de la producción de papa en la Argentina. *Primer Seminario de Refrescamiento del International Potato Course para Alumnos de América Latina y el Caribe.* IAC-Holanda y MINAG-Cuba, La Habana, Cuba, 10 pp.

Caldiz, D.O. & F.J. Gaspari, 1997. Análisis de los factores determinantes del rendimiento en papa (*Solanum tuberosum* L.) con especial referencia a la situación Argentina. *Revista de la Facultad de Agronomía, La Plata* 102: 203-228.

Caldiz, D.O. & F.J. Gaspari, 1998. *Agro-ecological zoning and potential yield of the potato crop in the southeast region of the province of Buenos Aires.* Research and Development Project Report, La Plata, Argentina, 24 pp.

Caldiz, D.O. & P.C. Struik, 1999. Survey of potato production and possible yield constraints in Argentina. *Potato Research* 42: 51-71.

Caldiz, D.O., F.K. Claver & A.R. Escande, 1984. Effect of harvesting time and storage system on the quality of seed potato tubers. *Turrialba* 34: 287-290.

Caldiz, D.O., D.M. Panelo, F. K. Claver & E.R. Montaldi, 1985. The effect of two planting dates on the physiological age and yielding potential of seed potatoes grown in a warm temperate climate in Argentina. *Potato Research* 28: 425-434.

Caldiz, D.O., J.R. Alaniz & F.K. Claver, 1986. Relaciones entre la edad fisiológica y el contenido de azúcares totales y reductores en tubérculos de papa (*Solanum tuberosum* L.) destinados a nueva plantación. *Turrialba* 36: 315-320.

Caldiz, D.O., C. Marchan, S.D. Tenembaum & E. Vera, 1988. Períodos de dormición, brotación e incubación en tres nuevas variedades de papa obtenidas por el INTA. *Horticultura Argentina* 7: 16-19.

Caldiz, D.O., C. Della Croce, E. Vera & C. Marchan, 1989. Efectos del almacenamiento y de la época de aplicación del nitrógeno sobre la cobertura foliar y el rendimiento en papa (*Solanum tuberosum* L.). *Revista Latinoamericana de la Papa* 2: 46-56.

Caldiz, D.O., D.M. Panelo & M. Inchausti, 1994. Edad fisiológica y rendimiento en papa "semilla" (*Solanum tuberosum* L.) modificados por el prebrotado y la defoliación anticipada. *Revista de la Facultad de Agronomía, La Plata* 70: 57-63.

Caldiz, D.O., L.V. Fernández & A. Clúa, 1996a. Cobertura del suelo, acumulación de materia seca y rendimiento en cultivares de papa con distinta edad fisiológica. *Actas XXI Reunión Argentina de Fisiología Vegetal*, Mendoza, Argentina, pp. 162-163.

Caldiz, D.O., G. Brocchi, J. Alaniz & C. Marchan, 1996b. Effects of the physiological age of seed potatoes on tuber initiation and starch and dry matter accumulation. *Pesquisa Agropecuaria Brasileira* 31: 853-858.

Caldiz, D.O., L.V. Fernández, F. Marco & A. Clúa, 1997. Efectos de la hidrazida maleica sobre el rendimiento, contenido de materia seca y brotación en papa (*Solanum tuberosum* L. cv. Spunta) destinada al consumo fresco. *Revista de la Facultad de Agronomía, La Plata* 102: 163-173.

Caldiz, D.O., L.V. Fernández, N. Zamudio, C. Del Caso, M.A. Huarte & J. Ortego, 1998a. Edad fisiológica de tubérculos de papa de diferentes regiones de la Argentina y sus efectos sobre el rendimiento del cultivo posterior. *Actas XXII Reunión Argentina de Fisiología Vegetal*, Mar del Plata, Argentina, pp. 264-265.

Caldiz, D.O., A. Clúa, J. Beltrano & S.D. Tenembaum, 1998b. Ground cover, photosynthetic rate and tuber yield of potato (*Solanum tuberosum* L.) crops from seed tubers with different physiological age modified by foliar applications of plant growth regulators. *Potato Research* 41: 175-186.

Caldiz, D.O., O.H. Caso, G. Vater & L. V. Fernández, 1999. The potential for production of high quality seed potatoes in Tierra del Fuego Island, Argentina. *Potato Research* 42: 9-23.

Caldiz, D.O., F.J. Gaspari & A. Moreno Kiernan, 2000a. Potential yield of the potato crop in the Argentinian patagonia. The case of the Río Negro river valley. *Submitted.*

Caldiz, D.O., F.J. Gaspari, P.C. Struik & A.J. Haverkort, 2000b. Agro-ecological zoning and potential yield of the potato crop in Argentina. *Submitted.*

Caldiz, D.O., L.V. Fernández & P.C. Struik, 2000c. Physiological age index: a new, simple and reliable index to assess the physiological age of seed potato tubers *(Solanum tuberosum* L.*)* based on haulm killing date and length of the incubation period. *Submitted.*

Caldiz, D.O., L.V. Fernández, N. Zamudio, J. Ortego, C. del Caso, M. Huarte & P.C. Struik, 2000d. Seed origin, seed supply, seed flow and physiological age of seed potatoes and its effects on crop growth and yield in different seasons in Argentina. *Submitted.*

Caldiz, D.O., L.V. Fernández & M.H. Inchausti, 2000e. Maleic hydrazide effects on tuber yield and french fry processing quality in various potato (*Solanum tubersoum* L.) cultivars grown under Argentinian conditions. *Submitted.*

Caldiz, D.O., P.C. Struik & L.V. Fernández, 2000f. Yield gap analysis for different agro-ecological potato growing zones in Argentina with the LINTUL-POTATO model. *Submitted.*

Cantos de Ruiz, S., 1988. *Rendimiento potencial del cultivo de papa en Balcarce. Causas que limitan la productividad real.* MSc Thesis, Facultad de Ciencias Agrarias, UN Mar del Plata, Balcarce, Argentina, 60 pp.

Cantos de Ruiz, S., F.H. Andrade & A.O. Mendiburu, 1989. Rendimiento potencial del cultivo de papa en Balcarce. Causas que limitan la productividad real. *Revista Latinoamericana de la Papa.* 2: 29-45.

Centro Internacional de la Papa, 1986. Un método sencillo para determinar la cobertura foliar. *Circular CIP* 14: 6-8.

Chacra Experimental de Miramar, 1991. *Memoria Técnica de la Chacra Experimental de Miramar*, Years: 1987-1991, Asociación Cooperadora Chacra Experimental de Miramar, Miramar, Argentina.

Chaves, E., 1989. Distribución de *Meloidogyne* spp. en la provincia de Buenos Aires. *Actas XIV Reunión de la Asociación Latinoamericana de la Papa.* Mar del Plata, Argentina, pp. 39.

Chiarlo, N., 1996. Legislación y evolución de la producción de papa semilla en Malargüe. *Actas III Jornadas Técnicas de Papa Semilla. Papa Semilla Para Latinoamerica*. Malargüe, 14 - 16 February, 1996, pp. 21-28.

Claver, F.K., 1951. Influencia de luz, oscuridad y temperatura sobre la incubación de la papa. *Phyton* 1: 3-12.

Claver, F.K., 1953. Factores que influyen en la incubación de la papa. *Turrialba* 3: 32-34.

Claver, F.K., 1973. Influence of temperature during the formation of tubers in relation with their incubation state (physiological age) and seed value. *Experientia* 30: 97.

Claver, F.K., 1975. Influence of temperature during the formation of potato tubers and its effects on the first progeny. *Phyton* 33: 1-5.

Claver, F.K., R.M. Tizio & E.R. Montaldi, 1957. Efecto degenerativo de altas temperaturas durante la formación de los tubérculos de papa, *Revista de Investigaciones Agrícolas* 11: 209-214.

Claver, F.K., A. Mitidieri & P.R. Bianchini, 1971. Influencia del origen y tratamiento con bajas temperaturas de la papa semilla sobre el rendimiento de la segunda plantación en la zona de Rosario. *Revista de Investigaciones Agrícolas* 8: 13-28.

Costilla, M.A., S. González de Ojeda & T. Hasselrot de Gómez, 1978. El falso nematode del nudo *Nacobbus aberrans* en cultivo de papa en Tucumán. *Actas III Jornadas Fitosanitarias Argentinas*, San Miguel de Tucumán, Argentina, pp. 323-340.

Dam, J. van, P.L. Kooman & P.C. Struik, 1995. Effects of temperature and photoperiod on early growth and final number of tubers in potato (*Solanum tuberosum* L.). *Potato Research* 39: 51-62.

Doucet, M.E., 1980. Técnicas básicas en nematología del suelo. *IDIA* 388: 34-43.

Dwelle, R.B. & P.J. Hurley, 1984. The effects of foliar applications of cytokinins on potato yields in southeastern Idaho. *American Potato Journal* 64: 293-299.

Eastman, J.R., 1993. *IDRISI v. 4.0.* Clark University, Graduate School of Geography, Worcerster, MA 01610, USA. March 1992, Revised Version July 1993.

Echeverría, H.E., E.E. Suero & F.H. Andrade, 1992. *Radiación, temperatura, nutrientes y agua como determinantes de la producción del cultivo de papa.* Boletín Técnico 103, EEA Balcarce. 19 pp.

Ediciones Aguilar, 1992. *Atlas Clarín.* Arte Gráfico Editorial Argentino S.A., 279 pp.

Es, A. van & K.J. Hartmans, 1984. Some aspects of changes in chemical composition of tubers and sprouts during physiological aging. *Abstracts of Conference Papers, 9th Triennial Conference EAPR*, Interlaken, Switzerland, pp. 231-232.

Es, A. van & K.J. Hartmans, 1987. Effect of physiological age on growth vigour of seed potatoes of two cultivars. 2. Influence of storage and storage temperature on dry matter content and peroxidase activity of sprouts. *Potato Research* 30: 411-421.

Escande, A.R., 1990. Control integrado de enfermedades de papa. *Jornada de Actualización Técnica en Papa.* AIA Balcarce, Agencia de Extensión, Instituto Nacional de Tecnología Agropecuaria, Balcarce, pp. 20-21.

Escande, A.R., A. Melegari, D.O. Caldiz, J.C. Rodriguez, H. Palladino & R.H. Mirón, 1985. Influencias del sistema de almacenamiento sobre la capacidad simiente de tubérculos de papa (*Solanum tuberosum* L. cvs. Spunta y Sierra Volcán). *IDIA* 440: 24-30.

Escande, A.R., D.O. Caldiz, & J.C. Rodríguez, 1986. Influencias del sistema de almacenamiento y de la época de plantación sobre la productividad de tubérculos de papa (*Solanum tuberosum* L.) simiente. *Turrialba* 36: 237-244.

Escarrá, A.M., 1989. Etapa de consolidación del abastecimiento. Hacia la exportación de semilla? *Enfoques del Sudeste* 51: 9-10 & 13.

Fahem, M. & A.J. Haverkort, 1988. Comparison of the growth of potato crops grown in autumn and spring in North Africa. *Potato Research* 31: 557-568.

FAO, 1990. *FAOCLIM Global Weather database.* Release 1990. Agrometeorology Group, Remote Sensing Centre, Research and Technology Division, FAO, Rome, Italy.

FAO, 1995. *Production Yearbooks 1948-1995.* FAO, Rome, Italy.

Fernández, H., R. Bertolasi & S. Pena, 1999. Papa: el cultivo en la Argentina. *Panorama Agrícola* 4: 36-41.

Ferreyra, R.E., 1990. Producción de semilla en Malargüe, Mendoza. *Actas Jornada de Actualización Técnica: Papa.* Asociación Ingenieros Agrónomos Balcarce - Agencia de Extensión INTA Balcarce, Balcarce, pp. 11-13.

Fishman, S., H. Talpaz, R. Winograd, M. Dinar, Y. Arazi, Y. Roseman & S. Varshavski, 1985. A model for simulation of potato growth on the plant community level. *Agricultural Systems* 18:115-128.

Fundación ArgenINTA, INTA & Aeroterra, 1995. *Atlas de Suelos de la República Argentina.* Versión digitalizada en CD para su uso con Arcview v. 1.0. Buenos Aires, Argentina.

Gatzuk, L.E., O.V. Sminova, L.F. Vorontzova, L.B. Zaugolnova & L.A. Zhukova, 1980. Age states of plants of various growth forms: a review. *Journal of Ecology* 68: 675-696.

Goodwin P.B., F.L. Milthorpe, A. Brown & J.H. Lennard, 1966. Effect of the center of production and maturity of seed tubers on yields of early potatoes. *Experimental Horticulture* 14: 31-38.

Griffin, T.S., B.S. Johnson & J.T. Ritchie, 1992. *SUBSTOR-potato Version 2.0: A simulation model for potato growth and development.* Michigan State University, 32 pp. + fig.

Haren, R.J.F. van, 1998. Ecoregional application of the LINTUL-POTATO model. In: J.J. Stoorvogel, J. Bouma & W.T. Bowen, Eds. *Information Technology as a Tool to Assess Land Use Options in Space and Time. Quantitative Approaches in Systems Analysis N° 16*, AB-DLO and The C.T. de Wit Graduate School for Production Ecology, Wageningen, pp. 58-61.

Hartmans, K.J. & C.D. van Loon, 1987. Effect of physiological age on growth vigour of seed potatoes of two cultivars. 1. Influence of storage period and temperature on sprouting characteristics. *Potato Research* 30: 397-409.

Haverkort, A.J., 1986. Yield levels of potato crops in central Africa. *Agricultural Systems* 21: 227-235.

Haverkort, A.J., 1990. Ecology of potato cropping systems in relation to latitude and altitude. *Agricultural Systems* 32: 251-272.

Haverkort, A.J. & P.M. Harris, 1986. Conversion coefficients between intercepted solar radiation and tuber yields of potato crops under tropical highland conditions. *Potato Research* 29: 529-533.

Haverkort, A.J. & P.M. Harris, 1987. A model for potato growth and yield under tropical highland conditions. *Agricultural and Forest Meteorology* 39: 271-282.

Haverkort, A.J. & D.O. Caldiz, 1994. Aardappelproduktie in Argentinië. *Aardappelwereld Magazine* 48: 18-20.

Haverkort, A.J. & D.K.L. MacKerron, 1995. *Potato Ecology and Modelling of Crops Under Conditions Limiting Growth.* Kluwer Academic Publishers, Dordrecht, 379 pp.

Haverkort, A.J. & P.L. Kooman, 1997. The use of systems analysis and modelling of growth and development in potato ideotyping under conditions affecting yield. *Euphytica* 94: 191-200.

Hawkes, J.G., 1967. The history of the potato. *Journal Royal Horticultural Society* 92: 207-224; 249-262; 288-302; 364-65.

Headford, D.W.R., 1962. Sprout development and subsequent plant growth. *European Potato Journal* 5: 14-22.

Hijmans, R.J., 1999. Simulation models for studying limiting factors in potato production. International Potato Center, Lima, Perú, Internet: *www.grida.no/cgiar/awapck/simulat.htm*

Hille Ris Lambers, D., 1980. Pulgones: sus ciclos biológicos y su papel como vectores de virus. In: J.A. de Bokx, Ed. *Virosis de la papa y de la semilla de papa*. Editorial Hemisferio Sur S.A., Buenos Aires, pp. 25-53.

Huarte, M.A., 1989. Situación actual de la producción de tubérculo-semilla de papa en la Argentina. In: O.A. Hidalgo & H. Rincón, Eds. *Avances en la Producción de Tubérculo-Semilla de Papa en los Países del Cono Sur.* CIP, Lima, Perú, pp. 15-21.

Huarte, M.A., 1994. Determinación de prioridades de investigación en papa. *Simposio-Taller: Eficiencia en la producción y comercialización de papa.* ASAHO and INTA, Huerta Grande, Argentina. *Unpublished.*

Huarte, M.A., 1996. Situación de la producción de papa en la Argentina (1995-96). *Actas III Jornadas Técnicas de Papa Semilla. Papa Semilla Para Latinoamerica.* Malargüe, Argentina, pp. 40-44.

Huarte, M. & I.P. Butzonich, 1984. *Estudio de factibilidad para la producción de semillas de alta sanidad en Tierra del Fuego.* Informe Técnico INTA Balcarce, 4 pp.

Huarte, M.A. & M.H. Inchausti, 1994. La producción de papa en la República Argentina y su relación con el Mercosur. *Actas III Simposio de Integración Frutihorícola del Cono Sur.* Montevideo, Uruguay, pp. 11-41.

Huarte, M.A. & E. Cacace, 1998. Producción de papa para la industria. *4ta Agrodemostración del Sudeste*, INTA Balcarce. *Unpublished.*

Hunt, R., 1982. *Plant growth curves.* Edward Arnold Publishers, London, 248 pp.

Hutchinson, R.W., 1978. The dormancy of seed potatoes. 1. The effect of time of haulm destruction and harvesting. *Potato Research* 21: 257-265.

IBSNAT, 1989. *Decision Support System for Agrotechnology Transfer V. 2.10 (DSSAT V. 2.10).* Department of Agronomy and Soil Science, University of Hawaii, Honolulu.

Inchausti, M.H., 1989. Eficiencia del proceso de comercialización de papa desde la apertura del Mercado Central de Buenos Aires. In: *Resúmenes XIV Reunión ALAP*, Mar del Plata, Argentina, pp. 95.

Inchausti, M.H., 1996. Sistema de abastecimiento y producción de semilla de papa en la Argentina. *Primer Seminario de Refrescamiento del International Potato Course para Alumnos de América Latina y el Caribe.* IAC-Holanda y MINAG-Cuba, La Habana, Cuba, 16 pp.

INTA Balcarce, 1980. Historia del cultivo de la papa en la República Argentina. *Actas Segunda Reunión Nacional de Programación de Papa*. Balcarce, Argentina, pp. 1-18.

Iritani, W.M., 1968a. Factors affecting physiological aging (degeneration) of potato tubers used as seed. *American Potato Journal* 45: 111-116.

Iritani, W.M., 1968b. The effect of storage temperature and source on productivity of Russet Burbank seed. *American Potato Journal* 45: 322- 327.

Iritani, W.M., 1983. Manipulation and control of seed tuber behaviour. *Proceedings International Congress: Research for the potato in the year 2000.* International Potato Center, Lima, pp. 102.

Iritani, W.M., L.D. Weller & N.R. Knowles, 1983. Relationships between stem number, tuber set and yield of Russet Burbank potatoes. *American Potato Journal* 60: 423-431.

Ittersum, M.K. van, 1992. *Dormancy and growth vigour of seed potatoes.* PhD Thesis, Wageningen Agricultural University, Wageningen, The Netherlands, 187 pp.

Ittersum, M.K. van, 1993. Advancing growth vigour of seed potatoes by storage temperature regimes. *Netherlnads Journal of Agricultural Science* 41: 23-36.

Ittersum, M.K. van & K. Scholte, 1993. Shortening dormancy of seed potatoes by a haulm application of gibberellic acid and storage temperature regimes. *American Potato Journal* 70: 7-19.

Ittersum, M.K. van, K. Scholte & S. Warshavsky, 1993. Advancing growth vigour of seed potatoes by a haulm application of gibberellic acid and storage temperature regimes. *American Potato Journal* 70: 21-34

Ivins, J.D. & P.M. Bremmer, 1964. Growth, development and yield in the potato. *Outlook on Agriculture* 4: 211-217.

Kawakami, K., 1936. Improving potato seed tubers for spring crops. *Nogyo-Keizai* 3: 399-405.

Kawakami, K., 1952. Physiological aspects of potato seed. *Hyogo Agricultural College Sasayama*, Japan, 113 pp.

Kawakami, K., 1962. The physiological degeneration of potato seed tubers and its control. *European Potato Journal* 5: 40-49.

Kawakami, K., 1963. Age of potato seed tubers affects growth and yield. *American Potato Journal* 40: 25-29.

Keulen, H., van & W. Stol, 1995. Agro-ecological zonation for potato production. In: A.J. Haverkort and D.K.L. MacKerron, Eds. *Potato Ecology and Modelling of Crops Under Conditions Limiting Growth*. Kluwer Academic Publishers, Dordrecht, pp. 357-372.

Kooman, P.L., 1995. *Yielding ability of potato crops as influenced by temperature and daylength.* PhD Thesis, Wageningen Agricultural University, Wageningen, The Netherlands, 155 pp.

Kooman, P.L. & A.J. Haverkort, 1995. Modelling development and growth of the potato crop influenced by temperature and daylength: LINTUL-POTATO. In: A.J. Haverkort & D.K.L. MacKerron, Eds. *Potato Ecology and Modelling of Crops Under Conditions Limiting Growth.* Kluwer Academic Publishers, Dordrecht, pp. 41-59.

Krenke, N.P., 1940. The theory of cyclic ageing and rejuvenation of plants and its practical use. *Selkhozgia*, Moscow.

Krijthe, N.K., 1958. Changes in the germinating power of seed potatoes. *European Potato Journal* 1: 69-71.

Krijthe, N.K., 1962. Observations on the sprouting of seed potatoes. *European Potato Journal* 5: 316-333.

Kunkel, R. & G.S. Campbell, 1987. Maximum potential yield in the Columbia basin: model and measured values. *American Potato Journal* 64: 355-366.

Lanfranconi, L.E., 1993. *Recopilación sobre el control integrado de malezas en el cultivo de papa. Un avance para su discusión.* INTA, EEA Manfredi, Manfredi, Argentina, 22 pp.

Lanfranconi, L.E., 1994. *Competitividad del cultivo de la papa de la Provincia de Córdoba en el marco del MERCOSUR.* INTA, Agencia Extensión Rural Río Primero, Río Primero, Argentina, 8 pp.

Lanen, H.A.J. van, C.A. van Diepen, G.J. Reinds, G.H.J. de Koning, J.D. Bulens & A.K. Bregt, 1992. Physical land evaluation methods and GIS to explore the crop growth potential and its effects within the European communities. *Agricultural Systems* 39: 307-328.

Loon, C.D. van, 1987. Effect of physiological age on growth vigour of seed potato of two cultivars. 4. Influence of storage period and storage temperature on growth and yield in the field. *Potato Research* 30: 411-450.

MacKerron, D.K.L. & P.D.Waister, 1985. A simple model of potato growth and yield. Part I. Model development and sensitivity analysis. *Agricultural and Forest Meteorology* 34: 241-252.

Madec, P., 1956. La nature et les causes du boulage chez pomme de terre. *Annales de l' Amélioration des Plantes* 6: 151-169.

Madec, P. & P. Perennec, 1955. Les possibilités d'évolution des germes de la pomme de terre et leurs conséquences. *Annales de l'Amélioration des Plantes* 5: 555-574.

Madec, P. & P. Perennec, 1956. Influence de l'origine sur le comportement des plants de pomme de terre. *Annales de l'Amélioration des Plantes* 6: 5-26

Manrique, L.A., J.R. Kiniry, T. Hodges & D.S. Axness, 1991. Dry matter production and radiation interception of potato. *Crop Science* 31: 1044-1049.

Marinus, J., 1993. The effect of potato seed tuber age and soil temperature on the phenomenon of non-emergence. *Potato Research* 36: 63-69.

Marinus, J. & K.B.A. Bodlaender, 1975. Response of some potato varieties to temperature. *Potato Research* 18: 189-204.

Marinus, J. & K.B.A. Bodlaender, 1978. Growth and yield of seed potatoes after application of gibberellic acid to the tubers before planting. *Netherlands Journal of Agricultural Science* 26: 354-365.

Mendiburu, A.O., 1986. *Antecedentes de la producción de semilla en la Argentina*. Reunión Técnica en Producción de Semilla Básica, Chacra Experimental de Miramar, Miramar, Argentina, 2 pp.

Mendiburu, A.O. & O. Lucarini, 1980. Manipulaciones genéticas para la producción y el aprovechamiento de la papa. *Revista de la Facultad de Agronomía, Buenos Aires* 1: 129-139.

Menzel, C.M., 1985. Tuberization in potato at high temperatures: responses of physiological young plants to disbudding and growth inhibitors. *Potato Research* 28: 267-269.

Midmore, D.J., 1990. Influence of temperature and radiation on photosynthesis, respiration and growth parameters of the potato. *Potato Research* 33: 293-294.

Mikitzel, L.J., 1995. Daminozide applied to the foliage of three potato cultivars increased tuber eye number. *American Potato Journal* 72: 177-183.

Ministry of Agriculture, Fisheries and Food, 1979. *Potato virus diseases*. Leaflet 139, Ministry of Agriculture, Fisheries and Food, Edinburgh, 8 pp.

Moll, A., 1994. Einfluss der physiologischen Alterung bei Pflanzknollen verschiedener Sorten auf Wachstumcharakteristika im Laborversuch. *Potato Research* 37: 11-20.

Munck, C., 1940. *El cultivo de la papa en la zona sudeste de la provincia de Buenos Aires*. Publicación N° 27 FFCC Sud y Oeste, Sección Fomento Rural, Establecimiento Gráfico Argentino, Buenos Aires, Argentina, 83 pp.

Nemecek, T., 1993. *The role of aphid behaviour in the epidemiology of Potato Virus Y: a simulation study*. PhD thesis, Swiss Federal Institute of Technology, ETH Zürich, 232 pp.

Ng, E. & R.S. Loomis, 1984. Simulation of growth and yield of the potato crop. *Simulation Monographs,* Pudoc, Wageningen, 147 pp.

O'Brien, P.J. & E.J. Allen, 1975. Effect of area of seed production and date of lifting of seed crops on the performance of the progeny tubers. *Abstracts of Conference Papers, 6th Triennial Conference EAPR*, Wageningen, The Netherlands, pp. 41-42.

O'Brien, P.J. & E.J. Allen, 1981. The concept and measurement of physiological age. *Abstracts of Conference Papers, 8th Triennial Conference EAPR,* München, Germany, pp. 64-66.

O'Brien, P.J., E.J. Allen, J.N. Bean, R.J. Griffith, S.A. Jones & J.L. Jones, 1983. Accumulated day-degrees as a measure of physiological age and the relationships with growth and yield in early potato varieties. *Journal Agricultural Science, Cambridge* 101: 613-631.

Oostenbrink, M., 1960. Estimating nematode populations by some select methods. In: J.N. Sasser and W.R. Jenkins, Eds. *Nematology*. University NC, Chapel Hill, pp. 85-102.

Orell, R., 1990. Papa semilla en Tafi del Valle. *Actas Jornada de Actualización Técnica: Papa.* Asociación Ingenieros Agrónomos de Balcarce - Agencia de Extensión INTA Balcarce, Balcarce, pp. 5-10.

Ortego, J., 1995. Evolución de la infección con PVYn en papa en relación al grado de infección inicial y la actividad de los vectores. *XVII Reunión de la Asociación Latinoamericana de la Papa.* Mérida, Venezuela, 1995.

Ortego, J., 1996. Producción de papa semilla sin uso de biocidas en Malargüe, Mendoza. *Actas III Jornadas Técnicas de Papa Semilla. Papa Semilla Para Latinoamerica.* Malargüe, Argentina, pp. 29-33.

Panelo, M., D.O. Caldiz & F.K. Claver, 1982. La tuberización y el rendimiento de tres variedades de papa cultivadas en Miramar, Argentina. *Revista de la Facultad de Agronomía, La Plata* 58: 99-120.

Panelo, D.M. & D.O. Caldiz, 1989. Influence of early haulm killing of seed crops on subsequent sprouting, physiological ageing and tuber yield. *Potato Research* 32: 3-7.

Passecker, F., 1977. Theorie der ontogenischen Evolution und Alterung helziger Gewasche. *Bodenkultur* 28: 277-294.

Penning de Vries, F.W.T. & R. Rabbinge, 1995. Models in research and education, planning and practice. In. A.J. Haverkort & D.K.L. MacKerron, Eds. *Potato Ecology and Modelling of Crops Under Conditions Limiting Growth.* Kluwer Academic Publishers, Dordrecht, pp. 1-18.

Perennec, P. & P. Madec, 1980. Age physiologique du plant de pomme de terre. Incidence sur la germination et repercusions sur le comportement des plantes. *Potato Research* 23: 183-199.

Petterssen, S., 1976. *Introducción a la meteorologia.* Espasa-Calpe S.S., Madrid, Spain, pp. 395-412.

Radley, R.W., M.A. Taha & P.M. Bremner, 1961. Tuber bulking in the potato crop. *Nature* 191: 782-783.

Ratera, E.L., 1945. *El cultivo de la papa.* Editorial Sudamericana, Buenos Aires, 164 pp.

Reust, W., 1982. *Contribution à l'appréciation de l'âge physiologique des tubercules de pomme de terre (Solanum tuberosum* L.) *et étude de son importance sur le rendement.* Thèse Dr., Ecole Polytechnique Fédérale, Zürich, Suisse, 114 pp.

Reust, W., 1986. EAPR Working group Physiological age of the potato. *Potato Research* 29: 268-271.

Reust, W. & W. Munster, 1975. La période d'incubation des variétés de pommes de terre de l'assortiment suisse et son importance. *Revue Suisse d'Agriculture* 7: 185-187.

Reust, W. & J. Aerny, 1985. Determination of physiological age of potato tubers with using sucrose, citric and malic acid as indicators. *Potato Research* 28: 251-261.

Robbins, W.I., 1957. Physiological aspects of ageing in plants. *American Journal of Botany* 44: 289-294.

Rodriguez Quijano, P.A., 1989. *La selección de tecnologia por los agricultores. El caso de las variedades de papa en el sudeste de la provincia de Buenos Aires, Argentina.* MSc Thesis, Facultad de Agronomía, UBA-INTA, Buenos Aires, Argentina, 105 pp.

Rojas, E., E.V. Viirsoo & J. Ploper, 1975. Producción de papa semilla en Tafi del Valle. *Revista Industrial y Agrícola de Tucumán* 52: 61-76.

Rojas, E., E.V. Viirsoo & N. Zamudio, 1979. Resultados obtenidos en cultivos de primicia con papa semilla multiplicada en Tafi del Valle. *Revista Industrial y Agrícola de Tucumán* 56: 1-9.

Sacher, R.F. & W.M. Iritani, 1982. Tetrazolium tests as indicators of tuber physiological age and yield potential. *American Potato Journal* 59: 613-625.

SAGyP, 1989. *Mapa de suelos de la Provincia de Buenos Aires.* Secretaría de Agricultura, Ganadería y Pesca, INTA, CIRN, Instituto de Evaluación de Tierras, Buenos Aires, 525 pp.

SAGyP, 1990. *Atlas de suelos de la República Argentina Tomo I y II.* Secretaría de Agricultura, Ganadería y Pesca, INTA, CIRN, Buenos Aires, Argentina.

SAGyP, 1995. *Estadísticas Agropecuarias y Pesqueras Año 1994.* Secretaría de Agricultura, Ganadería y Pesca, SIIAP, Buenos Aires, Argentina, pp. 97-118.

SAGPyA, 1997. *La Siembra y la Cosecha. El Crecimiento del Sector Agropecuario y Pesquero Argentino.* Buenos Aires, Argentina, 107 pp.

SAGPyA, 1998. *Estimaciones Agrícolas-Hortalizas.* SAGPyA, SIIAP, Argentina. Internet: http://www.siiap.sagyp.mecon.ar/scripts/ingles/ihortali.idc.

Saluzzo, J.A., 1994. *Comportamiento de cultivares de papa con distintio ciclo en respuesta a la fertilización nitrogenada.* MSc. Thesis, Facultad de Ciencias Agrarias UN Mar del Plata - INTA Balcarce, Balcarce, 52 pp.

Sawyer, R.L. & R.C. Cetas, 1962. Yield variability among Katahdin seed sources. *American Potato Journal* 39: 116-121.

Scaramella Petri, P., 1959. Morphological characters considered as an indication of physiological age of *Solanum tuberosum* plants cultivated in different ecological localities. *European Potato Journal* 2: 153-164.

Schaffalitzky de Muckadell, M., 1959. Investigation of ageing of apical meristems in woody plants and its importance in silviculture. *Førstlige Førsøgsvaesen, Danmark* 4: 307-455.

Scholte, K., 1986. Relation between storage T sum and vigour of seed potatoes. *Abstract of Conference Papers, 10th Triennial Conference EAPR*, Aalborg, Denmark, pp. 28-29.

Servicio Meteorológico Nacional, 1992. *Estadísticas climáticas 1981-90.* Serie B N° 37, Capital Federal, Argentina, 709 pp.

Sívori, E.M., 1951. La degeneración de la papa. *Ciencia e Investigación* 8: 289-336.

Smithsonian Institute, 1951. *Smithsonian meteorological tables.* Smithsonian Institute, Washington, USA.

Soil Survey Staff, 1992. *Keys to soil taxonomy, 5th Edition.* SMSS Technical Monograph N° 19, Pocahontas Press Inc., Blacksburg, Virginia, 556 pp.

Spiertz, J.H.J., H.D.J. van Heemst, & F.W.T. Penning de Vries, 1984. Modelling growth and production of potatoes. *Proceedings 9th Triennial Conference EAPR,* Interlaken, Switzerland, pp. 99-113.

Spitters, C.J.T., 1987. An analysis of variation in yield among potato cultivars in terms of light absorption, light utilization and dry matter partitioning. *Acta Horticulturae* 214: 71-84.

Stoorvogel, J.J., 1995. Linking GIS and models: structure and operationalisation for a Costa Rica case study. *Netherlands Journal of Agricultural Science* 43: 19-29.

Stol, W., G.H.J. de Koning, P.L. Kooman, A.J. Haverkort, H. van Keulen & F.W.T. Penning de Vries, 1991. *Agro-ecological characterization for potato production.* CABO-DLO Report 155, Wageningen, 53 pp.

Struik, P.C. & S.G. Wiersema, 1999. *Seed potato technology*. Wageningen Pers, Wageningen, The Netherlands, 383 pp.

Struik, P.C., G. Kramer & N.P. Smit, 1989. Effects of soil applications of gibberellic acid on the yield and quality of tubers of *Solanum tuberosum* L. cv. Bintje. *Potato Research* 32: 203-209.

Susnoschi, M., 1981. Seed potato quality as influence by high temperatures during the growth period. 2. Sprouting pattern in several cultivars in response to storage temperature. *Potato Research* 24: 381-388.

Thornton, R.E. & J.B. Sieczka, 1980. Commercial Potato Production in North America. *American Potato Journal Supplement* 57, 36 pp.

Timm, H. & V.H. Schweers, 1965. Effect of temperature and seed treatment on respiration, sprouting and decay of seed potatoes. *American Society of Horticultural Science* 86: 502-510.

Tizio, R., E.R. Montaldi & O. Garay, 1954. Verificación de la degeneración de la papa por el efecto de las altas temperaturas. *Revista de Investigaciones Agricolas, Argentina* 8: 225-261.

Tizio, R. & C.R. Tizio, 1981. Effet de températures de conservation sur le degrée d'incubation du plant de pomme de terre (*Solanum tuberosum* L.) et leur incidence sur la productivité. *Phyton* 40: 61-71.

Ugent, D. & L.W. Peterson, 1988. Restos arqueológicos de papa y batata en el Perú. *CIP Circular* 16: 1-10.

Uranov, A.A., 1975. Age spectrum of the phytocoenopopulation as a function of time and energetic wave processes. *Biologicheskie Nauki* 2: 7-34.

Vakis, N.J., 1986. Influence of physiological ageing of seed potatoes on yield and earliness. *Potato Research* 29: 417-425.

Watson, D.J., 1952. The physiological basis of variation in yield. *Advances in Agronomy* 4: 101-145.

Weerd, J.W. de, L.K. Hiller & R.E. Thornton, 1995. Electrolyte leakage of aging potato tubers and its relationship with sprouting capacity. *Potato Research* 38: 257-270.

Went, F.W., 1959. Effects of environment of parent and grandparent generation on tuber production by potatoes. *American Journal of Botany* 46: 277-282.

Willmott, C.J., 1982. Some comments on the evaluation of model performance. *Bulletin American Meteorological Society* 63: 1309-1312.

Wurr, D.C.E., 1979. The effect of variation in the storage temperature of seed potatoes on sprout growth and subsequent yield. *Journal Agricultural Science, Cambridge* 93: 619-622.

Wurr, D.C.E., 1980. Physiological quality of potato seed tubers. *ADAS Quarterly Review* 36: 27-39.

Zaag, D.E. van der, 1973. Requirements of the user of seed potatoes - standards of health, grading and physiological age; time and mode of delivery; price, *Proccedings 5th Triennial Conference EAPR*, Norwich, UK, pp. 38-46.

Zaag, D.E. van der, 1984. Reliability and significance of a simple method of estimating the potential yield of the potato crop. *Potato Research* 27: 51-73.

Zaag, D.E. van der, 1986. The potential demand for seed potatoes: a world perspective. *Potato Research* 29: 541-548.

Zaag, D.E. van der & W.G. Burton, 1978. Potential yield of the potato crop and its limitations. *Survey of Conference Papers 7th Triennial Conference of the EAPR.* Warsaw, Poland, pp. 7-22.

Zaag, D.E. van der & C.D. van Loon, 1987. Effect of physiological age on growth vigour of seed potatoes of two cultivars. 5. Review of literature and integration of some experimental results. *Potato Research* 30: 451-472.

Zamudio, N., 1996. Mejoramiento de poblaciones y obtención de variedades precoces y de dormición corta en Tucumán, Argentina. *Primer Seminario de Refrescamiento del International Potato Course para Alumnos de América Latina y el Caribe.* IAC-Holanda y MINAG-Cuba, La Habana, Cuba, 10 pp.

Zamudio, N., N.O. de Martínez & R. Lobo, 1996. Uso de agroquímicos para control de áfidos en Tafí del Valle. Acciones tendientes a su racionalización. *Avance Agroindustrial* 17: 36-38.

SUMMARY

The aim of this thesis was to analyze the Argentinian seed and ware potato production systems and their possible yield constraints in order to develop specific strategies to increase seed quality and tuber yield. The approach used for these purposes was based on a field survey, the use of Geographic Information Systems and crop simulation models, a yield gap analysis and the development of specific strategies to overcome seed quality and tuber yield constraints.

Actual and potential production in Argentina

Potato is the most important horticultural crop in Argentina and at present 100,000 ha are grown. Its commercial cultivation started in 1872/73 and production greatly increased due to area and yield increases. There are four growing seasons possible: early (June-October), medium-early (July-November), medium-late (October-March) and late (February-June). They are characterized according to weather, soil and crop type, yield level and yield determining, yield limiting and yield reducing factors. Factors affecting seed, ware and processing crops are identified for each area and season and possibilities for further yield improvement are discussed. The survey establishes that important yield improvements were achieved in the country during the last 20 years, mainly due to the use of high quality seed, although physiological and phytosanitary quality should still need to be improved. However, there is scarce information on the possibilities of expanding actual crop frontiers, either at regional or national level and the potential yield of the crop in different agro-ecological zones. Hence, (1) agro-ecological zones for potential potato production are characterized; (2) potential growing seasons are established; (3) the potential yield of the crop in these zones and seasons is estimated with the LINTUL-POTATO simulation model and (4) it is demonstrated how the combined use of Geographic Information Systems (GIS) for land evaluation and simulation models that establish the potential yield of the crop are important tools to assess possibilities of increasing crop production at local, regional or national scale. Moreover a general framework for the analysis of different cropping system is proposed based on the results of this thesis.

Yield prediction and yield gap analysis

For these studies two models were used. The SUBSTOR-POTATO model was used for yield prediction and the LINTUL-POTATO model to estimate yield potential of the crop and for the yield gap analysis. To evaluate their performance under Argentinian conditions these models were calibrated and validated using experimental results from different sites and years. For the

SUBSTOR-POTATO model cultivar-specific coefficients were obtained during calibration. Validation based on several independent sets of field data, including cvs Huinkul, Kennebec, Mailén and Spunta showed good agreement (R^2=0.915; n=24) between observed and simulated values in normal ranges of tuber yields. However, when the input parameter maturity date was not taken into account, tuber yields were overvalued due to an overestimation of LAI values during maturation. To solve this problem, a genetic coefficient for the duration of tuber bulking needs to be included in the model.

A study with data for five different potato growing regions was carried out and potential yield data from the LINTUL-POTATO simulation model were compared with the actual and attainable yields in order to perform a yield gap analysis and make further suggestions for yield improvement. The actual average yield of 30 t ha^{-1} for the main potato growing region, the southeast of the province of Buenos Aires, is far below the 126 t ha^{-1} potential calculated in this study with the LINTUL-POTATO model. Differences between actual and potential yield could be attributed to suboptimal light interception by the foliage. Improved water and fertilizer management could reduce the gap between actual and potential yield, as shown by attainable yields of 50 and 100 t ha^{-1} achieved in areas where the late and medium-late crops are grown. For other areas, physiological age of seed tubers, water and fertilizer management were identified as main yield limiting factors, while phytosanitary state of the seed tubers and crops were idenfied as main yield reducing factors. For Tucumán, where the early crops are carried, out the actual average yield is 18 t ha^{-1} but attainable yields of 50 t ha^{-1} were achieved when seed of suitable age and water and nutrients were not limiting factors for tuber yield.

Physiological age of seed tubers

A new, simple and reliable physiological age index (PAI) that considers (and reconciles) both the effect of chronological and physiological age is presented. PAI calculations were based on different key-dates of the life cycle of a seed tuber, which are easy to assess, i.e. the haulm killing date of the seed crop (T_0) and the end of the incubation period of seed tubers, measured under standard conditons. The PAI formula is: PAI= T_1/T_2, where T_1 is days from haulm killing (T_0) to possible planting day, while T_2 is days from T_0 to the end of the incubation period The PAI expresses physiological ageing of seed potato tubers within a range from 0 for physiologically young seed tubers to 1 for old tubers. To test the PAI existing data were re-evaluated and re-elaborated and specific experiments ont the effects of seed origin and storage conditions in different cultivars were performed during various years. Results showed that the PAI can be used to assess differences due to growing conditions, cultivars, seed origins and storage systems, haulm killing dates and different pre-planting treatments. The PAI is easy to measure, objectively, reproducibly and reliably and could be used to describe seed performance in future crops.

Seed supply is based on local production of pre-basic, basic and registered seed. About 50% of total seed requirement is under certification of the seed services, i.e about 5,000 ha. Seeds are produced in different areas and from them flow to the ware areas during the year. This situation determines that not always the seed arrived to the new planting season with a proper physiological age. Post-harvest period and storage conditions were identified as main factors affecting physiological age for different cultivars, but mainly for cv. Spunta, sensitive to physiological ageing. As crops are carried out throughout the whole year it would also be possible to improve seed flow provided proper phytosanitary management is considered.

Strategies to improve seed quality and yield

As mentioned in the previous section, physiological age of the seed tubers is one of the main yield limiting factors in Argentina while tuber and plant diseases, like viruses, are important yield and quality reducing factors. Different strategies to overcome these problems were presented.

The modifying effects of applying the plant growth regulators (PGRs) benzylaminopurine (BAP), gibberellic acid (GA_3) and BAP + GA_3 on crops grown from seed with different physiological ages were studied. In both seasons seed tubers stored in heaps reached an advanced physiological age at planting, compared with tubers from the cold store. Seed tubers of cv. Pampeana were older than those of Huinkul. BAP could overcome effects of advanced physiological age on crop senescence and tuber yield due to their effects on ground cover and photosynthetic rate.

In Argentina, different areas are suitable for seed potato production; however, each of them has particular problems, mainly related to different pest and diseases as shown in previous sections of this work. Tierra del Fuego island is well isolated from traditional potato growing areas. Therefore, it was tested for its potential for seed production. The cultivars Achatt, Mailén INTA, Pampeana INTA and Spunta were grown in Río Grande, San Pablo and Ushuaia from 1991-1994. Presence of nematodes was assessed and aphid population dynamics were recorded. Average tuber yield ranged from 20.1-37.6 t ha^{-1} and after three years the PVY and PLRV percentage remained low (0-1% for different cultivars and locations), due to low aphid densities during crop growth. Moreover, seed tubers obtained were physiologically young. Long days, early frosts and strong winds may limit tuber yield in some years but quality of the seed potatoes obtained was excellent. The island can be considered as an ecological "safe haven" and is very suitable to obtain healthy and physiologically adequate seed potatoes.

Conclusions

The area cropped with potato stabilizes at around 100,000 ha, while tubers yields per unit area are still increasing, due to the use of high quality seed, new cultivars and improved technology. However, it is still possible to substantially increase the cropped area and achieve further improvements in tuber yield.

Physiological age of seed tubers was identified as one of the most important yield limiting factors, and substantial yield improvements are still possible when use of seed tubers with the proper age is enhanced. Proper age should take into account cultivar, season and purpose of the crop. Successful strategies to reduce physiological and phytosanitary constraints were developed and could be used in the future to improve seed yield and quality.

This thesis combines the use of a survey at field level, GIS, simulation models and yield gap analysis. It may serve as an example of a framework for system analysis for different cropping systems in regions with highly variable agro-ecological zones. The approach allows the identification of yield defining, yield limiting and yield reducing factors and the development of proper strategies to counteract their effects.

SAMENVATTING

Dit proefschrift beoogt de productiesystemen van aardappelpootgoed en van consumptie-aardappelen in Argentinië te analyseren en te onderzoeken welke opbrengstbeperkingen mogelijk aanwezig zijn, teneinde specifieke strategieën te ontwikkelen om de pootgoedkwaliteit te verbeteren en de opbrengsten te verhogen. Teneinde deze doelstellingen te bereiken werd gekozen voor een benadering gebaseerd op een overzichtstudie in het veld en het gebruik van Geografische Informatie Systemen en van gewassimulatiemodellen. Daarnaast werd een analyse uitgevoerd van de kloof tussen potentiële en actuele opbrengsten en werden strategieën ontwikkeld teneinde problemen met betrekking tot pootgoedkwaliteit en opbrengstbeperkingen op te lossen.

Actuele en potentiële productie in Argentinië

De aardappel is het belangrijkste tuinbouwgewas in Argentinië. Op dit moment beslaat het areaal 100.000 ha. De commerciële teelt begon in 1872/1873 en de productie nam sterk toe als gevolg van een toename van het areaal en van de opbrengst per hectare. De teelt kan plaatsvinden in vier verschillende teeltseizoenen: de vroege teelt (juni-oktober), de middelvroege teelt (juli-november), de middellate teelt (oktober-maart) en de late teelt (februari-juni). Deze teeltseizoenen kunnen worden gekarakteriseerd op basis van weer, bodemgesteldheid, gewastype of teeltdoel, opbrengstniveau en de opbrengstbepalende, -beperkende en -reducerende factoren. Voor elk teeltgebied en teeltseizoen worden de factoren bediscussieerd die van invloed zijn op de gewassen die worden geteeld voor de productie van pootgoed, tafelaardappelen en aardappelen voor de verwerkende industrie. Tevens worden de mogelijkheden voor verdere opbrengstverbetering besproken. In de overzichtstudie wordt vastgesteld dat er gedurende de laatste 20 jaren belangrijke opbrengstverbeteringen zijn gerealiseerd in Argentinië. Dit komt vooral door het gebruik van beter pootgoed, hoewel de kwaliteit van pootgoed zowel fysiologisch als fytosanitair nog aanmerkelijk verbeterd kan worden. Er is evenwel weinig bekend over de mogelijkheden de teelt verder uit te breiden, zowel op regionaal als nationaal niveau. Er is evenmin veel bekend over de potentiële opbrengsten van de aardappel in de zeer uiteenlopende agro-ecologische zones van het land. Daarom werden de volgende activiteiten ontplooid: 1. karakterisering van de agro-ecologische zones; 2. vaststellen van de potentiële groeiseizoenen; 3. berekenen van de potentiële opbrengsten in elk van deze gebieden en groeiseizoenen met behulp van het gewasgroeimodel LINTUL-POTATO; 4. het combineren van het gebruik van Geografische Informatie Systemen

(GIS) voor landevaluatie met het gebruik van simulatiemodellen die de potentiële opbrengst kunnen berekenen teneinde de mogelijkheden te onderzoeken voor stijgingen in areaal en opbrengst op lokaal, regionaal of nationaal niveau. Bovendien wordt op basis van dit proefschrift een raamwerk voorgesteld voor het analyseren van verschillende productie- en gewassystemen.

Opbrengstvoorspelling en analyse van de kloof tussen potentiële en actuele opbrengsten

Twee gewasgroeimodellen werden gebruikt. Het model SUBSTOR-POTATO werd gebruikt voor opbrengstvoorspelling en het model LINTUL-POTATO werd gebruikt voor de berekening van potentiële opbrengsten en het vaststellen van de kloof tussen potentiële en actuele opbrengsten. Om te onderzoeken hoe goed deze modellen onder Argentijnse omstandigheden functioneren werden deze modellen gecalibreerd met en gevalideerd tegen experimentele data van verschillende locaties en jaren. Voor het model SUBSTOR-POTATO werden via calibratie ras-specifieke coëfficiënten verkregen. Validatie op basis van verschillende onafhankelijke sets van veldgegevens voor de rassen Huinkul, Kennebec, Mailén en Spunta leverde een goede overeenkomst tussen waargenomen en gesimuleerde opbrengsten op (R^2=0,915; n=24), althans in het traject van normale knolopbrengsten. Als de invoerparameter rijpheidsdatum echter niet werd meegenomen, werden knolopbrengsten zwaar overschat als gevolg van een overschatting van de waardes voor de bebladeringsindex tijdens rijping. Om dit probleem op te lossen is het noodzakelijk een genotype-specifieke coëfficiënt voor de duur van de knolgroei in het model op te nemen.

Vijf verschillende gebieden waarin aardappels worden geteeld werden aan een nadere analyse onderworpen. De potentiële opbrengsten die werden berekend met het model LINTUL-POTATO werden vergeleken met de actuele en de haalbare opbrengsten. Op basis van deze vergelijkingen kon vervolgens een analyse van de kloof tussen actuele en potentiële opbrengsten worden gemaakt en konden maatregelen worden gesuggereerd om de opbrengst te verhogen. Het belangrijkste teeltgebied is het zuidoosten van de provincie Buenos Aires. In dat gebied ligt de actuele opbrengst op 30 ton ha^{-1}. Dat is veel minder dan de 126 ton ha^{-1} die met LINTUL-POTATO werd berekend. Verschillen tussen actuele en potentiële opbrengsten konden worden toegeschreven aan verschillen in lichtonderschepping door het gewas. Betere regulatie van de water- en kunstmestvoorziening kon de kloof tussen actuele en potentiële opbrengsten doen afnemen. Haalbare opbrengsten van 50 en 100 ton ha^{-1} in de gebieden met de late en middellate teelten tonen zulks aan. In andere gebieden bleken de fysiologische leeftijd van het pootgoed en de water- en nutriëntenvoorziening de belangrijkste opbrengstbeperkende factoren te zijn. De gezondheid van het pootgoed en van de gewassen bleken belangrijke opbrengstreducerende factoren. Voor de regio Tucumán, waar alleen de vroege teelt plaatsvindt, is de actuele opbrengst gemiddeld 18 ton ha^{-1}, terwijl de haalbare opbrengst van 50 ton ha^{-1} werd gerealiseerd wanneer pootgoed van de juiste leeftijd werd gebruikt en ervoor werd gezorgd dat water en nutriënten niet limiterend waren.

Fysiologische leeftijd van het pootgoed

Een nieuwe, eenvoudige en betrouwbare index voor de fysiologische leeftijd (FLI) werd ontwikkeld, die rekening houdt met de effecten van chronologische en fysiologische leeftijd en die de effecten van deze beide vormen van leeftijd combineert. De berekeningen van de FLI waren gebaseerd op enkele belangrijke, maar eenvoudige te kwantificeren gebeurtenissen in het leven van een poter, te weten de datum van loofdoding van het pootgoedgewas (T_0) en het eind van de incubatieperiode van het pootgoed, bepaald onder standaardcondities. De formule voor de FLI is dan $FLI=T_1/T_2$, waarbij T_1 het aantal dagen is tussen het moment van loofdoding (T_0) en het moment waarop de poters worden geplant, terwijl T_1 het aantal dagen is tussen loofdoding en het eind van de incubatieperiode. De FLI geeft de fysiologische leeftijd weer van pootgoed in een traject van 0 voor fysiologisch zeer jong pootgoed tot 1 voor fysiologisch zeer oud pootgoed. De FLI werd getest door bestaande datasets opnieuw te evalueren en te bewerken. Bovendien werden er speciaal voor dit doel experimenten uitgevoerd, waarin de effecten van herkomst van het pootgoed en bewaarcondities gedurende verschillende jaren onderzocht werden. Uit de resultaten kan worden geconcludeerd dat de FLI goed kan worden gebruikt om de effecten op fysiologische leeftijd vast te stellen van condities tijdens de teelt, ras, herkomst van het pootgoed, bewaarsysteem, tijdstip van loofdoding, alsmede die van verschillende behandelingen voor het poten van het pootgoed. De FLI is makkelijk te meten, is objectief, reproduceerbaar en betrouwbaar en kan derhalve nuttig zijn om het groeivermogen van het pootgoed te beschrijven.

Strategieën om pootgoedkwaliteit te verbeteren en opbrengsten te verhogen

Zoals hierboven reeds werd gemeld is de fysiologische leeftijd van het pootgoed in Argentinië één van de belangrijkste opbrengstbeperkende factoren. Knol- en loofziektes, zoals veroorzaakt door virussen, zijn belangrijke factoren die de opbrengst en kwaliteit reduceren. Het proefschrift bevat een beschrijving van verschillende strategieën om deze problemen te verhelpen.

Er werd onderzoek gedaan naar de effecten van bespuitingen van het loof met oplossingen van groeistoffen, zoals benzylaminopurine (BAP), gibberellinezuur (GA_3) en de combinatie van

BAP + GA_3, in gewassen die geteeld werden vanuit pootgoed van verschillende leeftijd. Deze groeistoffen kunnen wellicht het effect van fysiologische leeftijd van het pootgoed beïnvloeden. In twee seizoenen bleek pootgoed dat bewaard was in aardappelhopen ouder te zijn dan pootgoed dat koud bewaard was. Pootgoed van het ras Pampeana was ouder dan pootgoed van Huinkul. BAP bleek het effect van gevorderde fysiologische leeftijd op het verouderen van het gewas te onderdrukken. Daardoor werd een langere bebladeringsduur bereikt en bleef de fotosynthesesnelheid hoger. Deze effecten vertaalden zich ook in een hogere opbrengst.

In Argentinië zijn verschillende gebieden geschikt voor de teelt van pootgoed. Zoals eerder reeds bleek, kent elk van deze gebieden echter specifieke problemen, die vooral te maken hebben met het vóórkomen van ziektes en plagen. Het eiland Tierra del Fuego ligt zeer geïsoleerd van de traditionele teeltgebieden van de aardappel. Daarom werd nagegaan of op dit eiland wellicht pootgoedteelt kon plaatsvinden. De rassen Achatt, Mailén INTA, Pampeana INTA en Spunta werden geteeld in Río Grande, San Pablo en Ushuaia in de jaren 1991-1994. Waargenomen werd of er nematoden voorkwamen en hoe de populatie van luizen zich ontwikkelde. De gemiddelde knolopbrengsten bedroegen 20,1 tot 37,6 ton per ha. Na drie jaar bleken de percentages knollen aangetast met de virussen PVY en PLRV nog steeds laag (tussen de 0 en 1% voor verschillende rassen en locaties). Dit kwam doordat er gedurende de teelt nauwelijks luizen vóórkwamen. Bovendien bleek het geteelde pootgoed relatief jong. Lange dag, vroege vorst en harde wind kunnen weliswaar de opbrengsten beperken, maar de kwaliteit van het verkregen pootgoed was uitstekend. Het eiland kan derhalve worden beschouwd als een "ecologische vrijplaats" en is zeer geschikt voor het produceren van gezond pootgoed van een hoge fysiologische kwaliteit.

Conclusies

Het areaal aardappel stabiliseert zich in Argentinië rond de 100,000 ha. De knolopbrengsten per hectare nemen nog steeds toe, dankzij het gebruik van kwalitatief goed pootgoed, de teelt van nieuwe rassen en een verbeterde landbouwtechnologie. Er zijn echter nog steeds grote toenames mogelijk van het areaal aardappel en van de opbrengst per hectare.

De fysiologische leeftijd van het pootgoed is één van de belangrijkste opbrengstbeperkende factoren. Indien het gebruik van pootgoed van de juiste fysiologische leeftijd wordt bevorderd zijn grote opbrengststijgingen mogelijk. De juiste leeftijd hangt af van het ras, het teeltseizoen en het teeltdoel. Het bleek mogelijk maatregelen te nemen die er toe leiden dat de fysiologische of fytosanitaire beperkingen van het pootgoed worden opgeheven. Dergelijke maatregelen kunnen bijdragen aan het ontwikkelen van een pootgoedteelt met hogere opbrengsten van kwalitatief beter pootgoed.

In dit proefschrift werden verschillende benaderingen gecombineerd. Het proefschrift beschrijft de resultaten van een overzichtstudie, GIS studies, simulatiestudies en analyses van de kloof tussen actuele en potentiële opbrengsten. Bovendien werden enkele aspecten in detail nader geanalyseerd. Een dergelijke benadering van de analyse van een aardappel-productiesysteem kan dienen als raamwerk voor andere productiesystemen in gebieden met grote variatie in agro-ecologische condities. Met een dergelijke benadering is het mogelijk de opbrengstbepalende, opbrengstbeperkende en opbrengstkortende factoren nader te bepalen en vervolgens maatregelen te ontwikkelen die de gevolgen van deze factoren teniet kunnen doen.

RESUMEN

El propósito de esta tesis es analizar el sistema de producción de papa *semilla* y consumo en la Argentina y los posibles factores que restringen el rendimiento, a fin de desarrollar estrategias específicas para incrementar la calidad de la *semilla* y los rendimientos. La propuesta para llevar a cabo estos objetivos se basa en un relevamiento de campo, el uso de Sistemas de Información Geográfica y modelos de simulación, un análisis de las diferencias de rendimiento y el desarrollo de estrategias específicas para lograr los objetivos propuestos.

Producción actual y potencial en la Argentina

La papa es el cultivo hortícola más importante de la Argentina y actualmente se cultivan 100.000 hectáreas. Comercialmente, el cultivo se inicio en 1872/73 y su producción aumentó, gradualmente, tanto por el aumento en la superficie cultivada como por el aumento en los rendimientos. Existen cuatro épocas de cultivo: temprana (Junio-Octubre), semi-temprana (Julio-Noviembre), semi-tardía (Octubre-Marzo) y tardía (Febrero-Junio). Estas se caracterizaron de acuerdo al clima, tipo de cultivo, tipo de suelo, nivel de rendimiento y de acuerdo a los factores que determinan, limitan o reducen el rendimiento. Se analizan, además, los factores que afectan la producción de los cultivos destinados a *semilla*, consumo o industria, para cada época y área de cultivo y, asimismo se discuten, distintas posibilidades para lograr aún, mayores rendimientos. El relevamiento establece que, en la Argentina, durante los últimos 20 años, se han logrado importantes aumentos en los rendimientos, principalmente debido al uso de semilla de alta calidad, a pesar de que, la calidad fisiológica y fitosanitaria de la semilla todavía puede ser mejorada. De todos modos, es escasa la información que existe acerca de las posibilidades de expansión del cultivo, ya sea a nivel nacional o regional y acerca del potencial de rendimiento del mismo. Por ello, (1) se caracterizan distintas zonas agro-ecológicas de acuerdo al potencial de rendimiento del cultivo; (2) se establece la duración potencial de las épocas de cultivo; (3) se estima, a través del modelo de simulación LINTUL-POTATO el potencial de rendimiento en estas zonas y épocas y (4) se demuestra que como el uso combinado de un Sistema de Información Geográfica (GIS) para la evaluación de tierras, y de modelos de simulación del rendimiento resulta una importante herramienta para estimar las posibilidades de incrementar la producción, tanto a nivel, regional como nacional. Por ello, y basado en los resultados de esta tesis, se propone un marco de trabajo general para el análisis de diferentes sistemas de cultivo.

Predicción del rendimiento y análisis de las diferencias en rendimiento

Para llevar a cabo estos estudios se utilizaron dos modelos de simulación. El modelo SUSBSTOR-POTATO fue utilizado para las predicciones de rendimiento y el modelo LINTUL-POTATO para llevar a cabo las estimaciones de rendimiento potencial del cultivo y para analizar las diferencias en rendimiento. Para analizar su comportamiento bajo las condiciones de Argentina ambos modelos fueron calibrados y validados utilizando resultados experimentales de diversos sitios y años. Durante la calibración del modelo SUBSTOR-POTATO se obtuvieron coeficientes específicos para cada cultivar. La validación se realizó en base a datos independientes obtenidos a nivel de campo, que incluyeron los cultivares Huinkul MAG, Kennebec, Mailén INTA y Spunta; y se encontró una muy buena correlación entre los valores observados y simulados dentro de los límites normales de rendimiento del cultivo. A pesar de ello, cuando el parámetro de entrada, fecha de maduración, no era considerado, los rendimientos eran sobre-evaluados, debido a la sobre-estimación de los valores del Indice de Area Foliar (IAF) durante la maduración. Para resolver este problema es necesario incluir en el modelo un coeficiente genético referido a la duración del período de *llenado* de los tubérculos.

Se llevó a cabo un estudio con datos provenientes de cinco distintas regiones de cultivo a fin de comparar los datos de rendimiento potencial, obtenidos con el modelo de simulación LINTUL-POTATO, con los rendimientos actuales y posibles de ser obtenidos, a fin de realizar un análisis de las diferencias en rendimiento y sugerir distintas alternativas para aumentar el rendimiento. En el sudeste de la provincia de Buenos Aires, la región productora de papa más importante del país, el rendimiento promedio actual es de 30 t ha^{-1} y está muy por debajo del rendimiento potencial de 126 t ha^{-1} calculado con el modelo de simulación LINTUL-POTATO. Las diferencias entre el rendimiento actual y potencial pueden ser atribuídas a la sub-óptima intercepción de la radiación. Esta diferencia entre el rendimiento actual y potencial podría ser disminuída a través de una mejora en el manejo del agua y los nutrientes, tal como lo demuestran los niveles de rendimiento posibles de ser alcanzados de 50 y 100 t ha^{-1} para las áreas de cultivo tardío y semitardío, respectivamente. En otras áreas se identificaron como principales limitantes del rendimiento la edad fisiológica de los tubérculos y el manejo del agua y los nutrientes, en tanto que en otras áreas se identificó, como principal factor responsable de reducciones en el rendimiento, al estado fitosanitario de los tubérculos. En Tucumán, donde se lleva a cabo el cultivo temprano, el rendimiento promedio actual es de 18 t ha^{-1}, pero se han obtenido rendimientos posibles de 50 t ha^{-1}, cuando la eda fisiológica de la semilla era adecuada y el agua y los nutrientes no resultaron limitantes para el rendimiento del cultivo.

Edad fisiológica de los tubérculos semilla

Se presenta un nuevo, sencillo y confiable Indice de Edad Fisiológica (IEF) que considera y reconcilia tanto el efecto de la edad cronológica como fisiológica de la semilla. Los cálculos del IEF están basados en distintos días-clave dentro del ciclo de vida un un tubérculo semilla, que son muy sencillos de determinar, tales como, la fecha de destrucción del follaje del cultivo destinado a semilla (T_0) y la duración del período de incubacion de los tubérculos *semilla*, medida bajo condiciones estándares. La fórmula del IEF es: T_1/T_2, donde T_1 corresponde a la cantidad de días transcurridos desde T_0 hasta el momento de posible plantación de los tubérculos y T_2 corresponde a la cantidad de días transcurridos desde T_0 hasta el final del período de incubación de los tubérculos. El IEF expresa el envejecimiento fisiológico de los tubérculos dentro de los límites, 0, para tubérculos fisiológicamente jóvenes a 1, para tubérculos envejecidos. Para testear el IEF se re-evaluaron y re-elaboraron datos pre-existentes y además se llevaron a cabo durante varios años, experimentos específicos acerca de los efectos del origen de la *semilla* y las condiciones de almacenamiento en distintos cultivares. Los resultados obtenidos demostraron que, el IEF puede ser utilizado para establecer diferencias en la edad fisiológica debidas a condiciones de cultivo, períodos y sistemas de almacenamiento, cultivares, origen de los tubérculos *semilla*, fecha de destrucción del follaje y diferentes tratamientos de pre-plantación. El IEF es fácil de medir, objetivo, reproducible y confiable y podría ser utilizado para describir el desempeño de la *semilla* en los cultivos siguientes.

El abastecimiento de *semilla* está basado en la producción nacional de *semilla* pre-básica, básica y registrada. Alrededro de un 50% del total de la semilla requerida esta sometida a certificación a través de los servicios de análisis de *semilla*, aproximadamente unas 5000 hectáreas. Los tubérculos *semilla* se producen en diferentes áreas, desde donde se distribuyen a las áreas de cultivos para consumo e industria a lo largo del año. Esta situación determina que no siempre la semilla alcance la nueva plantación con una adecuada edad fisiológica. El período de post-cosecha y las condiciones de almacenamiento fueron identificados como los principales factores que afectan la edad fisiológica en distintos cultivares, pero principalmente en el cv. Spunta, que es altamente sensible al envejecimiento fisiológico. Dado que el cultivo de papa se lleva a cabo a lo largo de todo el año calendario, sería posible mejorar el flujo de *semilla*, siempre y cuando se considere llevar a cabo un adecuado manejo fitosanitario de los cultivos.

Estrategias para mejorar la calidad de la semilla y el rendimiento

Tal como se mencionó en las secciones anteriores, en Argentina, la edad fisiológica de los tubérculos *semilla* es uno de los principales factores que limitan el rendimiento, en tanto que las enfermedades, como por ejemplo aquellas causadas por virus, son importantes factores capaces de reducir el rendimiento. Diferentes estrategias pueden ser utilizadas para superar estos problemas.

Se estudiaron los efectos de la aplicación de reguladores vegetales del crecimiento (RVC), bencilaminopurina (BAP) y ácido giberélico (AG_3) y BAP+AG_3 sobre cultivos provenientes de *semilla* con distinta edad fisiológica. En ambas campañanas, los tubérculos almacenados en pilas a campo alcanzaron la nueva plantación con una mayor edad fisiológica que aquellos conservados en cámaras refrigeradas. Los tubérculos del cv. Pampeana INTA resultaron fisiológicamente más envejecidos que aquellos del cv. Huinkul MAG. Las aplicaciones de BAP, en los cultivos provenientes de tubérculos semilla fisiológicamente envejecidos, permitieron revertir los efectos de la edad fisiológica sobre la senescencia y el rendimiento, dado sus efectos sobre la tasa fotosintética y la cobertura del suelo.

En la Argentina, existen distintas áreas que resultan adecuadas para la producción de tubérculos *semilla*; a pesar de ello en estas áreas existen problemas específicos, principalmente relacionados con la presencia de diferentes plagas y enfermedades, tal como se ha demostrado en secciones anteriores de este trabajo. La isla de Tierra del Fuego se encuentra aislada de las áreas tradicionales del cultivo. Por lo tanto se evaluó su potencial respecto a la producción de tubérculos *semilla*. Durante 1991-1994 se llevaron a cabo ensayos a campo, en las localidades de Río Grande, San Pablo y Ushuaia con los cultivares Achatt, Mailén INTA, Pampeana INTA y Spunta. Se determinó la presencia de nematodes y la dinámica poblacional de áfidos. El rendimiento promedio de los cultivos fue de 20.1–37.6 t ha^{-1} y luego de tres años de experiencias los porcentajes de infección con PVY y PLRV se mantuvieron muy bajos (0-1% para los diferentes cultivares y localidades), debido a la baja población de áfidos registrada durante el cultivo. Además, los tubérculos *semilla* resultaron fisiológicamente jóvenes. En algunos años, los días largos, las heladas tempranas y los fuertes vientos son determinantes en cuanto a los rendimientos, pero la calidad de los tubérculos-*semilla* fue excelente. La isla puede ser considerada, desde el punto de vista ecológico, un paraíso a salvo de plagas y enfermedades, y es muy adecuada para la obtención de *semilla* sana y fisiológicamente joven.

Conclusiones

El área cultivada con papa se ha estabilizado alrededor de las 100,000 hectáreas, en tanto que los rendimientos por unidad de área continuan incrementándose debido al uso de *semilla* de calidad, nuevos cultivares y mejoras en la tecnología del cultivo. Al margen de estos hechos, todavía es posible aumentar, substancialmente, el área cultivada y los rendimientos.

La edad fisiológica de la *semilla* fue identificada como uno de los principales factores que limitan el rendimiento, por lo tanto es posible aumentar el rendimiento si se utiliza *semilla* de una adecuada edad fisiológica. La edad fisiológica adecuada debe considerarse en función de los cultivares y la época y destino del cultivo. Se desarrollaron estrategias exitosas, tanto para reducir el impacto de las limitantes fisiológicas, como de aquellas causadas por factores que reducen el rendimiento; en el futuro estas estrategias pueden ser utilizadas para mejorar el rendimiento y la calidad de los cultivos para *semilla*.

Esta tesis combina el uso de un relevamiento a nivel de campo con Sistemas de Información Geográfica (GIS), modelos de simulación y análisis de las diferencias en el rendimiento. Esto puede servir como ejemplo de un marco de trabajo para el análisis de diferentes sistemas de cultivo en regiones con zonas agro-ecológicas muy contrastantes. Esta propuesta permite además la identificación de factores que determinan, limitan o reducen el rendimiento y el desarrollo de estrategias adecuadas para contrarrestar estos efectos.

CURRICULUM VITAE

Daniel Osmar Caldiz was born on 19 June 1955 in La Plata, Argentina. After obtaining a *Bachiller Nacional* diploma from the Colegio Nacional, La Plata National University, he started his studies at the Faculty of Agronomy of the same university in 1974. He graduated as an *Agricultural Engineer* in 1978. From 1979-1983 he was a fellow of the Scientific Research Board, Province of Buenos Aires, and from 1984-85 of the National Research Council, CONICET, specializing in potato physiology. Meanwhile, in 1981, with a fellowship from the Netherlands Government he attended the International Potato Course held in Wageningen. He is member of the Instituto de Fisiología since 1977, occupying positions as Assistant Student, Teacher and Professor; since 1994 he is Full Adjunct Professor in Plant Physiology. Since 1985, he is also member of the Scientific Research and Technological Carreer at the National Research Council, CONICET, as Assistant, Adjunct and, at present, Independent Researcher. He has published about 60 research and extension papers in recognized scientific journals and lectured at national and international meetings and post-graduate courses. He was Secretary-Treasurer of the National and Latin American Plant Physiology Association (1983/85 and 1987/89); founder-member (1994) and Vice-President for Central and South America of the International Allelopathy Society (1994-96); Associated Editor of the scientific journal *Revista de la Facultad de Agronomía, La Plata* (1988-1997); nominated *Who's Who in the World 1997* and consultant of different national and international government organizations, universities and agricultural companies in Argentina and Latin America.

PUBLICATIONS BY THE AUTHOR

Potato

Beltrano, J. & D.O. Caldiz, 1993. Effects of Johnsongrass densities on potato yield. *Pesquisa Agropecuaria Brasileira* 28: 21-24.

Caldiz, D.O., 1981. Potato production in Argentina. In: *Reports of Participants, 10th International Potato Course.* Wageningen, The Netherlands, pp. 1-7.

Caldiz, D.O., 1983. La edad fisiológica de los tubérculos de papa. *Enfoques del Sudeste,* Oct., Nov., Dic., 1983, pp. 7, 6-7 y 11.

Caldiz, D.O., 1983. Seed potato tuber production in Argentina. *Proceedings 6th Symposium International Society Tropical Root Crops.* International Potato Center, Lima, Perú, pp. 174.

Caldiz, D.O., 1989. *Fisiología de los tubérculos de papa durante el cultivo y el almacenamiento.* Frigopap SA, Balcarce, 27 pp. Edición especial en adhesión a la *XIV Reunión de la ALAP,* 1989.

Caldiz, D.O., 1990. Fisiología de la conservación. *Actas de la Jornada de Actualización Técnica en Papa.* Círculo de Ingenieros Agrónomos de Balcarce - Agencia de Extensión INTA Balcarce, Balcarce, pp. 23-27.

Caldiz, D.O., 1991. Influence of origin and storage system on the physiological age, crop growth and tuber yield of seed potatoes. *Indian Journal of Agricultural Sciences* 61: 1-6.

Caldiz, D.O., 1994. Genetic improvement and associated physiological changes in the potato. In: *Genetic Improvement of Field Crops.* G. Slafer, Ed. Marcel Dekker, New York, pp. 361-411.

Caldiz, D.O., 1996. Seed potato (*Solanum tuberosum* L.) yield and tuber number increase after foliar applications of cytokinins and gibberellic acid under field and glasshouse conditions. *Plant Growth Regulation* 20: 185-188.

Caldiz, D.O., 1996. Efectos del manejo del cultivo y el almacenamiento sobre la productividad de papa semilla en la Argentina. *Primer Seminario de Refrescamiento del International Potato Course para Alumnos de América Latina y el Caribe.* IAC-Holanda y MINAG-Cuba, La Habana, Cuba, 11 pp.

Caldiz, D.O. & F.K. Claver, 1981. Influencia de las temperaturas sobre la capacidad simiente de la papa. *Boletín Sobre Desarrollo y Transferencia de Tecnología CIC* 5: 15.

Caldiz, D.O. & M. Panelo, 1986. Efectos de la competencia de malezas de hoja ancha y angosta sobre el crecimiento y el rendimiento en papa. *Revista Facultad de Agronomía, La Plata* 62: 37-43.

Caldiz, D.O. & J. Beltrano, 1992. Physiology and improvement of potatoes (*Solanum tuberosum* L.). *Transactions of the Malaysian Society of Plant Physiology* 3: 80-83.

Caldiz, D.O. & A.J. Haverkort, 1994. Alternativas para incrementar la producción de papa en el área de Villa Dolores, Córdoba. *Gaceta Agronómica* 14: 186-189.

Caldiz, D.O. & F.J. Gaspari, 1997. Análisis de los factores determinantes del rendimiento en papa (*Solanum tuberosum* L.) con especial referencia a la situación argentina. *Revista de la Facultad de Agronomía, La Plata* 102: 203-228.

Caldiz, D.O. & P.C. Struik, 1999. Survey of actual potato production and possible yield constraints in Argentina. *Potato Research* 42: 43-63.

Caldiz, D.O., F.K. Claver & A.R. Escande, 1984. Effect of harvesting time and storage system on the quality of seed potato tubers. *Turrialba* 34: 287-290.

Caldiz, D.O., M. Panelo, F.K. Claver & E.R. Montaldi, 1985. The effect of two planting dates on the physiological age and yielding potential of seed potatoes grown in a warm-temperate climate in Argentina. *Potato Research* 28: 425-434.

Caldiz, D.O., J.R. Alaniz & F.K. Claver, 1986. Relaciones entre la edad fisiológica y el contenido de azúcares totales y reductores en tubérculos de papa *(Solanum tuberosum* L.*)* destinados a nueva plantación. *Turrialba* 36: 315-320.

Caldiz, D.O., C. Marchan, S.D. Tenenbaum & E. Vera, 1988. Períodos de dormición, brotación e incubación en tres nuevas variedades de papa obtenidas por el INTA. *Horticultura Argentina* 7: 16-19.

Caldiz, D.O., C. Della Croce, E. Vera & C. Marchan, 1989. Efectos del almacenamiento y de la época de aplicación del nitrógeno sobre la cobertura foliar y el rendimiento en papa. *Revista Latinoamericana de la Papa* 2: 46-56.

Caldiz, D.O., M. Panelo & M. Inchausti, 1994. Edad fisiológica y rendimiento en papa "semilla" (*Solanum tuberosum* L.) modificados por el prebrotado y la defoliación anticipada. *Revista de la Facultad de Agronomía, La Plata* 70: 57-63.

Caldiz, D.O., G.N. Brocchi, J.R. Alaniz & C. Marchan, 1996. Starch synthase activity and starch and dry matter accumulation in potato tubers of different physiological age. *Pesquisa Agropecuaria Brasileira* 31: 853-858.

Caldiz, D.O., L.V. Fernandez, F. Marco & A. Clúa, 1997. Efectos de la hidrazida maleica sobre el rendimiento, contenido de materia seca y brotación en papa (*Solanum tuberosum* L.)

destinada al consumo fresco. *Revista de la Facultad de Agronomía, La Plata* 102: 163-173.

Caldiz, D.O., A. Clúa, J. Beltrano & S.D. Tenenbaum, 1998. Ground cover, photosynthetic rate and tuber yield in seed potatoes (*Solanum tuberosum* L.) with different physiological age modified by foliar applications of plant growth regulators. *Potato Research* 41: 175-186.

Caldiz, D.O., L. Lanfranconi, L.V. Fernández & M. Nasetta, 1999. Aplicación de hidrazida maleica en papa (*Solanum tuberosum* L. cv. Spunta) y sus efectos sobre el rendimiento, la brotación y el nivel de residuos de los tubérculos. *Revista Latinoamericana de la Papa* 11: 164-172.

Caldiz, D.O., O.H. Caso, G. Vater & L.V. Fernández, 1999. The potential for the production of high quality seed potatoes in Tierra del Fuego island, Argentina. *Potato Research* 42: 9-23.

Escande, A.R., A. Melegari, D.O. Caldiz, J.C. Rodriguez, H. Palladino & R.H. Miron, 1985. Influencia del sistema de almacenamiento sobre la capacidad simiente de tubérculos de papa (*Solanum tuberosum* L. cvs. Spunta y Sierra Volcán). *Idia* 440: 24-30.

Escande, A.R., D.O. Caldiz & J.C. Rodriguez, 1986. Influencias del sistema de almacenamiento y de la época de plantación sobre la productividad de tubérculos de papa *(Solanum tubersoum* L.) simiente. *Turrialba* 36: 237-244.

Haverkort, A.J. & D.O. Caldiz, 1994. Aardappelproduktie in Argentinië. *Aardappelwereld Magazine* 48: 18-20.

Panelo, M. & D.O. Caldiz, 1989. Influence of early haulm killing of seed crops on subsequent sprouting, physiological ageing and tuber yield. *Potato Research* 32: 3-7.

Panelo, M., D.O. Caldiz & F.K. Claver, 1982. La tuberización y el rendimiento de tres variedades de papa cultivadas en Miramar, Argentina. *Revista Facultad de Agronomía, La Plata* 58: 99-120.

Travasso, M.I., D.O. Caldiz & J.A. Saluzzo, 1996. Yield prediction using the SUBSTOR-POTATO model under argentinian conditions. *Potato Research* 39: 305-312.

Other crops and weeds

Bartoli, C.G., J. Beltrano, L.V. Fernández & D.O. Caldiz, 1993. Control of the epiphytic weeds *Tillandsia recurvata* and *T. aeranthos* with different herbicides. *Forest Ecology and Management* 59: 289-294.

Beltrano, J., D.O. Caldiz, R. Barreyro, G. Sánchez Vallduvi & R. Bezus, 1994. Effects of foliar applied gibberellic acid and benzyladenine upon yield components and grain yield in sunflower (*Helianthus annus* L.). *Plant Growth Regulation* 15: 101-106.

Caamaño, A., M. Maturano, E. Andres, M. Osinalde, D.O. Caldiz, J. Beltrano, D. Gimenez & P.A. Balatti, 1991. *Herbicidas: clasificación, características y acción fisiológica.* Centro de Estudiantes de la Facultad de Ciencias Agrarias y Forestales, UNLP, 12 pp.

Caldiz, D.O., 1994. *Cultivo In Vitro y Micropropagación.* Centro de Estudiantes de la Facultad de Ciencias Agrarias y Forestales, UNLP, 19 pp.

Caldiz, D.O., 1996. *Bioproductividad en sistemas agrícolas y naturales.* Centro de Estudiantes de la Facultad de Ciencias Agrarias y Forestales, UNLP, 21 pp.

Caldiz, D.O. & C.M. Teruel, 1982. Evaluación de cuatro praderas perennes bajo las condiciones ecológicas del valle de Lerma. *Gaceta Agronómica* 2: 552-558.

Caldiz, D.O. & S.J. Sarandon, 1988. Influence of shading in different periods upon ear development, grain yield and its components in two wheat cultivars. *Agronomie* 8: 327-332.

Caldiz, D.O. & J. Beltrano, 1989. Control of the epiphytic weeds *Tillandsia recurvata* and *T. aëranthos* with simazine. *Forest Ecology and Management* 28: 153-159.

Caldiz, D.O. & S.J. Sarandon, 1989. Efectos de la aplicación de urea por vía foliar y radical sobre los componentes del rendimiento, el rendimiento y el porcentaje de proteínas en trigo pan. *Revista Facultad de Agronomía, La Plata* 65: 89-92.

Caldiz, D.O. & S.J. Sarandon, 1995. Genetic improvement of bread wheat (*Triticum aestivum* L.) in Argentina: relationships between yield and its components under different nitrogen supply. *Agriscientia* 12: 3-9.

Caldiz, D.O. & L.V. Fernández, 1995. The role of the epiphytic weeds *Tillandsia recurvata* and *T. aëranthos* in native rural and urban forests. *International Journal of Ecology and Environmental Sciences* 21: 177-197.

Caldiz, D.O. & L.V. Fernández, 1999. Allelopathy as a possible strategy for weed control in agriculture and forestry systems, Chapter 41. In: *Recent Advances in Allelopathy, vol. I. A Science for the Future.* F.A. Macías, J.C.G. Galindo, J.M.G. Molinillo & H.G. Cutler, Eds. Servicio de Publicaciones Universidad de Cádiz-International Allelopathy Society, Cádiz, Spain, pp. 237-248.

Caldiz, D.O., S.J. Sarandon & J. Beltrano, 1984. Efectos de la cinetina y del ácido giberélico sobre los componentes del rendimiento y el porcentaje de proteínas en dos cultivares de trigo pan. *Revista Facultad de Agronomía, La Plata* 60: 15-20.

Caldiz, D.O., J. Beltrano, L.V. Fernandez, S.J. Sarandon & C. Favoretti, 1991. Effects of foliar applied benzyladenine on grain yield and grain protein in wheat *(Triticum aestivum* L.*)*. *Plant Growth Regulation* 10: 197-204.

Caldiz, D.O., J. Beltrano, L.V. Fernández & I. Andia, 1993. Survey of *Tillandsia recurvata* L. Preference, abundance and its significance for natural forests. *Forest Ecology and Management* 57: 161-168.

Claver, F.K., J.R. Alaniz & D.O. Caldiz, 1983. *Tillandsia spp.* Epiphytic weeds of trees and bushes. *Forest Ecology and Management* 6: 367-372.

Fernandez, L.V., J. Beltrano & D.O. Caldiz, 1989. Germinación y longevidad de semillas de *Tillandsia recurvata* L. *Revista Facultad de Agronomía, La Plata* 65: 81-85.

Gianibelli, M.C., S.J. Sarandon & D.O. Caldiz, 1989. Efecto de la fertilización nitrogenada y azufrada sobre el rendimiento en grano y sus componentes en *Triticum aestivum* L. *Revista Facultad de Agronomía, La Plata* 65: 93-95.

Gianibelli, M.C., S.J. Sarandon & D.O. Caldiz, 1992. Efecto de la fertilización nitrogenada y azufrada sobre la composición de las gliadinas en una variedad de trigo *(Triticum aestivum* L.) *Revista Española de Ciencia y Tecnología de Alimentos* 32: 95-103.

Lanfranco, J.W., R. Marlats, J. Beltrano, L.V. Fernández & D.O. Caldiz, 1990. *Investigación capacidad de uso de áreas resultantes de relleno sanitario*. CEAMSE, Buenos Aires, 94 pp.

Rivas, M.C., M. Maturano, A. Caamaño & D.O. Caldiz, 1996. Determinantes fisiológicos del rendimiento, en condiciones de baja densidad, en cultivares de trigo (*Triticum aestivum* L.) obtenidos en la Argentina en el período 1942-1992. *Revista de la Facultad de Agronomía, La Plata* 101: 81-89.

Sarandon, S.J. & D.O. Caldiz, 1987. Influencias de la fertilización nitrogenada sobre la acumulación y partición del nitrógeno en dos cultivares de T*riticum aestivum L. Revista Facultad de Agronomía, La Plata* 63: 35-45.

Sarandon, S.J. & D.O. Caldiz, 1990. Effects of varying nitrogen supply at different growth stages on nitrogen uptake and nitrogen partitioning efficiency in two wheat cultivars. *Fertilizer Research* 22: 21-27.