PRECISION IRRIGATION IN SOUTH AFRICA

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ABSTRACT

The Republic of South Africa covers an area of 122 million hectare of which 18 million hectare is potential land for cultivation. Eight percent of the potential arable land are under irrigation, which accounts for nearly half of the water requirement in South Africa. With a population of 42 million and an estimated annual population growth of 1,7%, urbanisation and industrialisation will increase the pressure on the availability of water resources and the allocation thereof in South Africa. The purpose of the National Water Act, Act 36 of 1998, is to ensure that the nation's water resources are protected, developed, conserved, managed and controlled. Agricultural production under irrigation in South Africa retrieves water from water resources such as groundwater which irrigates 24% of the irrigable area, while surface water irrigates 76% of the irrigable area in South Africa. Farmers using groundwater for irrigation is currently subjected to a water resource management charge of 0,54 c/m^3*. Users of surface water buy a water-right and pay an annual water levy, and groundwater belongs to the owner of the farm who can use it at no cost. Precision irrigation as an aspect of precision agriculture, is a relatively new concept in irrigation farming worldwide. It involves the application of irrigation water in optimum quantities over an area of land which are not uniform and has variations in soil type, soil water capacity, potential yield and topography. Precision irrigation provides a sustainable agricultural system which uses resources efficiently and develops and maintains the actual water demands. Precision agriculture is a knowledge-based technical management system which should optimise farm profit and minimise the impact of agriculture on the environment.*

BACKGROUND

Water is a natural resource that belongs to all people. The South African National Government has, however, recognised that water is a scarce commodity which is unevenly distributed in South Africa. Discriminatory laws and practices of the past have prevented equal access to water resources. The aim of water resource management is to protect the quality of water resources and to ensure sustainability of the nation's water resources in the interests of all water users. The National Water Act, Act 36 of 1998, was implemented in South Africa to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled (RSA, Government Gazette, 1998).

The total run-off per year from South African rivers is estimated at approximately 51 100 million m^3, but because of variable flow and high evaporation (Table 1), only 30 000 million m^3 can be practically and economically used. The total potential groundwater delivery is estimated at 12 000 million m^3, of which 5 400 million m^3 can be practically retrieved. The estimated total water used in South Africa during 2000 was 22 500 million m^3 (Stoltz, 1999:26). South Africa's annual population growth of 1,7% (Centre for African Studies, 1998), as well as urbanisation and industrialisation, put pressure upon the demand for water resources in South Africa. In an article by Stoltz in a farmers' magazine (1999:27), she quoted the assistant director of the Department of Water Affairs and Forestry, Mr Johan Wessels, who estimated that 1% of South Africa's irrigation water should be enough to supply in the basic food demands of 13 million people. According to Wessels there is approximately 1,3 million hectare under irrigation in South Africa, which is 7,2% of the total arable land in South Africa.

Ninety percent of the total area is arid and semi-arid as shown in Table 1 and is one of the reasons why it is important to protect the scarce water resources in South Africa.

Table 1: Bioclimatology of South Africa

Climatic zone	Area (%)	Annual rainfall (mm)	Annual evaporation (mm)	Aridity index
Arid	50	<500	>2 500	<0,2
Semi-arid	40	500 - 750	2 500 - 1 500	0,2 - 0,5
Sub-humid	10	>750	< 1 500	>0,5

Source: UNESCO (1977).

The irrigation sector uses approximately 50% of the water currently used in South Africa (Table 2). Groundwater irrigates 24% of the irrigable area, compared to surface water which irrigates 76% (Van Tonder & Dennis, 2000:1). South Africa has three major rivers (the Vaal, Oranje and Limpopo River) and irrigation schemes were developed near the riverbanks of these rivers and. Other irrigation schemes further away from these rivers are also supplied with water from these rivers. Groundwater is restricted and belongs to the owner of the farm. Groundwater can currently be used free of charge in South Africa, but within the next two years users will have to pay a levy for the use of groundwater for irrigation purposes. Users of surface water buy a water-right and pay an annual water levy. The average cost of water in South Africa increased by 11,9% in 1997, which is the largest increase among the countries investigated by Taylor (1998:5). If the water rates will increase during the next two years as expected (Table 2), it will have a negative effect on the economy of irrigation, which will make precision irrigation agriculture essential to be successful in irrigation farming. With the previous facts in mind it is evident that precision irrigation will become very important in the near future to protect South Africa's scarce water resources and to assist the South African irrigation farmers to farm sustainably.

Table 2 illustrates the annual sectoral water usage and charges in terms of the pricing strategy.

Table 2: Annual sector charges in terms of the pricing strategy

Catchment management activity	**SECTOR Total registered water use 1 400 × 106 m^3**			
	Municipal water use	Industrial water use	Irrigation water use	Forestry water use
Water use (☐ 10^6 m^3)	100	145	680	475
Sectoral charge (c/m^3)	0,83	0,83	0,54	0,49

Source: Pretorius (2000).

Precision agriculture in South Africa is in an infant phase and the information available is limited (Matela, 2001:5). Precision irrigation as an aspect of precision agriculture is worldwide a new concept in irrigation. To the author’s knowledge there have not been any research done in South Africa on precision irrigation. Precision irrigation involves differential delivery of irrigation water in optimum quantities over an area of land which is not uniform and has variations in soil type, soil-water capacity, yield potential and topography (Perry, 2000:1).

Precision agriculture has the potential to reduce costs and increase yields by means of more efficient and effective application of crop inputs. It can also reduce environmental impacts by allowing farmers to apply inputs at the appropriate rate only. The traditional irrigation farmer in South Africa manages crops as a unit, which is usually uniformly planted, fertilised and irrigated. Uniform application of fertiliser or water is applied to a field, but the yield potential causes that some zones are over-fertilised or over-irrigated and others are under-fertilised or under-irrigated. The purpose of this paper is to indicate the potential of precision irrigation in South Africa as well as the potential effect on the profit margin of an irrigation farm by means of a centre pivot case study of irrigated wheat.

STUDY AREA AND METHODOLOGY

The Vaalharts irrigation scheme in the Northern Cape Province in South Africa was chosen as the study area for this paper. The 1930's are remembered for the worldwide depression and drought in South Africa. Many farmers went bankrupt in these years and in November 1933 the government decided to develop the Vaalharts irrigation scheme to reduce the unemployment problem in South Africa (Strauss, 1991). In 1937 plots of 14,5 ha to 27,7 ha were allocated to beneficiary farmers. The Vaalharts irrigation scheme are known for its flat surface, and its homogeneous, red, sandy Hutton soil. The irrigation water for the Vaalharts irrigation scheme, which is estimated at 32 335 ha under irrigation, is supplied by a channel from the Vaal River. Farmers in the Vaalharts irrigation scheme receive a water quota of 7 700 cubic metre per hectare per year. Additional irrigation water can be bought at a higher price when available. (Strauss, 1991:9).

A case study of a 43 ha centre pivot irrigation plot under wheat production in the Hartswater area is used to indicate the potential gains in the profitability of precision irrigation. The circle (43 ha) under discussion showed a big variation in the yield (<3,5 ton/ha to >7,0 ton/ha) in November 2000 when the circle was harvested with a combine yield monitor.

There are many approaches in precision agriculture to manage inputs such as water, seed, lime, herbicides, pesticides and fertiliser more efficiently (Lowenberg-DeBoer, 1996:1). Yield-mapping has captured the interest of many farmers worldwide and is an important precision agriculture practice which could address the management of variation in yields. Full technical information on the operation of precision agriculture equipment (variable rate technology [VRT]) is available on the FlexiCoil webpage (www.flexicoil.com). The interpretation of yield maps, according to the University of Minnesota (1997), includes five steps, namely (i) setting a management goal; (ii) identifying consistent yield patterns; (iii) prioritising and analysing information; (iv) explaining variation, and (v) making management decisions. Yield-mapping is only truly valuable to the farmer if the yield map can be interpreted. Better management decisions can be made if the causes of yield variation in a field are understood. Possible causes of yield variation in a field are presented in Table 3.

Table 3: Causes of yield variation

Source	Natural causes
Weather	Wind Temperature
Soil-water relationships	Texture Structure Depth to and expression of restrictive layer Nutrient availability pH, organic matter
Slope and aspects of a site	Effects on erodibility, soil temperature, soil quality
Crop pest infestations	Weeds, insects and diseases
Source	**Management causes**
Crop inputs or condition	Hybrid or variety selection Plant population and uniformity Crop protection and nutrition inputs
Field history	Crop rotation Compaction Previous structures and practices
Cultural practices	Misapplication of water, nutrients or pesticides Planter, cultivar or harvesting problems Timeliness and effect of soil moisture

Source: Doerge (1997).

The main goal of precision agriculture is to identify the significant differences with relation to yield potential and actual yields. According to the United States Water Conservation Laboratory (2000), there are basic principles in the identification of management zones. A management zone is considered an area of the field that is (i) sufficiently homogeneous where crop input needs are not significantly different, and (ii) can be economically managed independently from other areas of a field. The establishment of irrigation management zones should consider the following: (i) the irrigation system used; (ii) variation in soil-water holding capacity, and (iii) impact of soil variability on yield potential (US Water Conservation Laboratory, 2000).

The approach in precision agriculture is to apply inputs (i.e. seed, fertiliser, lime, ect.) in optimum quantities, with the result of less inputs wasted and less nutrients entering the groundwater, which could lead to pollution. In South Africa soil sampling is a paid service to the farmers by the Agricultural Research Institute of the National Department of Agriculture, fertilising companies and agricultural faculties at universities. After the soil analysis have been done, the results should be combined with the yield map and the optimum quantities of fertiliser should be calculated according to this information. Soil-sampling is done to evaluate nutrients and to identify the nutrient needs for specific crops of a specific area in a field.

Knowledge of the water requirements for the different yield levels of different crops is important in precision irrigation. To apply water efficiently, the kW (for water pumps) needed per hectare can be reduced with an accompanying reduction in capital investment and reducing electricity costs. The centre pivot is designed to apply 12 mm of water in 24 hours over the entire field of 43 ha, which can be redesigned for precision irrigation. The most accurate measurement of crop water usage on a large scale can be an approach which integrates the understanding of the soil-plant-atmosphere continuum as mechanistically as possible (Annandale *et al.*, 1999:16). The Water Research Commission in South Africa developed a soil-water balance model (SWB) which calculates the water balance and crop growth using three factors, namely weather, soil and crop. Due to a lack of available data, the use of the SWB model will not be discussed in this paper, but will be applied in further research.

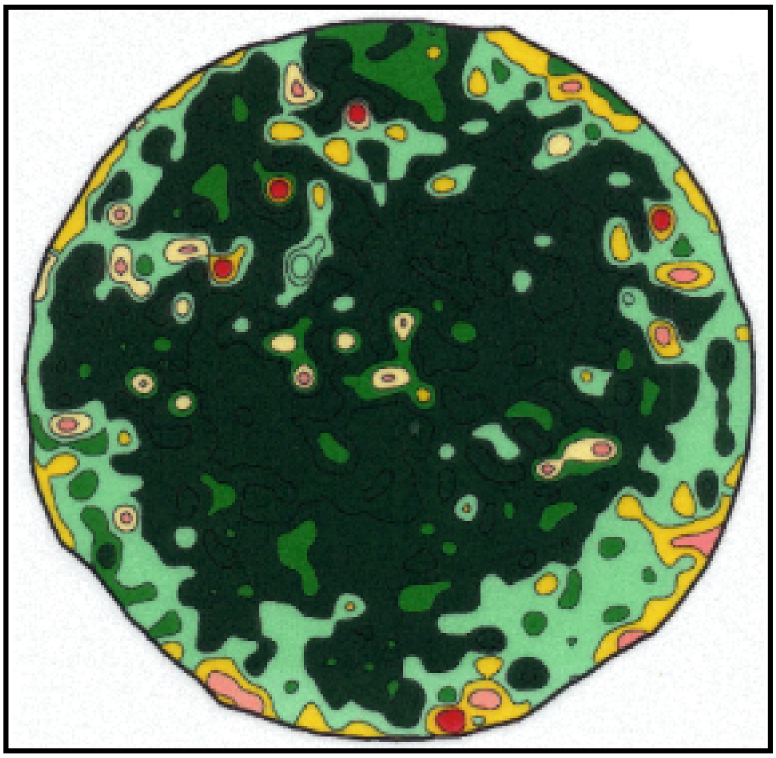
RESULTS AND DISCUSSION

It is important to set management goals or strategies when using precision agriculture. In the case study the main strategy is to maximise profit per hectare by implementing precision irrigation. Management goals are divided into long- and short-term goals.

The long-term goal will be to collect yield map precision information over at least three seasons, which should give a clearer picture of the consistency of performance of areas of a field. Over this period management zones can be identified within the field to maximise the profitability and efficiency of water usage and minimise environmental impacts. Seed, irrigation water, fertiliser, herbicides and pesticides and other management practices will be optimised for each management zone. Due to a lack of information of yield maps in the past, further research will be done on the farm to identify these management zones.

The short-term goals is to optimise the present inputs of production by means of reducing the cost of unnecessary inputs in some zones and the increase of yields in high potential areas with more inputs. The farmer under discussion started with GPS yield-mapping in November 2000 with the wheat crop and the yield map image of the centre pivot harvested with a combine yield monitor which is presented in Figure 1.

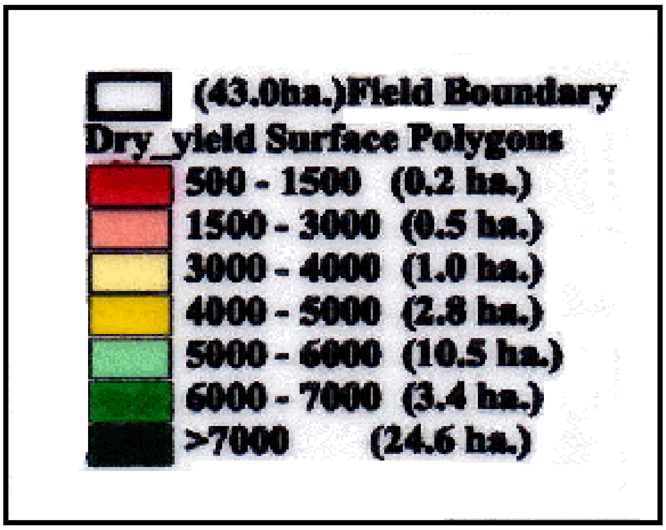
Figure 1: **Wheat Yield Map Image (43 ha)**



The yield map image (Figure 1) indicates a clear problem around the outer part (area) of the centre pivot which could be caused by wind, cold or the sprinkler package not applying enough water.

The different yield levels as identified by the yield monitor are presented in Table 4.

Table 4: Yield levels as identified by the yield monitor



(43.0ha.)Field Boundary	
Dry_yield Surface Polygons	
500 - 1500	(0.2 ha.)
1500 - 3000	(0.5 ha.)
3000 - 4000	(1.0 ha.)
4000 - 5000	(2.8 ha.)
5000 - 6000	(10.5 ha.)
6000 - 7000	(3.4 ha.)
>7000	(24.6 ha.)

Five zones (<3,5; 4,5; 5,5; 6,5; >7 ton/ha) have been identified to determine the potential benefit from precision agriculture. One major problem with the information received from the combine contractor is that no yields above 7 ton/ha were available, which limits the practical use of the image data. This short-coming causes that the full range of yield zones (i.e. 2 - 15 ton/ha) cannot be identified. More than 65% of the field produced a yield from 6 ton/ha and more, which is a good yield for the Vaalharts area. The short-term goal is to maximise profit per hectare by reducing input costs or increasing yields with more inputs. An estimation will be made of what the expected gross margin would have been with the wheat crop of 2000 if precision irrigation (agriculture) had been implemented. Fertiliser and the application of irrigation water are the variables that will be taken into consideration. No information concerning plant population and cultivars for different yield levels is available and seed costs will be kept constant for different yield levels.

It is necessary to know the current status of the soil nutrients when applying fertiliser at a variable rate. In August 2000 before the farmer planted the wheat, a soil analysis was done to identify the soil status. The result is indicated in Table 5.

Table 5: Soil analysis of the case study centre pivot

Soil analysis						
pH (KCL)	**K**	**Na**	**Ca**	**Mg**	**P**	**Zn**
5,26	168,0	214,0	415,3	116,5	48,1	4,84

In applying fertilisers at variable rates in the different yield potential zones (<3,5; 4,5; 5,5; 6,5; and >7 ton/ha), the total input of fertiliser over the whole field can be reduced. The different recommended fertiliser applications are shown in Table 6 according to the five different potential zones.

Table 6: Fertilising to different yield potential zones

Zones	Description	Traditional Application	Total (PA)	Precision agriculture				
				<3,5	**4,5**	**5,5**	**6,5**	**>7**
Area		43	43	1,7	2,8	10,5	3,4	24,6
Kg/ha	2:3:4(30)	250		90	120	150	180	250
Total kg	2:3:4(30)	10 750	8 826	153	336	1 575	612	6 150
Kg/ha	Ammonium sulphate	700		210	340	570	700	800
Total kg	Ammonium sulphate	30 100	29 354	357	952	5 985	2 380	19 680

The traditional production system uses 1,924 ton 2:3:4 (30) and 0,746 ton ammonium sulphate more than the precision production system. This is a wastage of ± R4 560 on 43 ha per season. Variable rate irrigation application for scarce water resources in South Africa and the effect of the National Water Law implemented in 1998 on the irrigation industry, appears to be a valid concept. Precision irrigation requires the determination of irrigation management zones and in this case study, limited information is available and research will continue to determine these zones. From the harvested wheat crop it can be determined how much water was used to produce the different yields in the field by using the product function [Evaporation (ET) = (Yield + 340)/11,38]. The efficiency of the irrigation system - a centre pivot in this case - has to be taken into account, which is estimated at 85%. The actual and estimated irrigation water used according to the yield achieved is shown in Table 7.

Table 7: Estimated water use in 2000 for wheat production.

Zones	Traditional application ('000 m3)	Total (PI) ('000 m3)	Precision irrigation ('000 m3)				
			<3,5	4,5	5,5	6,5	>7
Area	43	43	1,7	2,8	10,5	3,4	24,6
ET (100%)	27 864	25 061	573	1 190	5 387	2 044	15 867
ET (85%)	32 766	29 492	675	1 400	6 342	2 404	18 671

The traditional production system would have used 3 274 000 m^3 more water over the total area than that of the precision irrigation production system. This indicates that precision irrigation has the potential to use water more efficiently. The gross margin analysis for the traditional irrigation as well as the predicted analysis for the precision irrigation production system for the different yield zones are presented in Table 8.

The wheat crop for 2000 was produced by means of a traditional irrigation production system where equal quantities of fertiliser and irrigation water were applied. An average yield of 6,6 ton/ha was produced with a total gross margin of R33 510 on 43 ha. The projected results of the precision irrigation production system if the field was managed according to management zones, give a gross margin of R72 510 (estimated) which is R39 000 higher than that of the traditional irrigation production system.

Table 8: Gross margin analysis for a traditional, and predicted analysis for precision irrigation production system

Description	Traditional irrigation	Projected precision irrigation results					TOTAL
Zones ha*	43	1,7	2,8	10,5	3,4	24,6	43
Yield (ton/ha)	6,6	3,7	4,7	5,5	6,5	>7	
Gross income from production**							
Value per hectare	R6 600	R3 700	R4 700	R5 500	R6 500	R7 000	
Total value	R283 800	R6 290	R13 160	R57 750	R22 100	R184 500	R283 800
Total allocated cost							
Per hectare	R5 820	R3 608	R3 791	R4 256	R4 639	R4 950	
Total value	R250 290	R6 134	R10 615	R44 693	R15 773	R121 776	R198 991
Per ton	R882	R975	R807	R774	R714	R707	
Gross margin							
Per hectare	R779	R92	R908	R1 243	R1 860	R2 050	
Total value	R33 510	R156	R2 545	R13 057	R6 327	R50 425	R72 510
Per ton	R118	R25	R193	R226	R286	R293	

* One hectare equals 2,47 acres.
** Current exchange rate: R1 = approximately $8.00

Looking at the results, precision irrigation seems to be an efficient way to manage irrigation crop production. In South Africa precision agriculture is in an infant stage, which is a new field for agricultural research. Farmers will have to be trained to improve their management capacities to use this new technology of site specific management profitably. The investment in precision agriculture is relatively high if the training of farmers and the investment in precision agriculture equipment (VRT) is taken into account. The basic capital investment of precision agriculture and the costs of the equipment (VRT equipment excluded) is presented in Table 9 with an annual cost calculation over a period of five years.

Table 9: **Basic precision agriculture equipment costs (VRT equipment excluded)**

Equipment	Price	R/year
Computer:		
Hardware	R8 000	R2 387
Software	R12 000	R3 580
Harvesting:		
GPS and data monitor	R40 000	R11 933
Satellite costs (per year)	R13 800	R4 117
Yield monitor	R18 500	R5 519
TOTAL	R92 300	R27 536

Taking into account the additional costs of R27 536 per year for the basic precision agriculture equipment, the potential improvement of precision irrigation will be financially viable even on 43 ha under irrigation, where only fertiliser and water variation are taken into account. This possible financial advantage is enough to invest in this equipment (VRT) or to pay more for contractor VRT equipment.

CONCLUSION

Precision agriculture uses sophisticated equipment which supplies sophisticated information to the modern farm manage. Precision irrigation, which is one of the divisions in precision agriculture, will become more important in future to protect the scarce water resources in South Africa and the world. The calculations done for the centre pivot study case where only the variation in fertiliser and water is hypothesised, proved the potential of precision irrigation as a technique to improve the success of the modern irrigation farmer in South Africa. The potential difference between a traditional irrigation production system and a precision irrigation production system, is R39 000 on 43 ha per wheat season. The annual installment for the basic precision agriculture equipment (VRT equipment excluded) is R27 536. The balance of R267 per hectare can be used to hire contractor VRT equipment.

Further research will help in identifying irrigation management zones which will be managed under precision irrigation in optimising the gross margin per hectare by means of the fluctuation in inputs and outputs. To become a successful irrigation farmer South

Africa, precision irrigation will become necessary due to the envisaged increase in the costs of irrigation water and the scarcity thereof in South Africa. Precision agriculture is a knowledge-based technical management system which should optimise farm profit and minimise the impact of agriculture on the environment.

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BIBLIOGRAPHY

Annandale, J. G., Benade, N., Jovanovic, N. Z., Steyn, J. M. & Du Sautoy, N. 1999. *Facilitating irrigation scheduling by means of soil water balance model.* WRC Report no: 753/1/99. Pretoria: Water Research Commission.

Center for African Studies, University of Illinois. 1998. *Country information*. http://www.afrst.uiuc.edu/country.information/za.html.

Doerge, T. 1997. Yield map interpretation. *Crop Insights*. 7(23).

http://www.pioneer.com/usa/techology/i971219.htm. 17 March 2001. 9:26AM.

Lowenberg-DeBoer, J. 1996. *Economics of precision farming: Payoff in the future*. http://www.dynamo.ecn.purdue.edu/~biehl/SiteFarming/economic_issues.htm. 5 December 2000.

Matela, Ntsikane. 2001. *The status of precision agriculture in South Africa*. M.Agric. script. University of the Free State, Bloemfontein, South Africa. (In progress).

South Africa (Republic), Government Gazette. 1998. *National Water Act, No. 36 of 1998.* Cape Town: Government Press.Perry, C. 2000. Precision irrigation. http://nespal.cpes.peachnet.edu.fsa. University of Georgia. 10 November 2000.

Precision Agriculture Center, University of Minnesota. 1997. *Yield map interpretation*. CD: Version 1.0.

Pretorius, P. F. 2000. Ground water pricing and funding of catchment management. *Course on groundwater and the National Water and Water Services Acts.* Department of Water Affairs & Forestry, Pretoria.

Stoltz, Isabel. 1999. Hoe nuwe Waterwet boere raak. *Landbouweekblad*, 3 Desember (1999):2628.

Strauss, J. S. 1991. *'n Landbou-ekonomiese evaluasie van alternatiewe besproeiingstelsels in die Vaalhartsbesproeiingsgebied.* University of the Free State, Bloemfontein, South Africa.

Taylor, T. 1998. NUS survey predicts more big increases in water prices. *Imiesa*, March:5.

Van Tonder, G. & Dennis, I. 2000. Catchment, aquifer and groundwater balance. *Course on groundwater and the National Water and Water Services Acts*. Institute for Groundwater Studies, University of the Free State, Bloemfontein.

US Water Conservation Laboratory, Phoenix, Arizona. 2000. *Management zones and economic considerations for precision crop management.* http://www.uswcl.arsag.gov/epd/remsen/irrweb/zoneecon.htm. 22 March 2001.8:01PM

United Nations Educational, Scientific and Cultural Organisation (UNESCO). (1977). *World map of desertification.* United Nations Conference on Desertification Report A/Conf. 74/2. New York: United Nations.

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