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by

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Abstract

Many scholars suggest that North Korea's agriculture collapsed in the mid-1990s because of one of the three causes: overall economic decline, deficiencies of the socialist collective system, or environmental disaster. In contrast to these conventional explanations that view North Korea as an idiosyncratic failure, this paper argues that North Korea's agricultural crisis is attributable to the unsustainable nature of modern industrial agriculture, rooted in the worldwide modernization project of the past two centuries. From the outset, North Korea's agricultural production had been predicated upon a high consumption of energy, petroleum-based chemicals, mechanization, and irrigation. North Korea's uniqueness lies not in the industrial agricultural methods used but in the extremity of their extensiveness achieved. While the North achieved a substantial agricultural success for the first three decades thanks to these practices, it paid its early success with the collapse of the 1990s because these methods left an unsustainable level of physical and environmental externalities and because their insatiable need for inputs could no longer be met.

About the Author

Chong-Ae Yu is a PhD candidate in Development Sociology at Cornell University. She was the coordinator for the Carter Center's North Korea Food Security Project, and the agricultural coordinator for a US PVO Consortium to manage the first US-DPRK bilateral Food Assistance Program from 1998 to 2001. She has also worked as a consultant to the Rockefeller Foundation and the W. Alton Jones Foundation on issues related to North Korea.

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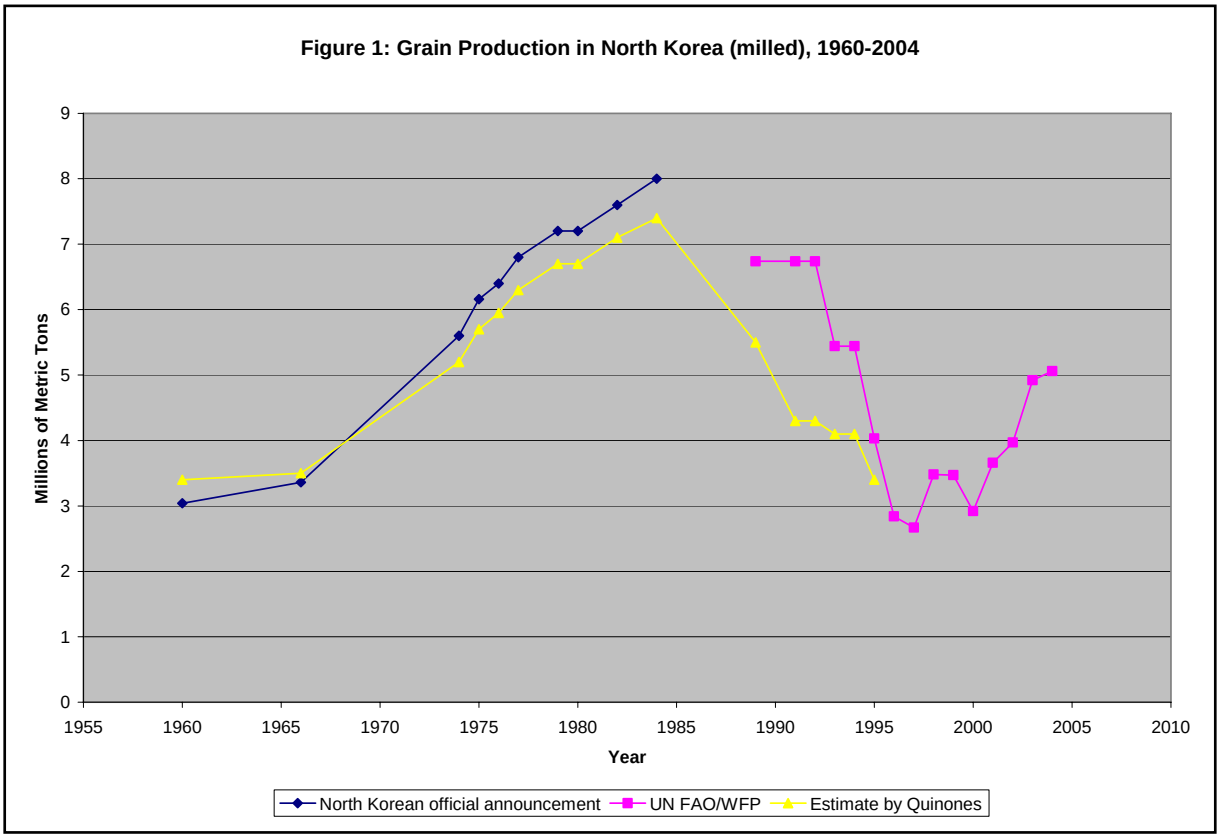
Introduction

Modern agriculture in the Democratic People's Republic of Korea (DPRK; hereafter refer to as North Korea) was a poster child for successful modernization for several decades until its spectacular collapse in the mid-1990s. This turn of events is a curious development considering the high level of agricultural achievement North Korea claimed until the mid-1980s. Just two decades prior to a mammoth-famine that claimed nearly 1 million lives out of a population of 22 million,[i] North Korea was considered the original "Korean miracle,"[ii] putting "all the economic miracles of the postwar world in the shade" by virtue of its achievements (Robinson 546). Many foreign observers of North Korea,[iii] as well as UN agencies, concurred that North Korea's development strategy was successful in industrializing the country and promoting agricultural development for many years prior to the collapse in the early 1990s. Despite the limits of nature and topographical disadvantages of being mountainous country with a short growing season, and despite the massive destruction inflicted during the Korean War and economic blockade, in 1984, only a decade prior to the famine, North Korea reported a record high grain production of 10 million (8.25 million tons milled at the conversion ratio of 80%), far exceeding the consumption requirement of its population.

Cereal yields grew rapidly from slightly over 3 million tons[iv] in 1960 to over 7 million tons in 1980, reaching around 8 million tons at the peak of grain production four years later,[v] as Figure 1 illustrates.[vi] By 1989, however, the North's grain production shrank to 6.74 million tons.

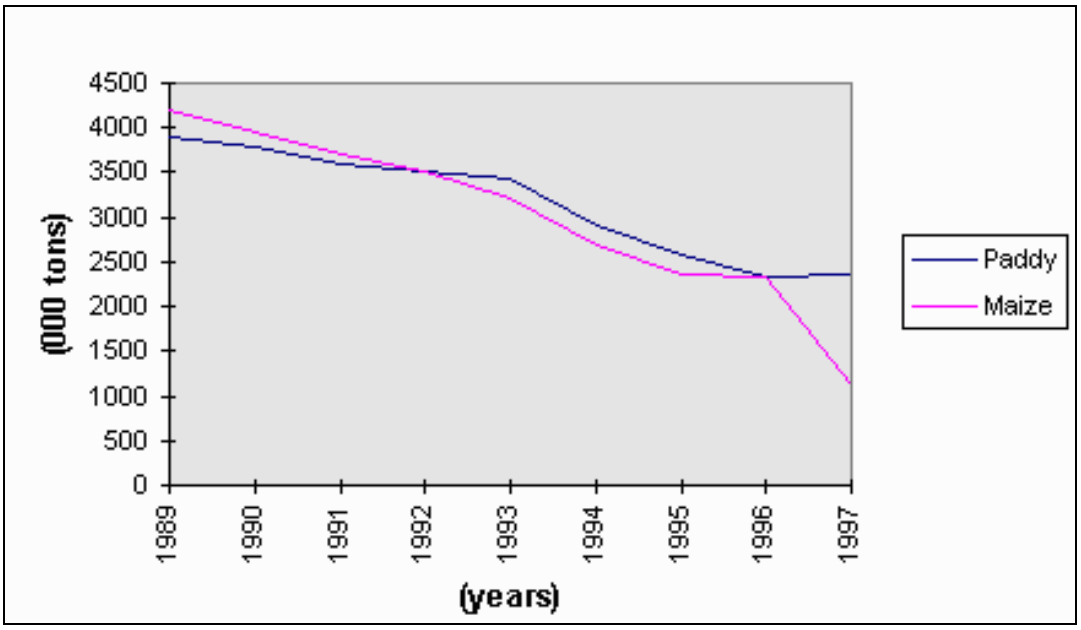
Figure 1: Grain Production in North Korea (milled), 1960-2004



Note: Figures are for rice, maize, and all other cereal grain. Source: Data was extracted from official North Korean publications: Kim Il Sung's annual New Year addresses, and Economic Development in the DPRK (Pyongyang: Foreign Languages Press, 1993), in K. Quinones; FAO/WFP Crop and Food Supply Assessment Mission to the DPRK, every year from 1995 to 2004. The 1995 report contained information for 1989, 1993 and 1995.

Its cereal production had fallen further to 5.44 million tons by 1993, a full year before adverse weather wreaked havoc on cereal production in 1994 and 1995 (UN FAO, *Crop and Food Supply Assessment* 1995). From 1989 to 1993, overall cereal production declined by some 20 percent, as Figure 2 shows. Even without the climatic setbacks of 1995, grain yields would have been some 3.1 million tons for paddy and 2.7 million for maize.[vii] While crops were clearly affected by the extreme variations in climatic conditions in 1994 and 1995, yields declined substantially more than can be explained by the direct effects of adverse weather conditions alone.

Figure 2: Estimated paddy and maize production in North Korea, 1989-1997 (Unit: thousand tons)



Note: Data 1989-1994 from the North Korean Agricultural Commission; 1995-1997 FAO Estimate. Source: FAO. Special Report FAO/WFP Crop and Food Supply Assessment Mission to the DPRK. November 1997

This paper analyzes the dramatic contrast between the two periods, North Korea's high performance for the two earlier decades and its disastrous one since the mid-1980s. How was North Korea able to manage in the 1960s and 1970s its agricultural sector to produce enough food for its growing population and to support its economic development? If it had been so successful then, why did its modern agriculture disintegrate so suddenly afterwards? This paper examines the processes involved in the rise and demise of modern, industrial agriculture in North Korea, from the beginning of its development to its failure in the mid-1990s, to see what lies behind that tragic collapse. It argues that the modern industrial agriculture that Pyongyand had wholeheartedly implemented since the beginning was responsible for both the successes of the 1960s and 1970s and the failures of the later period. The seed of its failure had been sown by its earlier success.

Explaining the North's Agriculture

The existing literature on the North Korean food crisis falls broadly within three archetypical arguments: economic decline, organizational/institutional deficiencies in the socialist collective system, or environmental/ecological factors. But the debates on the decline of the agricultural production typically take place within the confines of seeking the causal factors to famine and food crisis rather than focusing on the agricultural system as a whole. As a result, the literature may offer a partial explanation for part of the North's agriculture but fails to account for the entire trajectory, its early meteoric rise and precipitous demise later. Of the following explanations, the economic argument seems to carry the most currency among scholars within the study of North Korean agriculture, even if it has serious shortcomings.

Economic argument

Many scholars argue that North Korea's economic decline was the main culprit of its agricultural collapse. While differing on the causes of the economic decline, they share a consensus that North Korea was not free from the contours of world economy, despite its claims of economy self-reliance and independence. Although its critics called it autarkic and closed, North Korea was, like many other countries, an import-dependent country that relied heavily upon the former Soviet Union and China for such critical imports as crude oil, petroleum products, coking coal, and machine parts. And their imports were essential to the operation of its industrial sector.

As the socialist bloc disintegrated in 1989, and once Russia joined the ranks of the liberal economies in 1991, North Korea no longer received economic assistance or preferential treatment on trade from Russia. This situation was exacerbated by China's demand for hard currency when trading with North Korea in 1993. Consequently, North Korea's ability to import critical inputs was reduced drastically, and this meiosis placed a severe strain on the North Korea's industrial sector. Since North Korea's industrialized agriculture depended heavily on its industrial sector, as well as on imported fuel and petroleum products, agricultural decline occurred alongside the economic contraction (UN FAO *Crop and Food Supply Assessment, 1996*; UNDP, "DPRK"; Noland, Robinson and Wang).

In addition to above general points of the economic argument, Philip Park (2002) makes an observation that the structure of the North Korean economy as the source of agricultural breakdown. Park posits that the problem of agricultural decline stemmed from the overall structure of the North Korea's self-reliant economy. Since North Korea's policy of economic self-reliance promoted a comprehensive and integrated national economy, each sector of the economy was closely interlinked with the others. This interconnection meant that a setback in one industry was likely to cause a ripple effect throughout the entire economy. Park argues that even though the North Korean economy was mostly self-reliant, a small percentage (15 percent of GNP) of foreign trade was critical to the function of the economy, and when a severe reduction in the critical imports from Russia and China occurred, the shortage triggered a domino effect of severe economic problems in the North Korean economy. In other words, the industrial sector's failure to provide adequate inputs to the agricultural sector prompted a downward spiral; once the vicious cycle started, recovery was not possible because North Korea did not have access to the benefits offered by the global system to relieve bottlenecks or absorb economic shocks. Philip Park explained, "The cause of hunger lies in the deeply rooted structural problems" of the North Korean economy (116).

Another variation in this line of argument is proposed by Peter Hayes and a team of energy experts affiliated with the Nautilus Institute (2000). They argue that the decline in agricultural production in North Korea is directly linked to the crisis in the energy sector, attributable to the fact that North Korean agriculture is closely bounded to the energy regime. The Nautilus team cites two decisive factors in the deterioration in the energy sector: cessation of concessionary imports of oil and energy-related products in the early 1990s, and reduction in the domestic sources of commercial energy such as coal and hydroelectric power

due to contracting economy and the infrastructure damages incurred in the floods of 1995 and 1996. This crisis in the energy sector precipitated a grievous drop in fertilizer, fuels, and electricity that seriously affected fecundity of soil, availability of motive power for irrigation and agriculture including field and farm activities. Hence, the team suggests that to solve the food and agricultural problem North Korea first needs to rehabilitate its energy sector.

On the other hand, Chol Kyu Kim (2002) attributes the agricultural collapse to the disintegration of the "socialist international system" in which North Korean agriculture was embedded. North Korea's economy was developed within the socialist world economy, shaped by North Korea's semi-peripheral status within the socialist world system; consequently, its rise and fall depended upon the material condition of that system. The North Korean agricultural sector grew in part on the basis of imported inputs and external assistance during the 1960s and 1970s; when the socialist world system imploded, North Korea's external material base disappeared, resulting in the collapse of its agricultural production system.

Organizational/institutional argument

Alongside the economic argument, the institutional/organizational argument claims the majority of existing literatures. The main thesis in this line of argument focuses on inherent deficiencies in socialist collective farming, and it identifies over-centralization of decision-making in agricultural management and practices, an extensive and inflexible state bureaucracy in economic and social life, and the absence of farmer incentive stemming from collective farming as the primary causes of the agricultural collapse in North Korea (Choe; Eberstadt; Noland, Robinson, and Wang; Brem and Kim; Y. Y. Kim; Nam).

Within the realm of over-centralization of decision-making, one of the problems often cited is the use of *Juche* (self-reliance) farming methods, and organizational arrangements.[viii] For example, scholars refer to *Juche* farming methods as one of the primary causes of North Korea's drop in food production, arguing that such methods are based on political reasoning, not agricultural science (Bu et al., Kwon), with farmers being forced to implement the methods in a rigid political system. To the contrary, *Juche* methods are said to be based on agricultural science intended to increase productivity by intensive management of crop production system such as 'suitable crops for suitable land,' 'time of seeding,' 'high-density cultivation,' and 'systemic fertilization (Nam).' In order to understand the logic behind North Korea's crop management system, including *Juche* methods, is that it is a component of the much larger whole of industrial agriculture in North Korea; therefore the critique of *Juche* methods should be considered within the larger whole of industrial agriculture in North Korea, not apart from it. In the context of inadequate inputs to support these methods, however, the failure of *Juche* methods points to existing agricultural problems rather than serves to condemn the methods themselves.

Another issue frequently raised by the institutional line of argument is that of property ownership and farmer incentive. It has been argued that common property ownership prevents farmers from making an investment in agriculture, since under the collective system, farmers are de facto state employed agricultural workers, and as such they comply with government plans for production at a minimal level. Furthermore, bureaucratic

intervention is exogenous to any successful management of the farm organization, and because of this bureaucratic imperative, together with the individual farmer's inability to make any decisions on his/her own, farmers do not have any incentives to outperform. Often, these scholars propose the privatization of property and the transition to a market economy as the only viable option for North Korea's survival (Doh; Nam). Agricultural performance in China after decollectivization is often held up as an example of the major role collectivization has played in North Korea's agricultural failure. China's success in increasing the rate of annual grain yield from 2.7 percent during collectivization (1957–1978) to the annual rate of 8.9 percent after shifting to a household responsibility system (1979–1984) is often cited as evidence of the smashing success of decollectivization (Brem and Kim). However, this type of argument ignores the fact that the structure of economies of two countries are different: China's economy was dominated by agricultural sector at the time of decollectivization whereas North Korea's economy is not.

Environmental argument

The last of the three arguments lies within many existing literatures as a secondary factor contributing to North Korea's agricultural decline (Noland, Robinson and Wang; T.-J. Kwon). When the North Korean government first approached the international community for assistance in September 1995, it had indicated that food production collapsed because of the natural calamities that occurred in August of that year. The explanation of natural disaster was invoked by many non-governmental organizations and by the World Food Program (WFP) in providing humanitarian assistance to North Korea in 1995, 1996, and 1997. UN agencies and others also have acknowledged the 1995 and 1996 floods and the 1997 drought and tidal wave as having a devastating impact on food production and the subsequent collapse in agriculture (FAO/WFP annual report on crop and food supply assessment, from 1995-2004; UNDP 1998; Nautilus Institute 2000, 2001, 2002). Reports by UN agencies—the FAO/WFP—consistently raise the issue of environmental degradation as a factor contributing to decreases in agricultural production. The extent to which North Korean environmental degradation has occurred has been alarming, and in 2003, the UN Environmental Programme issued a status report on North Korea's environmental situation, noting a direct link between the national food production policy and land degradation. UNEP called for an increase in 'restorative policies and practices.'

Unlike others, Woo-Cumings identifies the environmental factor as one of the main elements in the occurrence of famine and agricultural crisis in North Korea. She traces a history of ecological disasters that had negatively affected fragile economies in the last three decades—such as the devastating droughts in sub-Saharan Africa in the 1970s and 1980s; the El Nino events of 1972–1973, when droughts occurred around the world simultaneously, affecting food production from the Soviet Union, China, India, Central America, Australia, Indonesia, Argentina, Brazil, West Africa, and Ethiopia—and the devastating El Nino, reconstituted on a larger scale in 1982, and again in 1997–1998. Woo-Cumings posits that the North Korean agricultural crisis, and of course famine, in large part, were caused by the ecological impact. She provides evidence of North Korea's aberrant weather pattern in the 1990s: 1995–1996 (floods), 1997 ("worst droughts in decades"), and 2000–2001 (drought) that swept away large parts of North Korea's arable land and its harvests. Woo-Cumings argues that North Korea was at the epicenter of a global ecological disaster in the 1990s,[ix]

and this explains the extent to which North Korea's agricultural production dropped. Woo-Cumings states, "The famine in North Korea was part and parcel of a global ecological disaster, happening with greater frequency as the result of the global warming." (33)

All three clusters of arguments contribute to partially advancing our understanding of the agricultural collapse in North Korea. None alone provides a causal understanding on what precipitated the collapse of the *agricultural production system*. If the economic argument attributing North Korean agricultural collapse to the overall economic decline holds, one could assume that once the required inputs are provided, production would recover to the previous level. However, such a recovery is unlikely considering the state of soil fecundity and environmental degradation. Rather, a growing body of evidence indicates the deterioration of land and water resources in North Korea. In the organizational argument, if one supposes that over-centralization of decision-making and lack of farmer incentive in North Korea is the main cause of production decline in the 1990s, how does one explain the fact that for many decades North Korea achieved an impressive increase in agricultural production with little change in incentives or planning systems? Furthermore, agriculture in North Korea was far more decentralized from the mid-1960s on, and even more so after the mid-1980s. By then, North Korea was far more decentralized, with fewer than seven to eight people on a team that was permanently assigned to a given area of land and implements.[x] Many of the farmers stayed in a small sub-team unit, often made up of their own relatives, for most of their lives. Finally, while the environmental argument explains the state of the ongoing devastation as well as the fact that its fragility was further aggravated by natural calamities of the scale of those in 1995 and 1996, it does not explain the cause of the environmental degradation itself. Certainly, environmental destruction has been caused by both internal and external elements, but it cannot be argued that global ecological disaster has caused the collapse of agriculture in North Korea.

In contrast to above three conventional explanations, this paper argues that North Korea's agricultural crisis is attributable to the unsustainable nature of modern industrial agriculture, rooted in the worldwide modernization project of the past two centuries.

Development of the agricultural system in North Korea

Reorganization of Agrarian Society from 1945 to 1960

From the time of the national liberation from Japan in 1945 to the time the Korean War broke out in 1950, political regimes in the north and south were in fierce competition with each other to win over the hearts and minds of the Korean people. During these five years, the political situation was still fluid, and the national division had not yet been firmly established; what happened in one zone influenced what followed in the other. In this context, the North Korean provisional government (the official name was the Provisional People's Committee of North Korea (PPCNK) until 1948)[xi] began reorganizing various parts of its economy and society in the northern zone. Because Korea was an agrarian society in which 80% of the people were involved in some type of agricultural production, the agrarian revolution was considered one of the most important elements in post-colonial nation-building. A successful agrarian revolution could have meant being one step closer to winning ultimate control of *the nation*.

In 1943, two years prior to the liberation, 44.2% of North Korean peasants were landless involved in tenant farming or employed as farm labor, and if the part-tenants (the peasants who had some land of their own, and rented the rest) are included in the calculation, the rate of tenancy goes up to 75%, with most farms less than 1 hectare, and only 4% of the farms larger than 5 hectares (Chung 5). In other words, three out of four farm households were either landless or perilously close to being landless, with too small of a plot to adequately sustain a farm family after rent was taken out. Against this backdrop, in March 1946, PPCNK instituted land reform where nearly one million hectares of confiscated land were redistributed to 724,522 households, with less than 2% under state ownership (S. B. Kim 175). Each household received an average of 1.33 hectares of arable land; the redistribution benefited more than 70% of the rural population, or about 50% of the total population of North Korea at the time, and covered more than 50% of the cultivable acreage (US Department of State 56).

Upon the completion of the land reform in March 1946, PPCNK initiated a series of agrarian policies to further reshape the productive relations and to restructure the management of natural resources. However, North Korea's well-known emphasis on food self-sufficiency as a cornerstone of its national development policy comes after the war. Their perception of agriculture as a fundamental base of "national security" seemed to have been forged from the experience of the devastation of the countryside and agricultural base during the war by the blanket bombing of the U.S. on one hand, and the continuing division of the Korean peninsula, and the threat of military hostility at the height of the Cold War, on the other. The North Korean government believed that without a secure base of food supply, North Korea would be vulnerable to foreign domination and military aggression (S. B. Kim, *Historical Experience*).

Immediately following the cessation of the war, North Korea instituted another round of agrarian reform, this time the changes affected not only land ownership, but also the way in which the rural communities were organized and administered. From 1954 to 1958, the country's farm households were transformed into cooperative farms through three phases of cooperativization, gradually leading to a full integration into becoming collectivized over the five-year period on a "voluntary" basis, and there were state-supported inducements for those communities that became "socialist cooperatives." These phases were not so clear-cut, and all three types existed over the five years until 1958, when the collectivization process was completed, and the entire rural population came under cooperative management except for a small population of agricultural workers employed by the state farms. Nevertheless, each farm household was allowed to keep a small garden plot ("kitchen-garden")[xii] and fruit trees and to raise small domestic livestock for family consumption and sale at the farmers' market (Robinson 546). The "phase-in" and "voluntary" strategies seemed to have worked to minimize potential resistance as well as to prepare peasants for a smoother transition into collectivization. The historical timing might have worked to the state's favor in the transition from private ownership to cooperative ownership. North Korea experienced high casualties and population migration to South Korea during the war that had contributed to labor shortage in the rural area. This situation, together with limited production tools and available

draught animals for individual farming in post-war North Korea might have peasants to consider pooling resources to be more beneficial option in contrast to individual farming.

While cooperativization was in progress, the size and scale of cooperatives grew. In 1953, the average size of a cooperative was 14.7 households, and the average size of a farm was around 13.6 hectares. The following year, the number of households per cooperative doubled to 32.9, with the corresponding landholdings quadrupling. The trend of increase in both cooperative size and landholdings continued until 1957. In the final year of the cooperativization process, the Government redistricted the basic, local administrative unit of *Ri*[xiii] to include all cooperatives within a *Ri*, and this resulted in enlarging the average size of a farm from 105 hectares to 466 hectares. Table 1 shows this consolidation process of cooperatives from 1953 to 1958. One of the main reasons for this consolidation appears to be to create large-scale farming, with a view to "speed up the technical revolution" that the Government believed to be the most advantageous for socialist construction (I. S. Kim, *Our Country's Experiences* 45). To the present day, cooperative farms have remained the dominant form of farm and rural organization in North Korea whereby everything, including land, farm facilities, and implements, is owned collectively by cooperative members, who are paid incomes in shares of what they produce.

Table 1: Agricultural cooperativization in North Korea, 1953–1958

Year	Total # of atives	Number hold	Percent hold	Size of ld per tive[(A)]	Average size rative o[xiv])[(B)]	Arable *ongbo*) l	Arable) involved
1953	806	11,879	1.2%	14.7	13.6	11,000	0.6%
1954	10,098	332,662	21.8%	32.9	57.0	576,000	30.9%
1955	12,132	511,323	49.0%	42.1	72.9	885,000	48.6%
1956	15,825	864,837	80.9%	54.7	88.3	1,397,000	77.9%
1957	16,032	1,025,106	95.6%	63.9	105.0	1,687,000	93.7%
1958	3,843	1,055,015	100.0%	274.5	466.0	1,791,000	100.0%

Source: (A) and (B) are extrapolated from Kyung-Saeng Bu et al. 2001, p.73; All other come from Democratic People's Republic of Korea (DPRK). Central Statistical Board of the State Planning Commission. *Statistical Returns of National Economy of the Democratic People's Republic of Korea (1946-1960).* Pyongyang: Foreign Languages Publishing House, 1981.

Modernization of North Korean Agriculture

North Korea's topography does not lend itself to be a fertile agricultural base. The total land area is about 12.3 million hectares, of which 75% is mountainous and unsuitable for agriculture (Bu et al.). Of the remaining land area, about 16.4% (1.99 million hectares) is arable (Bu et al.). The limited potential for expanding domestic food production through area expansion, together with the drive for food grain self-sufficiency, has meant that North Korea has stressed intensification of agriculture through modernization of the rural sector, the

country's stated policy goals since the early 1950s. The main features of the intensification strategy have been through irrigation, mechanization, the intensive use of agro-chemicals, and the development of hybrid seeds, and to support the strategy a full rural electrification.

A watershed decision in the future of agriculture in North Korea took place in February 1964, when the Korean Workers' Party (KWP) adopted "*Theses on the Socialist Rural Question in Our Country*," proposed by then-President Kim Il Sung. In the *Rural Theses*, the argument was made that the fundamental problem in rural North Korea was the *backwardness* of its population and the existing material and cultural gap between the rural and urban centers. The Government believed these were the elements that kept North Korea from transitioning into a successful communist country (Kim, *Implementation*). Solutions to the problem, the Government argued, have to begin with a paradigmatic shift in the way agrarian issues are problematized, and it offered three basic principles to address the problem: 1) technical, cultural, and ideological revolutions in the countryside; 2) the working-class leadership of the peasantry, the assistance of industry to agriculture, and the support of the towns to rural areas; and 3) industrial methods of management of agriculture and rural economy, as well as further consolidation of ownership and management of the agricultural collectivization (I. S. Kim, *Rural Theses* 163–212). The Government also believed it was the "backwardness" of semi-socialist cooperative ownership and non-scientific management that were preventing the peasantry from progressing toward the genuine form of 'socialist agriculture.' The Government advocated a, "[move] towards steadily bringing the method of management and operation of agricultural cooperative economy closer to the advanced industrial method of enterprise management" (I. S. Kim, *Implementation* 13). The Government also indicated that cooperative farming was "being rapidly equipped with modern technology," and that "the scale of management in agriculture is expanding and . . . approaching the level of industry in technical equipment" (*Implementation* 13).

This meant that North Korea would accelerate the modernization of the rural area through technological innovation and socialization process, not only to 'upgrade' agricultural technology on the production side but also to socialize the peasantry into becoming *socialist farmers* as the state gradually consolidated cooperative ownership into state ownership. What these three core principles reveal, then, is the state's attitude toward modernization and development in the context of the socialist construction: the notion of modernization and development of farm sector was synonymous with industrialization, and industrialization was viewed as a socialist silver bullet to North Korea's developmental challenges. The technical revolution was indeed a *social and political* project, not just an economic and technological solution to develop rural productive forces.

Within this framework, North Korean agriculture became more capital intensive in production, highly mechanized in labor, with high application of agro-chemicals, abandoning its traditional agriculture, with its rotational systems and organic fertilizing, in favor of the industrial model. North Korea wanted to produce an agricultural surplus sufficient to solve its food insecurity as well as to serve the needs of an industrializing North Korea. It was during this period that the country's industrial and agricultural sectors became irrevocably linked, so much so that the agricultural sector became a de facto hostage to the industrial sector. During this time, North Korea also began working on developing hybrid seed varieties of its staple

foods, rice and maize, that would require large amounts of fertilizer and water. From the 1960s to early part of the 1980s, substantial investments were made in agriculture. The land expansion programs and rural development plans were designed to take advantage of modern technology; therefore these programs accelerated the need for: 1) enlarging the irrigation networks, 2) electrification of the rural areas, 3) land realignment to establish large tracts of land for mechanization, and 4) further application of chemical fertilizers and other agro-chemicals. In addition, through the conversion of coastal and swamp lands, total agricultural land grew about 16%, from 1.8 million hectares in 1946 to 2.1 million hectares in 1984 (Republic of Korea, *Economic Statistics* 1992). The next five sub-sections will briefly detail the development of each of the four pillars of the technical revolution, and the development of hybrid seeds that was responsible for increasing food production for close to three decades.

Irrigation

In the *Rural Theses*, the centrality of irrigation in the technical revolution is emphasized since in the "hybrid seed-fertilizer-water" scheme of agricultural production, timely supply of water is an indispensable requirement. North Korea's annual rainfall of 1,000–1,200mm is concentrated in the period between May and September, and half of the rainfall tends to occur in July and August. This means that both drought and floods are frequent problems, particularly in the rice-bowl area of the southwest plains, and hence means to control the water becomes vital. Another contributing factor to the irrigation drive was that with the land expansion program the western sea reclamation area needed supply of fresh water.[xv]

Irrigation projects began with rice paddies then continued to fan out to non-paddy fields and upland areas. Irrigated land increased from 227,000 hectares in 1954 to 1.2 million hectares in 1988. According to a US Government source, by 1990, North Korea had more than "1,700 reservoirs throughout the country, watering 1.4 million hectares of fields with a ramified irrigation network of 40,000 kilometers, which irrigated about 70% of the country's arable land" (US Library of Congress, *North Korea Country Studies*). To create this extensive system of irrigation, North Korea developed vast and complex networks of waterways covering not only grain fields, but also the permanent crop area of around 300,000 hectares (UNDP FAO, *AREP 1998* WP 1:6), of which the majority were in upland areas, with the irrigation networks consisting of a double-circular system for drainage and irrigation throughout the agricultural areas, intended to provide protection against both drought and flood.

Counter-intuitive to a mountainous country, North Korea constructed an elaborate electrical and diesel fuel supported pumping system – there are 3,505 pump stations for the existing major networks alone – to irrigate both low and upland areas, instead of utilizing a gravity-fed system on such terrain. Frequently, Irrigation water is pumped to reservoirs from which it is distributed to crops by canals, a process which requires further pumping in many cases. Groundwater is not extensively used, except in the west coastal plains where there are 2,500 tube-wells, 53,000 open-wells, and 66,500 springs used for irrigation (UNDP FAO, *AREP 1998* WP [Working Paper] 1:7). In addition to establishing more of a general irrigation system, i.e., reservoir, canals, etc., North Korea has introduced an extensive field sprinkler system and other methods of supplying water to the fields. About 400,000 hectares of

irrigated uplands require pumping of water, supplied through pipelines from which the water is distributed by "mobile water guns, sprinkler, furrow and other drip methods for fruit trees" (UNDP FAO, *AREP 1998*, WP 1:7). According to the UNDP, the furrow irrigation in uplands is done on steep hillsides, potentially causing erosion, and this type of system is costly to operate, although the system greatly enhances production rate to more than twofold. This electricity and diesel fuel-dependent system was supported by what seemed to be a healthy energy sector as long as the entire system worked as planned.

Electrification

Rural electrification was the basic building block for the North Korean agricultural development, and of the four main tasks of the "technical revolution," electrification has been achieved most successfully. It has been reported that by spring of 1969, 91.2% of the North Korean rural households (both farm and non-farm households)[xvi] had access to electricity (M. W. Lee, *Rural North Korea* 72-73), and 100% of all rural households had access to electricity by 1974. Rural electrification in North Korea took place relatively early in its national development, and the system was quite extensive. One goal of electrification was to fuel rural mechanization with a limited use of gasoline/diesel fuel. Since North Korea lacks domestic petroleum reserves, but has an abundant amount of coal deposits for operating thermo-electric power plants and the capacity for hydroelectric generation because of its mountainous topography, it was much more rational and practical to build a self-reliant economy based on domestic sources of electric power rather than imported petroleum.

Mechanization

A visible, successful mechanization program was important to North Korea for both symbolic and practical reasons. First and foremost, mechanization was needed to increase labor productivity in the face of labor shortages, and to "ease the workload of the peasants" (I. S. Kim, *Implementation* 19) by relieving them of using rudimentary, manual implements for backbreaking farm labor. The Korean War left North Korea with a significantly reduced population, both from war casualties and from those who left the North for South Korea. Also, with the development of urban centers and an industrial sector, the population shift occurred in favor of industry; consequently, rural area felt the shortage of labor. Mechanization also meant that North Korea was socially and economically *progressing*—a sign of development and a symbol of socialist achievement. Relief from hard labor is evidenced by the priority given to the most difficult tasks in fieldwork. Plowing, transplanting, and transporting operations were the first to be fully mechanized.

North Korea's land utilization also gave impetus to mechanization. As discussed in the earlier part of this paper, upon the completion of cooperativization in 1958, a major program was initiated to expand the large-scale farming. The Government considered the prevailing size of cooperatives to be too small to realize economies of scale, particularly for taking advantage of farm machineries. Farm mechanization was regarded as one of the most powerful ways of transforming traditional farming into a modern system. All cooperatives, which had been based on the traditional village unit, were merged to make a single cooperative in each *Ri*. Consequently, the number of cooperatives fell from 16,000 to fewer than 4,000, while the average size of a cooperative's landholdings expanded to approximately 450-500 hectares, each containing about 300 farm households. Cooperative

farms account for about 90% of cultivated land and agricultural production, and state farms for 10%. State farms are model farms run as industrial enterprises involved in specialized production, e.g., seed farms, or test-run new production methods. They are generally larger and more highly mechanized than cooperatives. North Korea's mechanization was centered on tractor usage.

During the First Seven-Year Plan (1961–1970), the number of tractors tripled, and by 1992, the number reached 75,000. If that number is calculated based on 15 horsepower (HP), North Korea produced 764 in 1953, 2,561 in 1956, 12,500 in 1960, and 20,000 in 1964 (Republic of Korea, *Economic Statistics* 215). North Korea was able to allocate 1.22 tractors per 100 hectares in 1970, and 6–7 tractors per 100 hectares in 1980, based on approximately 2 million hectares of arable land. This increase in tractor usage can be attributed to North Korea's ability to produce its own machinery with indigenous technology and material fairly early in the nation's development. Overall mechanization in agriculture increased significantly throughout the three decades from the 1960s to 1980s, as the mechanization program intensified. Fieldwork requiring intensive labor such as plowing, transplanting, and threshing was fully mechanized by 1975 (S.-H. Ko). According to the UNDP, "77% of all field-level agricultural production needs, including on-farm primary processing," had been mechanized by the late 1980s. On the other hand, 9% of the farm power is contributed by the agricultural labor force of 3.4 million people under normal circumstances, and 14% by draught animals in North Korea (UNDP FAO, *AREP 1998* WP 2:1).

Chemicalization

North Korea's high productivity rate throughout the modernization drive of 1960 to the mid-1980s is partly attributed to increased usage of agro-chemicals: chemical fertilizer, insecticides, herbicides, and so forth. Of all agro-chemical inputs in North Korea, petroleum-based fertilizer has been one of the most significant inputs. However, North Korea does not produce any petroleum, hence whether fertilizer is produced in the country or imported from outside, North Korea is totally dependent on outside petroleum. At the time of decolonization, North Korea had several large functional chemical fertilizer factories, but the Korean War decimated these factories, and production fell to a negligible level. North Korea increased fertilizer production by building new small and medium-size plants or rebuilding existing old facilities, and President Kim Il Sung threw his weight behind it with the slogan, "*Fertilizer is rice, and rice is socialism!*" (*Experience in Solving* 87) By 1954, North Korea claimed to have reconstituted fertilizer production to 259,800 metric tons (*Experience in Solving* 87). Hungnam Ammonium Sulphate and Ammonium Nitrate production facilities were rebuilt in 1955 and 1958, respectively. In 1961, a decree was issued to promote the production and the usage of chemical fertilizer, especially petroleum-based urea and ammonium sulphate, and the first urea plant was commissioned in 1966. Subsequently, there was a strong push for building new fertilizer plants, and by 1984 North Korea reported the total production of 4.7 million tons (US Library of Congress, *North Korea Country Studies*). Most of North Korea's requirements for the nutrient nitrogen were met by the production from these plants. However, potassium fertilizer is not produced domestically due to a lack of the raw material potash although Sariwon Potassium Fertilizer Factory Complex has been in construction since 1988. If completed, Sariwon complex can produce 500,000 tons of potassium fertilizer annually (US Library of Congress, *North Korea Country Studies*). Again, even if North

Korea can produce its own potassium, it will be in a situation similar to petroleum products: to import the raw material.

Accordingly, the application of chemical fertilizer (NPK) grew rapidly between 1960 and 1984. North Korea reported that the rate of chemical fertilizer application in 1960 was 160 kg per hectare. By 1975, the application rate surpassed one metric ton per hectare (S.B. Kim 315), and by the mid-1980s, it claimed to have reached all time high of two tons per hectare (US Library of Congress, *North Korea Country Studies*). UN FAO confirms the high rate of chemical fertilizer application in North Korea over time. Table 2 provides a contextual glimpse into this situation by comparing North Korea's application rate with its East Asian neighbors. North Korea recorded on a par with South Korea in 1990 although the South Korean economy was far larger by than that of North Korea. Whether two tons per hectare in the mid-1980s or 0.4 tons per hectare in 1990, both figures indicate North Korea to be one of the highest fertilizer consumption nation in the world.

Table 2: Fertilizer use in North Korea and other East Asian countries (kg/hectare)

Year	Japan	China	Vietnam	South Korea	North Korea
1972	**386**	**53**	**45**	**288**	**194**
1990	**--**	**289**	**101**	**415**	**405**

Source: FAO Production Yearbooks in Smith and Huang (2004).[xvii]

North Korea has also been known to use a high rate of pesticide, fungicide, and herbicide from domestic production and from imports, mostly from China and Japan. North Korea produces a part of what it uses from imported raw material, but it also relies on the import of various agro-chemicals. Table 3 shows North Korea's production amount of pesticides and fungicide from 1979 to 1988. In 1994, domestic production dropped to about one-third that of 1988, and the total application amount of pesticides was approximately 18,000 tons (UNDP, *unpublished proposal*).

Table 3: North Korea's pesticide and fungicide production (Unit: metric ton)

Year	1979	1982–1983	1988
Production amount	**24,000**	**25,000**	**30,000**

Source: Extrapolated from Bu, Kyong-Saeng, et al. (2001) *North Korean Agriculture*. (Seoul National University Press, Seoul, Korea).

Development of Hybrid Seeds and Emphasis on Scientific Farming Method

In its quest for food self-sufficiency, North Korea emphasized scientific approaches to farming. In particular, North Korea intensified its efforts in the area of: 1) development of high yielding varieties, 2) transplantation of maize seedlings, 3) water management techniques, and 4) systematic management of fertilizer application. In many ways North Korea's scientific farming approach mirrored that of the US-led Green Revolution; it emphasized a "hybrid seed-fertilizer-water" approach and focused on mono-cropping, and to realize the varieties' high potential, it applied high doses of chemical fertilizer, pesticides, and water. North Korea embarked on revolutionizing its traditional seed varieties in the 1960s—because of US sanctions against North Korea since 1950, North Korea was not able to take advantage of the Green Revolution's gains in hybrid seeds—and succeeded in developing many different disease-resistant, high yielding varieties of rice and maize. North Korean agricultural scientists have also developed varieties suited to limiting climatic conditions and high altitude, along with a particular method of cold-bed seedlings.[xviii] The development of high yielding varieties for its staple food has been critical to modern food production in North Korea.

In 1977, President Kim Il Sung delivered a major address at a party central committee meeting raising the issue of potential crop damage from the oncoming cold front that year, and measures needed to be taken to protect crops. He alerted the North Korean bureaucracy to what seemed to be the trend in unfavorable weather conditions for a longer term period, possibly a cool front that would last until the year 2000. He suggested that there needed to be significant measures to deal with low temperatures, droughts, and torrential rains (*General Mobilization* vol. 32:113-133). One of the longer-term measures called for by President Kim was the development of new strains of rice and maize which would be resistant to cold and lodging, short in height and growth period, and high yielding. On September 21, 1980, President Kim announced that the new cultivar PY 15 was expected to yield 600 kilograms per hectare more than existing PY 8 variety. Kim also indicated a satisfactory progress in a maize hybrid, Unchon 5, and that North Korean scientists were also developing a hearty strain of sorghum (*On This Year's Experience*). Overall, North Korea has been quite successful in developing good rice and maize varieties over the years.

A second case of scientific farming developed in North Korea pertains to transplanting maize. The common method of maize planting is to drop seeds directly into the field and cover them. In North Korea, the practice of raising maize seedlings first and transplanting them, as in rice transplanting, was adopted in the early 1970s. This method was developed to lengthen the growing time by getting the maize seed started early in the spring in a long stretch under plastic or straw cover in the middle of the field—a sort of greenhouse system—and to provide necessary nutrients in the early stage of the seedlings' development. President Kim stated in December 1970 that in that year, the farmers who cultivated the yellow dent corn, a conventional strain, by raising the seedlings in humus cakes, produced 4.5 to 5 tons per hectare (*On Some Problems* vol.25:381-395). The grown seedlings were transplanted as soon as the frosty season was over, lengthening the total growing period by 15 to 20 days. President Kim emphasized the yield-boosting effects of stretching the growing period even by one day, especially against the effects of the cold front (*Speech Delivered* vol.30:318-339). A third case of scientific agronomics relates to the different functions of

different chemical fertilizers. North Korea emphasized the importance of fertilizer application not only as a means to provide nutrients to plants, but also as a means to strengthen the plants against the cold front. In the early 1970s, President Kim urged increased use of phosphorus and potassium along with the nitrogen North Korea was already in great quantities, and he reminded agricultural officials of the role of phosphorus and potassium in facilitating photosynthesis so that crops would be heartier in cold weather with limited sunlight (*Speech Delivered*).

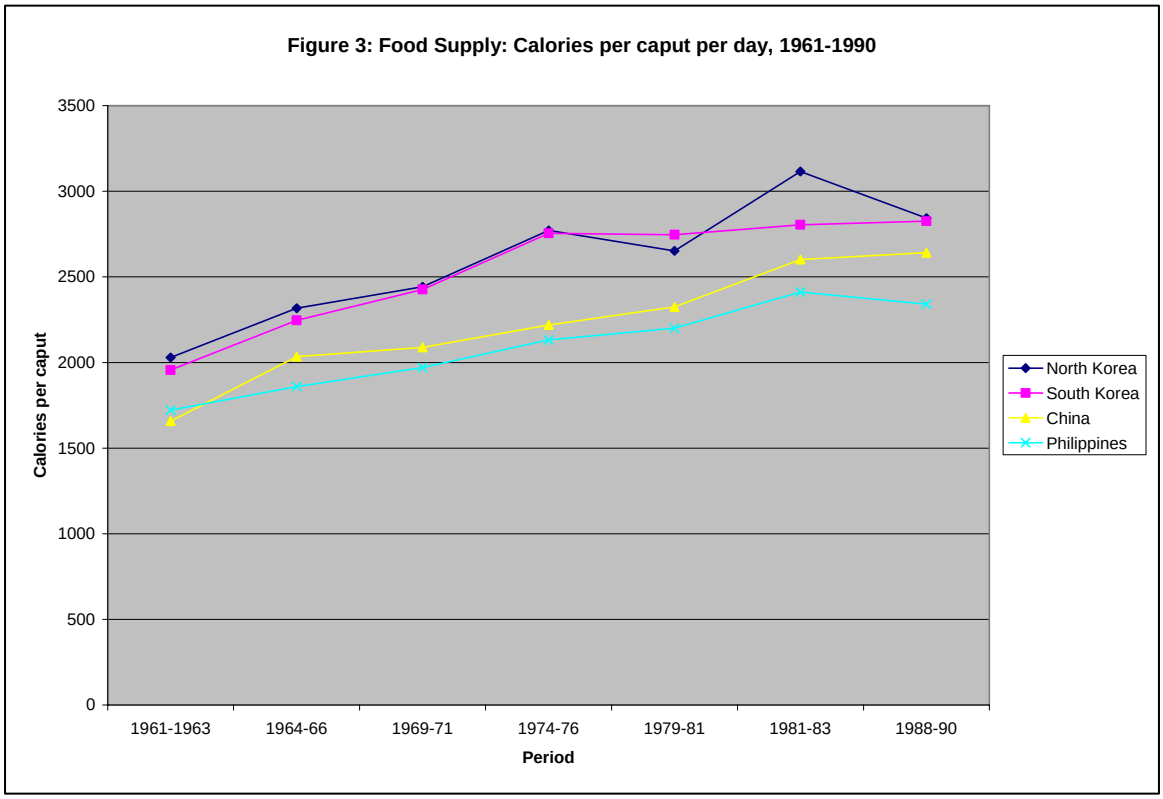
The last case to be described of the scientific agronomics practiced in North Korea pertains to the control of water temperature in the rice paddies. The technique involved was described by President Kim in 1982. The basic idea is to use water temperature control to mitigate the damage from weather disturbances, both cold fronts and excessive heat, by keeping the water temperature constant (*On Certain Tasks* vol.37:305-335).

In the four pillars of the technical revolution, irrigation was given a priority because of North Korea's climatic conditions; electrification was a basis to which the other technological innovations could take place by providing required motive power to both irrigation and mechanization efforts; chemicalization was to enhance productivity through supplementing soil fertility and to deal with the problems stemming from disease-prone mono-cropping. However, these four technological interventions are also closely associated with the choice of agricultural development; namely North Korea has taken the similar path as the Green Revolution in terms of developing high yielding varieties of rice and maize – two staple crops – that would require irrigation and chemical fertilizer to realize its crop potential.

Interdependency of Agriculture, Energy, and Industry

Through agricultural intensification, North Korea made substantial progress in resource development in agriculture. By the late 1970s, North Korean agriculture was highly mechanized (4 to 5 tractors per 100 hectares), fertilizer application was one of the highest in the world (2 tons of chemical fertilizer per hectare), and the irrigation networks were extensive (more than 1,700 reservoirs throughout the country, watering 1.4 million hectares of fields with an irrigation network of 40,000 kilometers) with close to complete provision of rural electrification. After 1964, agricultural modernization accelerated in large part because of the development of North Korea's industrial sector which was able to supply rural cooperatives and state farms with newer technology and agrochemical inputs. The state provided the material and technical assistance to undergird the modernization process, and public investment in agriculture steadily increased from an average of 9 percent of state expenditures during the Three-Year Plan (1954-1956) to over 12 percent during the Five-Year Plan (1957-1960), and to nearly 20 percent during the Seven-Year Plan (1961-1967). Based on these resource developments in agriculture, North Korea was able to achieve major advances in food production, and to meet consumption needs until 1990. Figure 3 illustrates North Korea and its East Asian neighbors daily per caput caloric intake between the periods ranging from 1961 to 1990. North Korea's ability to supply daily caloric requirement to its population was similar to that of South Korea, and consistently higher than that of China or the Philippines over the entire period.

Figure 3: Food Supply: Calories per caput per day, 1961-1990



Source: FAO Production Yearbook, 1985 and 1991.

However, this meant that North Korean agriculture became highly capital intensive and, consequently, energy dependent. Thus, in order to sustain the high growth in agriculture, industry had to supply adequate amounts of inputs such as tractors, fuels, and chemical fertilizers to the agricultural sector. Similarly, the growth of industry was not feasible without sufficient food and other agricultural production, and both industry and agriculture depended on an adequate and stable energy supply. Hence, given the high degree of interdependency between agriculture, industry, and energy, one sector's failure to provide adequate inputs to the other was likely to trigger a vicious cycle of economic downturns. Given the closed nature of the North Korean economy (foreign trade comprised only 15 percent of the total GNP), once the cycle of economic downturns started, recovery would be extremely difficult, because the country could not take advantage of foreign trade to alleviate economic bottlenecks and absorb shocks (P. Park).

There were unintended consequences as well. Because of North Korea's limited availability of agricultural land, fields were cropped continuously without fallow. Furthermore, in efforts to increase the production of cereal staples, North Korea switched gradually to monoculture of rice and maize, using hybrid varieties without any crop rotation. Such industrial agriculture practices require increased inputs each time as soils continue to deteriorate and plant diseases tend to proliferate and wipe out the monoculture crops. At the

same time, North Korea's agriculture became ever more thirsty for high energy, especially petroleum products, and as a result of increasing chemical inputs, its soil became acidified.

North Korea's Energy Crisis and its impact on agriculture

The precipitous decline in North Korea's industrialized economy in the 1990s—GNP reduced by half—and the realignment of the global politics have caused the crisis in North Korea's energy sector. The impressive pace of the economic development of the 1960s and 1970s was already slowing in the 1980s, prior to the sharp decline in the 1990s.[xix] Difficulties in the North Korean economy had been aggravated by the realignment of the international balance of power—in 1989, the Eastern bloc countries started to crumble and by 1991, they were all but gone as an alternative bloc to the capitalist bloc countries. In the past, the Soviet Union provided about 50% of North Korea's foreign trade volume, China, 15%, and all socialist countries together, about 70%. Trade with Eastern bloc countries, especially with the Soviet Union and China, had been on friendly terms, often on the basis of a barter trade or on credit. By 1991, trade volume between Russia, Eastern Europe, and North Korea decreased dramatically, and by 1993, imports from Russia shrunk to about 10% of the 1987-1990 average (Eberstadt, Rubin, and Tretyakova). China stopped providing infrastructure support even before the Soviets did, and by 1993, China was reluctant even to export oil to North Korea unless it was paid in hard currency at the time of transaction. North Korea found itself alone without key markets, financing, and sources of cheap energy supplies all at the same time. This drastic reduction of aid and of preferential terms of trade led to reduced industrial outputs based on energy shortages and on a corresponding shrinkage of foreign trade.

The decline in import capacity had serious consequences for the energy sector, which negatively affected industry and agriculture as a whole. Total domestic production of fertilizer decreased from 568,000 tons in 1989 to 130,000 tons in 1996, amounting to less than 20% of the national requirement. The situation is similar for all categories of inputs and manufactured goods to agriculture. Underlying the decrease in fertilizer production was the collapse of crude oil imports following the decrease in all imports from the Soviet Union. It has been estimated that petroleum imports dropped to about half their level in the 1980s, imposing severe stress on transportation and distribution of agricultural products. Coal production dropped to a level lower than that in the early 1980s, resulting in erratic supply delivery to all productive sectors and low overall utilization of installed machinery capacity; however, it affected none more than the energy sector.

In 1990, North Korea's estimated per capita electricity generation was 2,500KWh, which was on a par with that of South Korea (UNDP FAO, *AREP 1998* WP 1:35), and its per capita energy use was 71 gigajoules per person (2.4 tons coal equivalent/person), approximately 3.1 times that of China in the same year, and over half that of Japan (Williams, von Hippel, and Hayes). However, since then, the level of commercial energy supply and consumption in North Korea has dropped by more than one-half, and the crisis in the energy sector pushed the North Korean economy further into a tailspin. For instance, one of the two anchors in the North Korean energy sector for power generation is the coal industry. Without adequate supply of petroleum fuel to work the coalmines and to transport coals to factories,

there will be decrease in industrial production such as spare parts and/or steel, etc. This also meant further exacerbation of the condition of the machine and tool industry, and so forth.

Oil accounts for a small portion of North Korea's total primary energy consumption—only about 6%—and its use is limited to non-substitutables such as motor gasoline, diesel, kerosene, and jet fuel (US Department of Energy, *Country Analysis Briefs: North Korea*). Most imported oil is crude and is refined at domestic refineries.[xx] Nevertheless, North Korea *must* import all of the oil it consumes. Throughout the Cold War, the Soviet Union supplied North Korea with cheap oil at a subsidized rate. Soon after the demise of the Soviet Union, delivery of cheap oil discontinued, and instead North Korea had to purchase crude oil at a world market price. In 1990, North Korea imported a total of 2.45 million tons of crude oil from Russia, China, and Iran, and 0.6 million tons of refined products such as diesel and gasoline from China (Williams, von Hippel, and Hayes). In the same year, North Korea reportedly purchased 640,000 tons of oil-equivalent in refined products from the open market through Hong Kong (von Hippel, Savage, and Hayes 37). Although the amount of oil may be pale in comparison to that of other import-oil dependent countries, for a country like North Korea, this dependency represents a vulnerable spot in its system. For instance, even if North Korea wanted to expand its power generation capacity by using its coal resources, without adequate fuel support or electricity supply, it would be impossible to work the mines or transport coals to thermal stations. Table 4 shows the decline in crude oil imports from 1989 to 1996. The data suggest a significant drop in crude oil imports between 1990 and 1991 alone, and by 1996, China was the sole supplier. North Korea also imports coking coal, another strategic raw material for energy generation.[xxi] Coking coal is also required in North Korea's strategic metallurgic industry, which makes up a large portion of its export sector. The annual demand for coking coal was estimated to be at a level of 3 million tons, and North Korea imported coke from the Soviet Union until 1990; from 1992 to the present, China has been the main supplier.

Table 4: Crude oil imports to North Korea (Unit: thousand metric tons)

Exporter	1989	1990	1991	1992	1993	1994	1995	1996(A)
China	1,140	1,160	1,100	1,100	830	1,050	1,020	1,000
Russia	500	410	--	--	--	--	--	--
Libya	--	--	200	200	80	100	80	--
Iran	920	980	220	220	--	210	--	--
Total	2,650	2,450	1,890	1,520	910	1,360	1,100	1,000

Note: (A) Extrapolation of statistics for the first two quarters of 1996. More recent statistics suggest that the total was probably considerably lower.

Source: von Hippel, Savage and Hayes, p.38. This source is based on reports from a South Korean source, Korea Energy Economic Institute.

According to the U.S. Department of Energy, North Korea's total electricity consumption in 2001 was still 58% of what it was in 1991, no increase occurred in the year-to-year increase in electricity consumption during the entire period from 1992 to 2001, except in 1992, when there was a 1% increase. As discussed in the rural electrification section of this paper, although North Korea has an impressive national electricity transmission and distribution grid, extended to practically every corner of even the remotest villages, and a record of high per capita energy consumption in the past, the events of the past decade render North Korea's energy system useless.

In the mid-1990s, the vulnerabilities of the North Korean energy system took another decisive blow, this time from nature. A series of natural disasters—hails in 1994, floods in 1995 and 1996, followed by a drought, then tidal waves in 1997—severely damaged coalmines and hydropower plants. In addition to destructions to crops and agricultural land, the energy infrastructure was irrevocably damaged. Williams, von Hippel, and Hayes describe the impact of these disasters, stating:

> Coalmines were flooded (some mines producing the best quality coal, near Anju, were on the coast below sea level to begin with). Hydroelectric production was affected by floodwaters that damaged turbines and silted up reservoirs, then by drought that reduced water supplies below the levels needed to generate power. Electric transmission and distribution lines were damaged, as were roads and transportation equipment. Heavy erosion and scavenging for food denuded landscapes, reducing the availability of biomass for energy use. (5)

It is also likely that the majority of the damage done by the flooding was to fill impoundments with silt, reducing the capacity of dams and clogging spillways and channels. The floods undoubtedly not only damaged turbines, as Williams, von Hippel and Hayes indicate, but also gates and other mechanical equipment. These damages have been difficult for North Korea to reverse, as rebuilding required heavy equipment and fuel. In 1990, thermal (coal- and oil-fired) and hydroelectric power plants produced approximately equal amounts of electricity, but after flood damages to large hydroelectric plants, thermal plants became the primary source of power generation.

These converging factors resulted in a rapid contraction of the energy sector in the first half of the 1990s, and an incremental decline in the latter half of the 1990s along a similar line: a continuing decline in the supply of crude oil; continuing degradation of electricity infrastructures—power generation, electricity transmission and distribution—and of industrial facilities; damage to industrial electric motors from poor quality electricity (unstable voltage and frequency); continuing difficulties with the transport of all goods, especially coal; and difficulties in coal production related to lack of electricity. Consequently, shortages of fuel and electric supply were felt throughout the North Korean economy, and by 1996, energy consumption dropped by 51%, affecting all sectors, but by very different rates, during this period. By 1996, road and rail freight transport were reduced to 40% of their 1990 levels. Iron and steel production were reduced to 36% of 1990 levels, and cement production to 32%. Also affected were residential and commercial heating and lighting, as well as public health facilities (Williams, von Hippel, and Hayes 5–6).

Most of all, this crisis in the energy sector had a detrimental impact on North Korea's highly industrialized agriculture, which was/is based on its energy supply and fossil-fuel products. Since North Korea's agriculture is closely linked to industry and the energy regime, the collapse of the energy regime created a domino effect such that both manufacturing and agriculture that depended heavily on industrial inputs also collapsed, ultimately resulting in a human tragedy of truly biblical proportions in the mid-1990s.

The Collapse of Industrial Agriculture

The Collapse of Motive Power (Irrigation, Mechanization)

Irrigation Failure

The 1995 and 1996 floods severely damaged North Korea's agricultural sector, especially highly electrified irrigation networks and agricultural infrastructure. Although water is sourced from both surface supplies and ground aquifers, irrigation is mainly from surface water, and water for all but 300,000 hectares of 1 to 1.5 million hectares of irrigated area[xxii] must be pumped from rivers with considerable lifts using electricity and diesel fuel, after which it is distributed to crops by canals, often with further pumping, particularly for upland crops.

The bulk of the infrastructure—reservoirs, pump stations and ancillary equipment, weirs, water distribution and drainage systems—was constructed during the 1960s and 1970s. A large proportion of the 32,000 pumps for irrigation were installed more than 30 years ago (UNDP FAO, *AREP 1998* WP 1:14); consequently, most installations have reached the end of their economic life and are due for replacement. A significant portion of the irrigation system has deteriorated to the point of unreliability because of broken-down pump-sets, worn foot-valves, leaking distribution and steel delivery pipes, silted distribution systems, dysfunctional drainage systems, etc.; consequently, system losses have reached a critical level and have impacted significantly on yield. For instance, 102 reservoirs have "blown out" due to flood damage, and only 2,800 pump stations (or 10%) are operational; of the 2,000 km of distribution and delivery steel pipe, 180 km is over 30 years old and is severely corroded and unserviceable; an additional 830 km leaks badly and is in need of replacement. Some 2,088 km (or 40%) of the weirs is in need of urgent repairs or rehabilitation. North Korea states that 6,000 pump-sets should be replaced each year to bring the sector back to full operational efficiency.

North Korea's irrigation system is energy intensive: there are large complex irrigation networks, each composed of several sources, pumping stations, and reservoirs linked by canals, pipelines, and tunnels. Water pumping is required at various points in the system, and in order to pump water, the system requires electricity and/or diesel fuel. Rice requires an average of slightly less than 10,000 cubic meters of irrigation water per hectare per year, and wheat and maize require 3,060 and 1,265 cubic meters per hectare per year, respectively (UNDP FAO, *AREP 1998* WP 1:9). The UNDP states that satisfactorily pumping this amount of water requires an average of 1,200 kWh per hectare per year, corresponding to an annual national requirement of 1.2 billion kWh (9). Because electricity is also needed to

operate other stationary equipment on farms and machine tools, an additional 460 million kWh per year is needed, bringing the total agricultural electricity requirement to an estimated 1.7 billion kWh per year (Williams, von Hippel, and Hayes 10). According to Williams, von Hippel, and Hayes, the total current rural electricity consumption level is approximately 1.9 billion kWh per year, out of a total rural electricity requirement of 2.9 billion kWh per year, including residential, public, and commercial uses; this leaves a shortfall of 1 billion kWh (10).[xxiii] Of this, the most critical shortfall for agriculture has been a decrease of 300 million kWh in electricity for irrigation pumping, and a decrease of 350 million kWh decline for other agricultural uses.

Furthermore, other problems beyond the availability of electricity exist in meeting rural energy requirements. One such problem is the timing of the electricity supply: the nature of agriculture requires that water be delivered at the right times during the growing season; hence reliability is very important. With the energy sector in disarray, even if the agricultural sector is given priority in electricity distribution, a problem remains with receiving power at the time when agricultural production demands it. To illustrate this point, Williams, von Hippel, and Hayes posit that, given a national generating capacity of 4.7 GW, with an actual online capacity of 3.1 GW in 1996, after accounting for system losses in transmission and distribution, irrigation pumping demand represents "over one-third of all" of North Korea's generating capacity (10). Considering the deterioration of its energy infrastructure, it would be unrealistic to expect North Korea's energy sector to be able to increase its power generation on demand and redirect generated electricity supply to its agricultural sector at the peak time.

In sum, energy has been critical to the operation of North Korea's irrigation system, but scarcity of electricity and fuel has made it impossible to guarantee timely supplies of water to the field. The already precarious condition of canals and pumping stations has been severely damaged by the natural disasters of 1995 and 1996, while pumping stations and steel pipes used in the system have suffered from a lack of spare parts and from poor maintenance. The breakdown of the irrigation system due to the lack of spare parts and electricity has caused the severe drop in North Korea's grain production.

Shortage of Farm Power

The industrial base of North Korea enabled the country to motorize the agricultural sector in a major way, potentially providing 77% of all the farm power used in field level production and on-farm primary processing for its two major crops, rice and maize (UNDP FAO, *AREP 1998* WP 2:1).[xxiv] In contrast, under normal circumstances the agricultural population, through its labor force of 3.4 million, contributes only 9% of farm power, while draft animals contribute 14% to the total agricultural production power availability. To achieve this level of mechanization, a range of agricultural machinery and equipment had been developed and manufactured in country, and relatively large numbers of tractors, agricultural implements, and small engines and machinery were distributed to cooperatives.

On the other hand, the high level of mechanization in agriculture meant that when North Korea could no longer support its industrial and agricultural mechanization base, agriculture faced serious constraints in production. Two constraints stood out in particular: a

lack of fuel and electricity necessary to keep machinery and equipment running during the agricultural production process; and a lack of spare parts vital to keeping agricultural machinery operating. An acute shortage of fuel, electricity, raw materials, consumable machine tool parts (e.g., cutting steel) and other inputs depressed the manufacturing volume and distribution of new replacement machinery and equipment to the farms. There was no need to manufacture new tractors and machinery, even if it were possible, because the farms could not supply enough fuel to the existing fleet of equipment. Worn-out tires were kept in continuous use with metal plates bolted into the sidewalls, tractors still operated when the steering linkages were worn to unsafe limits, and tillage implements remained in use even after shares and tips had already worn out. Some 20,000 tractors were immobilized due to a lack of tires, as well as spare parts such as piston rings, cylinder liners, replacement gears, and so forth (UN FAO, *AREP* 1998 WP 2:6). By the end of 1998, much of the agricultural machinery and equipment had become inoperable, either because it reached the end of its service life or because of the lack of spare parts; fuel to operate the machinery for critical mechanized operations had become exceedingly scarce as fuel allocations were reduced to perhaps only 20% of pre-crisis levels (2).

The combined effect of acute shortages of fuel and vital spare parts significantly altered the balance of farm power availability. At this time, North Korea had only 20% of the motorized capacity of farm machinery and equipment, deeply compromising the timely completion of field operations, and leading to reduced yields and increased harvesting and post-harvest losses.

The net result of this shift in the balance of farm power is steep reduction of motive power, and by 1998, total farm power was composed of approximately one-third each of manual labor, draft animals, and mechanization. Even with North Korea's practice of one million plus labor mobilization during critical times during agricultural season,[xxv] the availability of farm power was still reduced dramatically. If quantified in terms of horsepower (hp), in 1998, the total potential power that could be used for agricultural production of rice and maize was 2,903 MW (3.89 million hp). This represented a potential power availability of approximately 1.4 kW per hectare (1.9 hp per hectare), of which 1.1 kW per hectare (1.5 hp per hectare) was mechanized. In other words, the total motorized farm power availability had been reduced from approximately 2,231 MW (3 million horsepower) to 20% of this figure (463 MW or 0.6 million horsepower).[xxvi] This signified an overall reduction in motorized mechanization levels of approximately 80% and an overall reduction of 60% of total farm power availability.

Shortages of fuel, functioning machinery, and equipment have necessitated the re-emergence of draft animal use and the additional requirement of manual labor. Land preparation, transplanting, and harvesting operations were done by machines in the past; now much of it is done manually or by draft animal. It has proved impossible to perform all operations previously carried out by machinery simply by use of manual labor or work animals (e.g., plowing, pumping of water for irrigation, harvesting, threshing, etc.) in a timely manner, in particular the peak times around harvesting and planting of double crops have been severely affected, reducing productivity and increasing post-harvest losses.

Consequently, it is not difficult to conclude the negative impact on crop yields and on overall agricultural production.

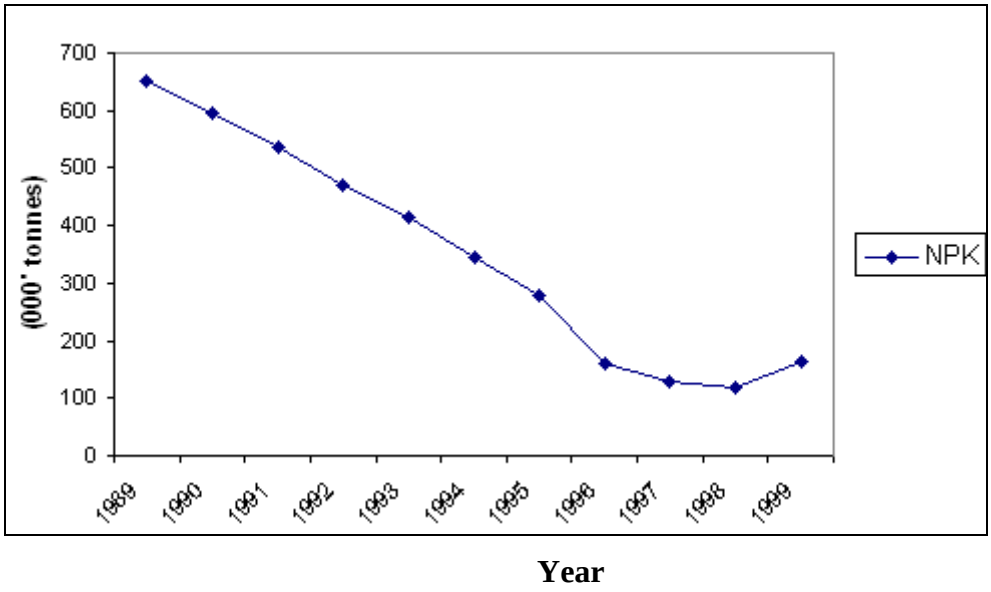
The Collapse of Soil Fertility (Fertilizer)

Industrial agriculture requires a steady flow of inorganic chemical fertilizers to guarantee a high yield. Under North Korean soil and growing conditions, the recommended rate of the plant nutrients nitrogen (N), phosphate (P), and potassium (K) is said to be approximately 694kg per hectare per year. This translates into an annual fertilizer requirement of around 800,000 tons of NPK per year for rice and maize production of 1,170,000 hectares.[xxvii]

Prior to 1990, North Korea's fertilizer industry was vibrant, meeting most of its agricultural needs for macronutrients N and P, but K was imported entirely due to a lack of usable potash reserve in the country. Fertilizer production requirements of feedstock, equipment and spares were also imported from the Soviet Union and China prior to 1990; however, since then, there had been marked decline in the capacity to import needed inputs for fertilizer production. Some of the production units and plants were running at nominal capacity, plagued by numerous problems relating to age of plants, lack of resources for replacement of equipment and procurement of spares, non-availability of petroleum-based feedstock and raw materials coupled with inefficient production technology and the shortage of electricity inevitably limited productivity of fertilizer plants.

By 1996, North Korean fertilizer production fell to 130,000 tons, less than 17% of the national requirement, with essentially no imports to supplement the consumption need of its agricultural sector. Figure 4 illustrates the relative decline in NPK consumption in North Korea from 1989 to 1999.

Figure 4: NPK Consumption in North Korea from 1989-1999



Source: United Nations FAO. *Special Report FAO/WFP Crop and Food Supply Assessment Mission to the DPRK* (June 29, 1999).

The Environmental Factors

As noted earlier in the paper, in 1995 and 1996, North Korea was struck by torrential rains, with high tidal waves and floods that engulfed a large part of its agricultural area, severely affecting not only the year's agricultural production, but more important, damaging agricultural infrastructures, such as the irrigation network, transport, and property (UN FAO, *Crop and Food Supply Assessment*, 22 December 1995), pushing the country's capacity to produce food further into the margins. In 1995, North Korea recorded 23 inches of rain in ten days, and in some areas as much as 18 inches of rain fell in a single day, bringing floods that were considered the worst in a century (Woo-Cumings). Sixty to seventy people were reported dead, and the North Korean Government estimated that the floods affected 75 percent of the country, displacing 5.2 million people. Damages were extensive: 1.2 million hectares of agricultural land affected, 1.9 million tons of grains lost, and the total cost of the flood damages at 15 billion dollars (UN Department of Humanitarian Affairs, *Assessment of Damage*).[xxviii] 1996 was no less severe; what is more, floods hit areas that were already struck by the previous year's floods. When the rain stopped in late July, 116 people were dead, 3 million people were displaced in 117 towns and counties, and 20% of the harvest was destroyed, with total damage estimated at 1.7 billion dollars (Actions by Churches Together International). The agricultural land was hit especially hard since the bulk of the rain fell on the western plains, where the country's most fertile land is found. Table 5 indicates the damages sustained in agricultural land in 1995 and 1996.

Table 5: Agricultural land damaged by floods in 1995 and 1996 in North Korea

(Unit: '000 ha)

Year	Land sub-merged	Land washed away	Land buried	Total damaged	Total arable land	Damaged in % of arable land
1995	331.0	10.7	18.2	359.9	1,853.0	19%
1996	273.1	9.7	15.0	297.7	1,853.0	16%

Source: Information is extracted from Draft report presented to the participants of Thematic Roundtable on AREP in DPR Korea in Geneva, Switzerland, hosted by UNDP, May 28-29, 1998. Information originates from North Korea's Flood Damage Rehabilitation Committee.

Although the exact toll the 1995 and 1996 floods had on North Korea may differ from the official governmental announcements, foreign observers agreed that the disasters devastated North Korea's industrial and agricultural infrastructures. Epic floods were followed by severe droughts in 1997, 2000, 2001, and complemented by cold winters (Woo-Cumings 28), further exacerbating North Korea's ability to produce food.

However, these natural disasters contributed to and hastened the collapse of agriculture in North Korea rather than created it. These natural calamities took such a devastating toll on North Korean agriculture because of the human-made ecological disaster that has been progressing ever since the modernization project accelerated in the 1960s. Preceding the natural disasters in the mid-1990s, in 1991, UNDP issued a concern regarding North Korea's intensive use of chemicals, stating that such practices had led to land degradation vis-à-vis declining soil fertility, erosion and acidification, and water pollution (US Library of Congress, *North Korea Country Studies*).

The Collapse of Seed Production

Along with the overall decline in other parts of the agricultural sector, the production of seed also collapsed in the mid-1990s. There are both quantity and quality problems associated with seed production. Quantitatively, seed production levels have been inadequate since the crisis began. Seed production in North Korea takes place at the county level, undertaken by 240 state seed farms. In the pre-crisis period these farms produced 250,000 tons of seed: 101,000 tons of rice, 37,000 tons of maize, 23,000 tons of other cereals, 83,000 tons of potatoes, 400 tons of vegetables, and 50 tons of industrial crops, with other crops the remainder (UNDP FAO, *AREP 1998* vol 1:35). Similar to that of other units in the agricultural sector, seed farms are also affected by the shortage of agro-inputs and the lack of an adequate energy supply to irrigate or to mobilize machines and equipment. Consequently, seed threshing, cleaning, treatment, processing, storage, packaging, and distribution have been adversely affected, leading to high post-production losses. Inadequate irrigation means lower crop yields (35). The lack of inputs and equipment has substantially decreased available seed quantity, and this means that farmers have to postpone seed renewal of non-hybrids for extended numbers of seasons and use lower-yielding retained seeds.

The quality of available seeds has been problematic for both hybrid seed production and traditional renewal varieties. Hybridization of seeds is based on plant germplasm; however, the local germplasm suffers from a narrow genetic base, and traditional major varieties are in need of renewal after 10–15 years of use. North Korea's seed multiplication system is relatively less developed compared to international standards, and the quality control system is also considered in need of improvement. One of the issues affecting North Korea's ability to access international germplasm and/or technologies is US economic sanctions against North Korea. As noted earlier US economic sanctions constrain North Korea from accessing many of the international agricultural research centers that receive US funds.

In addition, cooperatives are using higher rates of seeding to mitigate seed quality problems and the effects of cold weather. In North Korea, plant densities are high, and the seed application rate is 125 kg per hectare, in the case of paddy, and 45 kg per hectare, in the case of maize. However, the FAO reports that seed rates were increased to 150 kg per hectare for paddy and 60 kg per hectare for maize in 1998 because the supply of plastic sheets needed for covering seed beds during cold weather has been limited (UN FAO, *Crop and Food Supply Assessment*, November 1998). It has been noted that no more than 60 percent of the seed quantity actually used by cooperatives would be needed if it were of high quality (UNDP FAO, *AREP 1998* vol 1*:*35).

In sum, seed production decreased because of the lack of agro-inputs; the hybrid and traditional seeds being produced are suffering from low quality due to a narrow genetic base and non-renewal. In turn, the lack of agro-inputs, such as plastic sheets, and poor quality seeds force cooperatives to use higher rates of the shrinking supply of seeds.

Conclusion

For almost half a century, North Korea's agricultural sector was able to meet national needs for food grain, despite the topographical disadvantages, a harsh climate, and a growing population that doubled in size from 10 million to 22 million. This seeming success, however, was based on the fragile balance of a complex set of social, ecological, political, and economic forces; if any one of these factors became unstable, the entire system would shatter. In the mid-1990s, North Korea's agriculture collapsed, and the ensuing food crisis became a large-scale famine. Many explanations were offered by a series of studies and observations as to why the agricultural decline had taken place, and most of these explanations fall into three categories of arguments: economic, organizational, and environmental.

The economic arguments attribute North Korea's inability to provide needed inputs to either shrinkage in macroeconomic conditions, i.e., dissolution of the socialist system or the deterioration of North Korea's industries. The argument assumes that if needed inputs were provided, agricultural production would recover to its previous levels. However, such a recovery is unlikely given the state of environmental degradation in North Korea, the unpredictable global ecological impact yet to come, and the social changes that have occurred in North Korea as a result of the agricultural crisis during the last decade. The organizational argument provides insights into the shortcomings of the collective structure and planned economy, but as indicated earlier, it does not explain the fact that the system

functioned reasonably well for a half century without very much change. This line of argument frequently offers family farming and the market solution as a silver bullet; however, experiences in transition economies tell a different story. Would the market bring back traditional organic farming, and do away with industrial agriculture? Last, the environmental argument provides an explanation for the physical degradation of North Korea's agricultural land and the impact of the global ecological pattern, together with what may have tipped the balance of the nation's agricultural condition in the latter half of the 1990s. But this argument does not adequately explain the decline since the late 1980s, before the natural disasters occurred, or in the absence of the calamities in the years since.

All three arguments provide partial explanations for—but not a comprehensive picture of—the actual collapse of agriculture in North Korea. North Korea was a diligent student of modernization; modernization's notion of societal progress was synonymous with nation-building and liberation in North Korea. From the 1950s to the late 1980s, agriculture in North Korea underwent a drastic transformation as an important part of the country's modernization project. In striving for industrial agriculture, North Korea abandoned traditional rotational systems, including fallowing or planting with leguminous crops, and largely ended the practice of using organic fertilizers. From the outset, food grain production was an energy-intensive undertaking, designed to succeed only when energy was readily available. Modern farming practices emphasized chemicalization, with the intensive use of inorganic fertilizer and other, usually petroleum-based, agro-chemicals, without due consideration for the devastating impact such technical interventions would have on ecological relations. Paddy and maize fields were designed to take full advantage of the potential for mechanization, and irrigation systems were heavily dependent upon electrically-powered surface water pumping. All land with any potential for paddy and maize production was brought into cultivation without alternating crops or fallowing. Increasingly expensive and environmentally problematic tidelands reclamation and drainage projects were undertaken to increase arable land. The use of chemical fertilizer, insecticide, and herbicide was intense. The modern system of intensive agriculture introduced in North Korea enabled continuous production, including double-cropping of cereals, but has resulted in soils highly depleted of naturally-occurring nutrients.

There were other unintended consequences of the adoption of industrial farm techniques. Even before natural disasters brought devastation to North Korea, the country was already experiencing a decline in production due to both internal and external resource depletion. In an attempt to produce adequate cereal staples for the population, North Korea switched gradually to monoculture maize production, using hybrid varieties without any crop rotation. These industrial agriculture practices required increased inputs each time as soils continued to deteriorate and plant diseases tended to proliferate and wipe out the monoculture crops. At the same time, North Korea's agriculture industry required ever-increasing amounts of high energy, especially petroleum products, and as a result of increasing chemical inputs, the soil became acidified. In an effort to expand arable area, North Korea initiated reclamation projects and the terracing of hills. These projects, in turn, contributed to further environmental degradation.

On the other hand, in order to sustain the high growth in agriculture, North Korean industry had to supply adequate amounts of inputs such as tractors, fuels, and chemical fertilizers to the agricultural sector. This system was supported in part by the availability of energy. Most of the energy needed in the agricultural sector came from oil and natural gas, of which North Korea had neither. Similarly, the growth of industry was not feasible without sufficient food and other wage goods from the agricultural sector, as the growth of industry depended on the quality of its labor, requiring a significant increase in the supply of food and consumer goods. Given the highly interdependent relationship between agriculture and industry, one sector's failure to provide adequate inputs to the other was likely to trigger a vicious cycle of economic downturns.

Although North Korea strived for a self-reliant economy, in reality, its industrial agriculture was critically dependent on imports. Direct imports helped meet fertilizer needs and provided most other agro-chemicals as well as petroleum and fuel for farm machinery. Domestic industrial sector production in support of agriculture also depended heavily on imports of raw materials, ranging from petroleum feedstock for the fertilizer industry to coke for the steel needed for machinery manufacturing. The demise of the socialist bloc and the Soviet Union left North Korea bereft of political allies, trading partners, and led to the resultant agrarian crisis. Even though foreign trade occupies a small portion of the North Korean economy, that portion was critical to the entire system of the economy because it is composed of irreplaceable inputs such as crude oil, petroleum products, coking coal, and parts for machinery and equipment. Drastic declines in these critical inputs, which resulted from the breakdown of trade with the Soviet Union in 1991, had a detrimental impact on the North Korean economy.

At the same time, after several decades of extensive and intensive agricultural modernization, environmental degradation of production sites became visibly apparent, requiring more and more inputs just to maintain previous level of productivity. This fragile production system could not withstand the destruction impact of the natural calamities of 1995 and 1996, nor was it able to weather the precipitous decline in agro-chemical inputs; consequently, the agricultural system collapsed. North Korea's Green Revolution brought "ghost acres"[xxix]on which a glass house of greater food self-sufficiency was built. To bring ghost acres into production, fossil fuel had become as vital a resource for its agriculture as land and water resources, and this change in the production regime was made possible by the availability of internal and external fossil fuel resources to support the industrialization of agriculture.

Understanding the cause of the agricultural collapse is important, not only because North Korea is one of the least understood countries in the world, but also because its industrialized agriculture is an example of what can happen to highly energy-dependent, modern agriculture. To begin with, North Korea has shown the world that modern agriculture is unsustainable—economically, politically, socially, and environmentally. It damages land, draining water supplies and polluting the environment. And all of this requires greater and greater fossil fuel inputs to pump irrigation water, to replace nutrients, to provide pest protection, to remediate the environment, and to simply maintain crop production levels. Yet this necessary fossil fuel input will crash headlong into declining fossil fuel production. Oil

has dominated much of modern agriculture—as it has other sectors—in the last century, and an eventual contraction of petroleum supplies will likely result in reduced food production, as we have seen in North Korea during the last 15 years.

NOTES

[i]The North Korean Government has not released an official figure on the total number of famine-related deaths. There are, however, widely varied claims by foreign observers, especially in the U.S. regarding the number of famine-related deaths that ranges from 200,000 to 3.5 million. U.S. Congressional staffers, Mark Kirk, Peter Brooks and Maria Pica put the figure between 900,000 to 2.4 million from 1995-1998 (*Final Report of the Visit to North Korea and China to the International Relations Committee of the U.S. House of Representatives*, August 31, 1998);Peter Hayes of the Nautilus Institute put a figure between 200,000-300,000 as the lower range and 2 million as the upper range (PBS interview, *A News Hour with Jim Lehrer* on February 11, 1999); Marcus Noland and his colleagues estimate at 2.8 million to 3.5 million (Noland, Robinson, and Wang in *Famine in North Korea: Causes and Cures*, 1999); Nicholas Eberstadt estimates at "more than three million," (quoted in Noland et al.:1999); Andrew Natsios, current administrator of USAID put the figure between 2 million to 3 million (*The Great North Korean Famine: Famine, Politics, and Foreign Policy*, 2001:201); Two American demographers, Daniel Goodkind and Lorraine West estimates the numbers between 600,000 and one million (*The North Korean Famine and Its Demographic Impact*, 2001). Debates on the same subject within the South Korean scholarships resemble a similar number range to the U.S. After reviewing the method and 'empirical' evidence presented in each of the arguments in the number debate in the U.S. and South Korea, the numbers forwarded by authors Goodkind and West in the U.S., and Lee Suk (Lee estimates the famine-related deaths at 25,000 to 1.17 million between 1994 to 2000, with per annum rate of 36,000 to 167,000. 2004) in South Korea appear to be the most credible in the current context of research on North Korea (1994-2000 *nyon Bukhan Kikun* 2004). That is, all figures presented as 'facts' in the debates regarding the famine-related deaths in North Korea are estimates based on information that is largely founded on inferences from fragmented data, speculation, and political disposition.

[ii] South Korea is often referred to as the "Korean miracle" by many as a model of successful development. However, before South Korea earned its reputation as one of the four East Asia miracles—the others are Taiwan, Hong Kong and Singapore—North Korea exceeded South Korea in economic and social development.

[iii] To name a few, economists Gordon White, Jon Halliday, Joan Robinson; a well known historian, Bruce Cumings among others.

[iv] Metric ton is used in this paper.

[v] Quinones estimates at 7.4 million MT in 1984.

[vi] Figure 1 is a composite of three data sources: North Korean official report from 1960 to 1984, Ken Quinones's estimate from 1960 to 1995, and UN agencies estimate from 1989 to 2004.

[vii] FAO uses 1993 as the base year—there was a hailstorm in 1994—and calculated a rate of structural decline in agriculture, in the two year period between 1993 and 1995, the production of paddy is assumed to have decreased by 10% and maize 15%, i.e., the annual rate plus a factor for an increasing rate of decline. (UN FAO, *Special Report* 1995.)

[viii]Other organizational arrangements mean the organizational structure of the North Korean collective farms such as the sub-work teams, incentive structure, management arrangement and technical/extension services, etc.

[ix] Woo-Cumings argues that North Korea was profoundly affected by the ENSO (El Nino Southern Oscillation) of 1997-1998, said to be "one of the worst in recorded history going back some three hundred years." For more ENSO details refer to Mike Davis's (2001) *Late Victorian Holocausts: El Nino Famines and the Making of the Third World* (London: Verso).

[x]Until the mid-1980s, a sub-work team consisted of twenty to twenty-five people.

[xi] North Korea was formally established as the Democratic People's Republic of Korea in September 1948.

[xii] Size of a kitchen-garden is around 30 pyong (100 square meters).

[xiii] Ri is the smallest administrative unit in the rural area in North Korea, and it is comparable to a township in the U.S.

[xiv] 1 chongbo equals approximately 1 hectare (0.992).

[xv] North Korea's total arable land area of 1.99 million hectares, about 980,000 hectares have irrigation as of 1998 (UNDP FAO, *AREP 1998*).

[xvi] Rural households include both agricultural and non-agricultural users. This is due to the decentralized pattern of development, where each community is self-containing unit.
[xvii] The FAO figures used here are from Smith and Huang. Smith and Huang have indicated in their paper that these were from annual FAO Yearbook, and their data include more years than I have extrapolated here.
[xviii] Farmers plant rice seedlings in protected dry beds, enabling them to begin growing their rice crop before the normal cropping season.
[xix] Reasons for the slowdown included large increases in military spending due to the heightened political atmosphere in the Korean peninsula in the late 1960s (escalated military tension with South Korea and the US in the Cold War), the global oil crises of the 1970s and the slowdown of the world economy, and the foreign debt North Korea incurred to OECD countries in the early 1970s. North Korea struggled to repay the debt initially in the late 1970s, then continued with renegotiating the terms, but the debt crisis ultimately came to head. North Korea was declared by the Western banks to be a debt-defaulted nation in the mid-1980s.
[xx] In describing North Korea's refineries, David von Hippel and his colleagues state the following: "Two operating oil refineries produced as of 1990 the bulk of refined products used in the country. As of 1995 and 1996 (and 2000), only one of the two refineries was apparently operating, and imports of refined products had not expanded sufficiently to replace the lost production. A third, smaller refinery on the West Coast of the DPRK reportedly operates sporadically when crude oil shipments are available" (von Hippel, Savage, and Hayes 9)
[xxi] Coking coal is a type of bituminous coal from which coke is derived. Coke is used as a fuel and as a reducing agent in smelting iron ore in a blast furnace to make steel.
[xxii] Like many other facts about North Korea, there are conflicting reports and estimates on irrigated land area in North Korea. Most recent estimates by the US Library of Congress *North Korea Country Studies* (2004) put irrigated land at 1.4 million; P. Döll and S. Siebert estimate 1.46 million hectares by using FAOSTAT information in 1999; and the UNDP estimates it at about 1 million hectares (UNDP FAO, *AREP 1998* WP 1:6) in 1998.
[xxiii] According to the authors, in North Korea there are 1.5 million rural households that require over 900 million kWh per year for electrical loads such as lights, refrigerators, irons, and televisions. The public and commercial users require additional 300 million kWh per year, and all these combined bring the total rural electricity requirement to 2.9 billion kWh per year.
[xxiv]This does not include power needs for irrigation and domestic electricity supplies.
[xxv] Additional labor for the transplanting and harvest seasons is supplemented by urbanites. North Korea regularly uses labor mobilization campaigns during peak agricultural season to shift labor from urban areas to rural areas to assist in planting and harvesting, and participation of this type of voluntary labor force has increased substantially since the agricultural crisis. This "voluntary" labor has been a part of regular mass mobilization for decades, throughout the social hierarchy. Such mobilizations are frequent in North Korea, serving as important social gatherings, and as the volunteers join the regular agricultural work force, festivals and gatherings are organized.
[xxvi] 1 horsepower equals 746 watts, and 1 mega watt (MW) equals 1 million watts. Hence 2,231 MW equals 2,990,617 hp, and 463 MW equals 620,643 hp.
[xxvii] (UNDP FAO, *AREP 1998* WP 3:23); FAO/WFP puts the annual requirement of plant nutrient NPK at 700,000 tons in its June 1999 special report, but the report does not specify the amount of acreage associated with such requirement, hence I have decided to use the AREP assessment in this paper.
[xxviii]It is quite remarkable considering the scale of floods, and as the author recalls that the North Korean government sent military helicopters to rescue people in remote areas of the country.
[xxix] The concept of "Ghost Acres" is attributed to William R. Catton in his book *Overshoot: The Ecological Basis of Revolutionary Change* It refers to the fact that the stocks of fossil fuels being consumed today are the products of ancient photosynthesis ("congealed solar energy") that took place in long-gone forests and swamps hundreds of millions of years ago.

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